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Colin Hinson

In the village of Blunham, Bedfordshire, UK.

TELEGRAPHY

J. W. FREEBODY

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BY

J. W. FREEBODY

WHIT. SCHOL., B.Sc. (ENG.)
A.C.G.I., D.I.C., M.I.E.E.

Staff Engineer, Post Office
Engineering Department

THE NEW ERA PUBLISHING CO., LTD.
45 NEW OXFORD STREET, LONDON, W.C.1

© J. W. Freebody, 1958

MADE IN GREAT BRITAIN AT THE PITMAN PRESS, BATH
E9—(T.421)

PREFACE

THIS book, which is a successor to Herbert's *Telegraphy*, is devoted to the principles and practice of telegraphy, and although it has been written primarily for students and engineers, it is hoped that it will also prove of value to those engaged on the operational and traffic aspects of the subject. Every endeavour has been made to give a clear exposition of the theory and principles upon which practical systems and equipment are based, and fairly detailed information is given of the equipment employed in the telegraph services provided by the British Post Office for the inland and overseas public service and for private wires and telex. No more than an elementary knowledge of the principles of magnetism and electricity is required by the reader for an understanding of the text, which fully covers the syllabuses of the City and Guilds of London Institute examinations in telegraphy.

It is fitting to record here an expression of gratitude to the late T. E. Herbert whose textbook of telegraphy was for many years an indispensable work of reference, valued alike by engineers and telegraphists throughout the world. His book was first published in 1906 and the fifth and last edition was issued in 1930 at a time when teleprinters and multi-channel voice-frequency telegraph systems were just beginning to be introduced in many countries. These developments had a profound and rapid influence on telegraph practices throughout the world and continue to play a dominant role in current practices. The ensuing changes during the 1930s made it necessary to commence a revision of Herbert's *Telegraphy* even before 1939, and by that date, with the very able collaboration of J. A. S. Martin, who for many years was a prominent telegraph engineer in the Engineer-in-Chief's Office of the General Post Office, London, the manuscript of a sixth edition had been nearly completed. Unfortunately the outbreak of the second world war in 1939 made it impossible to proceed with the revision of the book and the work had to be abandoned for many years. During this interval T. E. Herbert died and the manuscript had by then become so out of date that a complete revision was again essential, with the exception of a chapter concerning Telegraph Transmission Theory. The latter material, which had been contributed by E. H. Jolley, O.B.E., who is now the Staff Engineer in charge of the Telegraph Branch, Engineer-in-Chief's Office, G.P.O., London, was published under his authorship in 1947 with the inclusion of some additional matter. This book has been of considerable value to students, teachers and engineers, and the author is greatly indebted to Mr. Jolley for permission to include his text, with only very minor changes, as Chapter 5 in this textbook.

After T. E. Herbert's death the responsibility for preparing a completely revised edition of *Telegraphy* was first entrusted to J. A. S. Martin and myself. This partnership, however, was unfortunately soon broken when ill health and retirement caused my good friend and colleague to withdraw from the work in 1952. This turn of events was indeed a great misfortune, and but for his encouragement and the generous assistance of many friends it would not have been possible for me to have completed this book. I have the greatest pleasure in recording my sincere thanks to them all, and particularly to J. A. S. Martin for his help and guidance in the initial determination of the scope and structure of the book and for his assistance in the preparation of Chapter 16.

I cordially acknowledge the Engineer-in-Chief of the General Post Office for his permission to make use of official information, including numerous diagrams and photographs, without which the publication of this book would not have been possible. I also record my gratitude and indebtedness to the Institution of Post Office Electrical Engineers whose publications have been freely used.

In the preparation of the manuscript and proof reading, many of my colleagues in the G.P.O. generously devoted much of their leisure time to assist me, and I wish to acknowledge especially my indebtedness and gratitude, for help on the chapters itemized, to the following: A. B. Easterbrook and L. K. Wheeler, Chapters 3 and 4; E. H. Jolley, O.B.E., Chapter 5; J. Rhodes, Chapter 6; G. Turner, Chapter 8; A. E. T. Forster, R. W. Barton and W. A. Ellis, Chapter 9; C. W. A. Mitchell and R. T. G. Sallis, Chapter 10; H. Todkill, Chapters 11 and 12; G. N. Davison, Chapters 13 and 14; H. A. Penn, Chapter 15, and H. E. Evans, Chapter 17.

I was very fortunate to secure help and guidance from my good friends R. L. Saunders of Cable and Wireless, Ltd. and R. A. Goodman of The Western Union Telegraph Co., London Office, in the preparation of Chapter 17, and I have pleasure in recording my grateful thanks to them for their expert assistance on this specialized subject. I am likewise indebted to R. E. H. Carpenter of the Telephone Manufacturing

Co., Ltd., who was good enough to read the manuscript of Chapter 4 relating to polarized telegraph relays and who supplied some excellent photographs and other information concerning Carpenter relays.

The numerous drawings were prepared by F. W. Dopson assisted by W. R. Ashley and the majority of the photographs were provided by W. R. Wickens of the G.P.O. I tender to them my sincere thanks for their admirable work.

The following manufacturers and companies have given generous assistance by supplying various illustrations, which are individually acknowledged, or other information used in the preparation of the text. To all of them I have pleasure in recording my obligation and thanks, viz. Cable and Wireless, Ltd., Creed & Co., Ltd., D. P. Battery Co., Ltd., The Exchange Telegraph Co., General Electric Co., Ltd., The Great Northern Telegraph Co., Ltd., Muirhead & Co., Ltd., Standard Telephones and Cables, Ltd., Submarine Cables, Ltd., Telephone Manufacturing Co., Ltd., and The Western Union Telegraph Co.

A. C. Croisdale cheerfully volunteered and undertook a considerable amount of proof reading, in the course of which he made many valuable suggestions which have improved the text. I cordially acknowledge his assistance in this work, and that of C. E. Easterling who read the proofs of Chapters 11 and 12, and A. W. Heywood who discharged the same task on Chapter 10.

In a work of this magnitude, in spite of the care which has been taken, it would be vain to hope that there is no remnant of error anywhere in the text. I shall therefore be grateful if any reader who detects an error will advise me under cover to the publishers.

J. W. FREEBODY

EWELL, SURREY, 1958

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CHAPTER 17

SUBMARINE CABLE TELEGRAPHY 667

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CHAPTER 1

TELEGRAPH CODES AND SIGNALLING

MODERN civilization involves complex social, commercial, industrial and international organizations and these have become increasingly dependent upon cheap and rapid communications. An outstanding feature of the many developments during the past century has been the ever increasing facility and rapidity with which communication has been made possible on a world-wide scale. An objective assessment of the contribution made to human progress by the developments and improvements in communications can best be made by future historians. Meantime, it is clear that the improvements in communication facilities have had a profound effect in the arts of both peace and war.

Introduction. For centuries past men of all nations and in many positions in life have been impressed with the need for communication and have devoted their attention to the subject. Many curious devices for the purpose are cited in the annals of all nations. Fire, smoke, bells, trumpets, drums and guns have in turn played a part, and even in modern times many primitive devices are still to be found in use in some parts of the world. The use of flags and various forms of semaphore signalling date from as long ago as the thirteenth century and are still retained in modified forms, although their use is restricted. The heliograph, in which signalling was effected by reflection of the sun's rays from one point to another, was a system employed for visual signalling in sunlight; in dull weather and at night, resort was made to lamp signalling. The vagaries of nature render communication by such systems somewhat precarious. Even under ideal conditions only a very restricted range of direct operation is possible and the speed of operation is relatively slow and cumbersome. Such methods are now only of historical interest to us and have no place in modern systems of telegraphy. However, for the sake of interest and completeness, a very brief note on the most important of the older systems of telegraphy is included in Chapter 2.

Telecommunications and Telegraphy. In recent years the word telecommunication has been adopted to denote and embrace all electrical signalling methods employed for the communication of intelligence at a distance. This term may be more specifically defined as follows—

"*Telecommunication.* Any telegraphic or telephonic communication of signs, signals, writing, images or sounds of any kind, by wire, radio, or other systems of electric or visual signalling."

The word telegraphy is derived from the Greek *tele*, meaning afar, and *graphos*, meaning that writes; hence telegraphy is concerned with those systems employed for the communication at a distance of the written word, as distinct from telephony, which is concerned with the communication of the spoken word. Telegraphy is the oldest branch of telecommunications and, although the advent of telephony dealt a severe blow in certain fields of application of telegraphy, the latter has nevertheless continued to prosper. In fact, contrary to early predictions that telephony would completely supersede telegraphy, experience has shown that telegraphy and telephony are not competing systems of communication but that each has separate and distinct fields of usefulness and that in many cases they are complementary. Telegraphy has the unique advantage of providing a permanent record of the intelligence transmitted and for many types of communication this is essential. At the present time, telegraphy ranges over many diverse fields of application. It provides invaluable and increasing service to the general public and also to administrations, commerce, industry, and civil and defence services. Furthermore, there is little doubt that, with increasing public appreciation of the usefulness and versatility of telegraphy, great developments and expansion in many fields of service will occur in the future.

This book deals with the basic principles of the various systems of telegraphy and gives a comprehensive description of the technical methods and salient features of equipment employed in Great Britain, and in particular in the telegraph services provided by the British Post Office (B.P.O.).

Telegraph Codes. In reviewing the various methods employed in the systems of telegraphy from earliest times, there is one feature that may be said to be common to them all—the use of a signalling code. This feature is a fundamental one. It enables substantial economies to be effected, in most cases, in the cost of provision of telegraph, as compared with telephone, channels. The signalling code used in any particular case must be predetermined, so that for each character a distinctive code is transmitted, which can be recognized and interpreted by the person or instrument receiving it. The particular form and choice of the signalling

code to be employed depend upon a number of factors which will now be discussed.

In the first place it is necessary to know the nature of the intelligence to be transmitted, for example, whether it is required to transmit the letters of the alphabet and numerals only, or a great variety of character forms such as a line drawing, or the detail of a half-tone photograph (as in the case of a phototelegraph system). This information determines how many different combinations of signal elements are required in order to provide a distinctive combination of signals for each of the characters or forms to be transmitted. The next consideration is the economic use of the code, and for this the code used should be such that all the available combinations inherent in the code are fully employed. The full significance of this will be better appreciated later. At this stage it may be stated that in general the most economic code to employ is one that provides just the exact number of combinations required for the number of characters necessary for the transmission of information. The more closely this ideal is approached, the greater will be the rate at which intelligence may be transmitted and hence the greater economy in the use of circuit time. It will also be evident that the selection of a code in this manner ensures that the code is as simple as possible.

In some cases, e.g. long-distance radio circuits, telegraph signals are at times subject to excessive distortion and falsification due to the effects of fading, noise, atmospherics, and interference. These effects may cause one or more elements of the code signals of a character to be received incorrectly in that a signal of one sense may be transposed into one having the opposite sense. Where the number of combinations is just equal to the number of characters to be transmitted, then, if any element in the code for a character is received incorrectly, it immediately transposes the code to that of another character and so produces an undetectable error, unless special checking means are employed by the operating staff. In order to reduce the vulnerability of a code to this type of error, it is necessary either—

(*a*) to employ combinations for the various characters which are markedly different one from another so that minor errors in transmission of the elements of one character are less likely to transpose the code into one corresponding to another character. This method greatly increases the number of possible combinations beyond the number actually required for the range of characters which it is required to transmit (see Hellschreiber code, page 14). This excess of information is termed *redundancy*, or (*b*) to incorporate a common characteristic in each code combination for every character such that, if this characteristic is absent when the signal is received, then a special error-detecting feature of the receiving equipment operates and gives an indication that an error has occurred (see Error-detecting codes, page 10).

In the former case a minor transposition occurring during the transmission of the code will not change the combination into that of another character but will produce a received record, which, although slightly mutilated, can nevertheless still be identified as the character transmitted.

Facsimile and phototelegraph systems are inherently good from the point of view of error detection as they produce a facsimile copy of the original. Therefore minor mutilations of the signal elements during transmission cause only minor blemishes in the received copy, without rendering it liable to erroneous interpretation at the receiving end of the circuit.

Another consideration affecting the choice of the code is whether it requires to be transmitted by hand signalling, e.g. with a morse key, or whether the transmission will be by means of automatic instruments, e.g. a teleprinter. In the former case it is important that the arrangement of the code should be such that the manual operations involved in signalling are simple and involve minimum fatigue of the operator. This implies that those characters which occur most frequently (i.e. having the greatest "frequency of occurrence") should be the ones involving the least number of manual operations; the number of manual operations by the operator in the transmission of characters having a lower frequency of occurrence is not so important. The frequency of occurrence of characters depends upon the nature of the messages transmitted and varies in different languages. Marked differences exist but letters such as e, i and t occur much more frequently than, for example, letters q and z. Ideally, therefore, close attention should be paid to this factor in determining the best allocation of the code combinations in manually operated systems.

In automatic systems the point is not of great importance, but there is evidence that, in the case of the five-unit code invented by Murray (see page 7), he made an allocation of the code so that those characters having the greatest frequency of occurrence involved the least number of mechanical operations by the automatic instruments, thereby reducing mechanical wear to a minimum.

With these general considerations in mind we will now turn to a detailed examination of the various telegraph codes employed in modern

systems, beginning with the Morse Code as this is so widely known.

The Morse Code. In the Morse code two distinctive signal elements are employed, namely the dot and the dash. The difference between a dot and a dash is usually one of time duration, a dash being three times as long in duration as a dot. Each character is made up of a number of dots and/or dashes, and the dot and dash elements comprising any character are separated from each other by a time interval equal to the duration of one dot. Between the characters forming each word there is a time interval equal to the duration of three dots, whilst the interval between words is equal to seven dots.* Thus summarizing—

(*a*) A dash is equal to three dots.

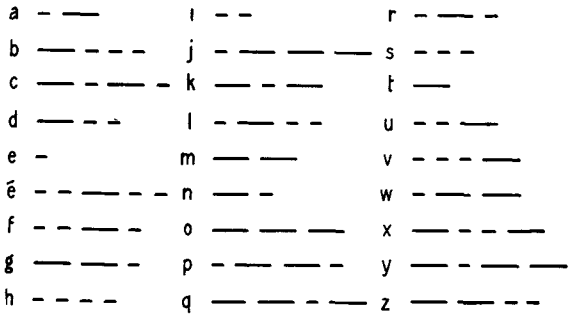
(*b*) The space between the signals forming a letter is equal to one dot.

(*c*) The space between the letters of a word is equal to three dots.

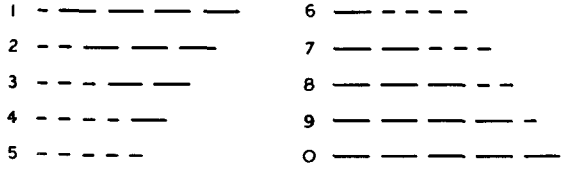
(*d*) The space between words is equal to seven dots.

The International Morse Code. To facilitate international working, an International Morse Code has been agreed upon and this is the code most commonly employed in Morse systems. The International Morse Code is illustrated and its use described in the following extract from the International Telegraph Regulations (Paris Revision, 1949) from which it will be seen that the code

LETTERS



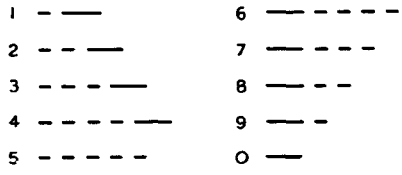
FIGURES



* The space between words in Morse code used to be five dots, but by International agreement it was decided in 1949 to make the space between words equal to seven dots.

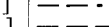
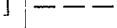
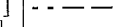
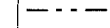
provides for the letters of the alphabet, figures and punctuation and other signs.

Note. In routine repetitions, if there can be no misunderstanding due to the presence together of figures and letters or groups of letters, figures may be rendered by means of the following signals—



Unless otherwise requested by the receiving office, the sending office may also use these signals in the preamble of telegrams, except in respect of distinguishing numbers of the office of origin, and in the text of telegrams consisting solely of figures. In the latter case the telegrams must bear the service instruction "in figures."

PUNCTUATION AND OTHER SIGNS

Full stop (period)	[.]	
Comma	[,]	
Colon	[:]	
Question mark (note of interrogation) or request for repetition of a transmission not understood	[?]	
Apostrophe	[']	
Hyphen or dash	[-]	
Fraction bar	[/]	
Brackets (parentheses) (before and after the words)	[( )]	
Inverted commas (quotation marks) (before and after words)	[" "]	
Administrations and recognized private operating agencies using code converters may use the apostrophe twice, before and after the words, to signal inverted commas (quotation marks).		
Double hyphen	[=]	
Understood		
Error		
Cross or signal for the end of a telegram or of transmission		
Invitation to transmit		
Wait		
End of work		
Starting signal (to precede every transmission)		

A number which includes a fraction shall be transmitted with the fraction linked to the whole number by a single hyphen. For example,

1-3/4 and not 13/4
3/4-8 and not 3/48
363-1/2 4 5642 and not 3631/2 4 5642

A group consisting of figures and letters shall be transmitted without space between figures and letters.

The following letters and signals may be used in relations between countries which accept them—

ä	- — - —	ñ	— — - — —
á or å	- — — - —	ó	— — — -
ch	— — — —	ü	- - — —

From examination of the foregoing it will be observed that each character contains a different combination of elements from that of any other character. It will also be seen that some regard has been paid to the frequency of occurrence of letters; thus letter E comprises one dot, I is two dots, T is one dash, and so on. The other important feature to observe about the Morse code is that the total duration of the signal combination is not constant for all the characters. In consequence this code is often referred to as an "uneven length code" although it is not considered that this is a very apt description.

It should also be observed that the duration of the signal for any character is always a multiple of the duration of the dot element, and this has an important bearing on the question of the speed of signalling, which will be more fully discussed later. It will be clear that the speed of signalling messages depends upon the duration of the dot element, and, whatever this may be for a particular transmission, it is essential that for correct reception the relative durations of the dots, dashes and spaces must be kept accurate.

The Morse code may be transmitted by the use of two basic signalling conditions; thus one type of signal for appropriate intervals is required for dots and dashes and another type of signal for appropriate intervals is required for spaces. The electrical circuit conditions employed for these basic signals depend upon the system of working. For example, in direct-current transmission systems the two signalling conditions may be indicated either by + ve or — ve current for one condition and no current for the other; or by positive current for one condition and negative current for the other. Similarly, in alternating-current transmission systems one signalling condition may be indicated by transmission of an alternating current and the other condition by no current; alternatively, an alternating current of different frequency may be employed for each signalling condition.

For convenience of expression, the two different signalling conditions have been termed respectively *marking* and *spacing*, and this convention is employed in reference to all types of telegraph signals employing a binary signalling code. The origin of the terms lies in Morse systems in which the received record was made by recording dots and dashes by ink marks and spaces on a paper tape. Thus the basic signalling condition corresponding to dots and dashes was called marking (M) and the signalling condition corresponding to spaces was called spacing (S). The significance originally attached to these terms is not applicable in many modern telegraph systems, but the terms have nevertheless been retained as the conventional names of the two circuit conditions required for signalling.

Cable Code. This is the name used to describe the special code employed extensively in submarine cable telegraphy. The code is based upon the Morse code, but, instead of the durations of the dot, dash and spaces varying as in the case of normal Morse code, they are all equal in time duration and differentiation between them is effected by a change in the signalling condition for each. Thus cable code requires three basic signalling conditions, which, in practice, normally take the form of negative battery to line for a dot, positive battery for a dash and earth for a space; the duration in each case being equal. Since dot and dash signals are identified by different battery polarity there is no necessity to employ a space between the dot and dash elements comprising a character; space is needed only to indicate the separation of characters and of words. For letter-space one space signal (i.e. earth) is transmitted, whilst for word-space three space signals (i.e. earth) are transmitted.* Fig. 1.1 (*b*) indicates typical signals for the letters A and B in cable code, and a comparison with normal Morse signals for the same letters is shown in Fig. 1.1 (*a*). It will be seen that, in the cable code, there is a considerable reduction in the time required for the signals as the result of making dot, dash and space signals of equal duration and by the elimination of space signals between the dot and dash elements of a character. It is usual in practice to work with 15–25 per cent earthing, that is to say the transmitter connects the signalling voltage to line for only 85–75 per cent of the duration of each dot and dash element and then connects an earth for the remaining 15–25 per cent of the element. This arrangement limits the period of sustained battery signal to line

* The use of two space signals, instead of three, for a word-space has been employed in emergency to increase the traffic-carrying capacity of a circuit, but the use of three is the normal and preferred arrangement as it makes word counting easy and enables dropped signal elements in a word to be more easily identified, since a single drop-out produces two space elements as compared with three for a word-space.

during successive dot or dash elements, and the 15–25 per cent earthing period causes the line to discharge after each signal. This results in an improved signal shape and therefore better transmission.

(*b*) More stable working conditions can be obtained on long submarine cable circuits.

(*c*) The signals are easily readable by an expert operator, even after considerable distortion such as is experienced in a long submarine cable circuit.

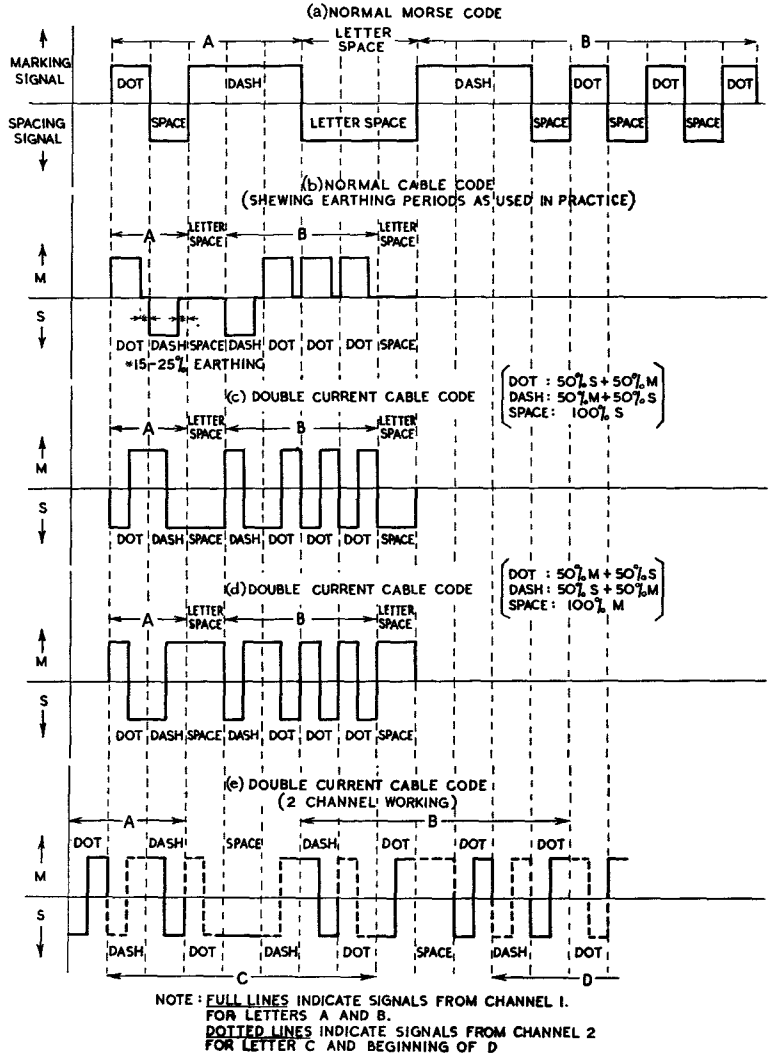


FIG. 1.1. COMPARISON OF MORSE CODE, CABLE CODE, AND DOUBLE-CURRENT CABLE CODE SIGNALS

The main advantages derived from cable code as compared with Morse code are as follows—

(*a*) The duration of the signals for the characters is considerably reduced on the average, and a corresponding saving in line time can thus be effected as a result of the increased speed at which traffic may be transmitted.

(*d*) Experience has shown that mutilations to the signals during transmission are unlikely to result in undetectable errors, due to the fact that the change of a dot into a dash or vice versa is improbable without there being some other obvious mutilation. Mutilations in the normal Morse code usually give rise either to the joining of two dots,

thus forming a dash, or to the splitting of a dash, thus forming two dots, usually resulting in a change of one letter into another.

Cable code can be sent either by hand keying or automatically from perforated tape and can be received manually by transcription from a siphon recorder tape or automatically by reperforator or direct printer.

Double-current Cable Code (D.C.C.C.). Normal cable code obviously requires a transmission channel which is capable of transmitting three basic signalling conditions and this has limited its use so far to physical circuits in submarine cables and to land lines. Radiotelegraph channels and multi-channel voice-frequency telegraph systems employed on land lines are normally designed for the transmission of only two signalling conditions, i.e. marking and spacing, and therefore are unsuitable for the transmission of normal cable code signals. In order that the advantages of cable code could be extended for use on radiotelegraph circuits and also to enable submarine circuits to be connected to channels in voice-frequency telegraph systems, a special form of cable code, known as double-current cable code, was introduced by Cable and Wireless, Ltd. In this code dot, dash and space were represented as follows—

dot = 100 per cent marking
dash = 100 per cent spacing
space = 50 per cent marking followed by 50 per cent spacing

(where 100 per cent indicates the duration of a unit element of signal, i.e. dot, dash or space).

It will be seen that this arrangement of code, although requiring only two basic signalling conditions (marking and spacing), nevertheless retains the advantages of normal cable code. It will be noted however that the signalling speed is doubled as "space" requires the transmission of marking and spacing elements having half the duration of a dot or dash signal.

In practice it was found that double-current cable code in this form suffered from the disadvantage that the sustained periods of marking or spacing signal, which could arise as the result of successive dots or dashes, produced an undesirable degree of distortion due to the operation of the automatic gain control (A.G.C.) of the radio receiver. This effect occurs principally in the case of radio circuits in which two channels are operated on a time-division multiplex principle. With this arrangement the signal elements of the two channels are interleaved, one element of signal being transmitted from each channel alternately. From consideration, it will be seen that in such a system, if a figure nought (i.e. 5 dashes) is being transmitted simultaneously in each of the two channels, a total period of $\frac{1}{2} + 5 + 5 = 10\frac{1}{2}$ units of spacing signal will occur.

To overcome this objection the following arrangement was adopted in which the signal for dot, dash and space was different in the two channels as shown below.

	Channel 1	Channel 2
Letter space .	100 per cent S	100 per cent M
Dot . .	50 per cent S followed by 50 per cent M	50 per cent M followed by 50 per cent S
Dash . .	50 per cent M followed by 50 per cent S	50 per cent S followed by 50 per cent M

(*Note.* 100 per cent indicates the duration of a unit element of signal.)

Using this modified form of double-current cable code the maximum spacing signal which can occur during transmission is two unit elements.

Fig. 1.1 (*c*) and (*d*) indicate the form of double-current cable code signals for single-channel working using the modified form of code. Fig. 1.1 (*e*) indicates the signals transmitted in the case of a two-channel time-division multiplex system having the signals interleaved.

It is sometimes necessary to connect a submarine cable circuit to a channel in a voice-frequency telegraph land-line system, e.g. from a coastal cable station to a distant traffic office inland. Systems of this type are normally designed to transmit only the two signalling conditions, marking and spacing, and it is therefore necessary in such cases to employ double-current cable code over the land-line section of the circuit. The original form of code is usually adopted for this purpose, i.e. dot = 100 per cent M, dash = 100 per cent S and space = 50 per cent M + 50 per cent S, since this gives a lower degree of distortion of dot and dash elements in the V.F. channel. In recent years Cable and Wireless Ltd. has developed a special frequency-modulated multi-channel voice-frequency telegraph system which enables 3-condition signal code to be transmitted over the land-line circuit and thus avoids the need for converting from cable code to D.C.C.C.

The Five-unit Code. The five-unit code is an example of what is often called an "even length" or "constant length" code, that is to say one in which the number of elements of signal for a character is the same for every character and the duration of each element is also constant. In the five-unit code each character and special function (e.g. letter- and word-space) consists of a combination of five signal elements and each element may consist of either of two basic signalling conditions,

namely, marking or spacing. Thus it will be seen that with this arrangement a total of $2^5 = 32$ combinations of the signal elements is possible.

The five-unit code is the most commonly used code in modern telegraphy and is universally employed for teleprinter operation, apart from a few specialized applications employing six-unit and seven-unit codes. A five-unit code is also used in many Time-division multiplex systems, the Baudot system being a notable example. Modern applications of five-unit multiplex systems are confined mainly to operation of long-distance submarine cables by cable companies, and the Baudot system, which was at one time extensively used for land-line telegraphy, has for many years been completely superseded in Great Britain by teleprinter systems employing the five-unit code.

The 32 possible combinations available from the five-unit code are insufficient for practical purposes, as it will be evident that 26 combinations are required in English for the letters of the alphabet alone, leaving only six for other purposes, e.g. numerals; this is obviously inadequate. In order to increase the usefulness of the five-unit code, it is therefore necessary to adopt an expedient to enable a larger number of characters to be catered for, and this is done as follows. Two of the 32 combinations are employed as *Shift-Signals*, the function of which is to enable the remaining 30 code combinations to be employed for two purposes if desired. In one case, the combinations may be employed for the purpose of letters, whilst in the second case the combinations may be employed for the purpose of numerals, punctuation signs, etc. The shift-signals are often referred to as *case-shift* signals; one case is letter-shift and the other figure-shift. When a letter-shift signal is transmitted, it causes the receiving instrument to set itself into a condition such that any signal combinations subsequently received are interpreted and recorded in the letter-case, until such times as a figure-shift signal is received, whereupon the receiving instrument sets itself into a condition in which the signal combinations subsequently received are interpreted and recorded in the figure-case. Hence the interpretation of a signal combination is determined by the previous shift-signal. Thus using this expedient enables 30 of the available 32 combinations to have two meanings if desired. It should perhaps be mentioned that it is common practice to refer to letters as either "lower-case" or "primary" characters, and figures, etc., as either "upper-case" or "secondary" characters.

As in the case of the Morse code, international standard alphabets have been agreed to facilitate working between different countries. These are the International Alphabet No. 1 for multiplex systems and the International Alphabet No. 2 for start-stop telegraph systems, i.e. teleprinter systems. Tables 1.1 and 1.2 show the allocations of the code combinations in the International Alphabets Nos. 1 and 2 respectively. In American practice there are slight departures from the international standards, and Table 1.3 shows the allocations of the code most commonly employed in American practice in the operation of the Teletypewriter, which is the American equivalent of the British Teleprinter.

In studying Tables 1.1 and 1.2 it will be observed that the allocation of the five-unit code combinations to the various letters and figures, etc., is completely different for the International Alphabets Nos. 1 and 2. The reason for this great disparity is that the No. 1 Alphabet is based upon the Baudot code, in which the transmission of the code for each character was set up manually from five keys on a pianoforte type of keyboard. As a result, in the Baudot code the allocation of the combinations was arranged so that the finger movements to be performed by the operator were as evenly divided as possible between the right and left hands and also as few as possible for those characters having the greatest frequency of occurrence. This ensured the minimum fatigue of the operator.

In the Murray code, on which the No. 2 Alphabet is based, the considerations involved were different, as it was designed for automatic telegraph systems in which the operator was relieved of the burden of setting up individual code elements and had, instead, to operate only a single key of a typewriter type of keyboard for each character transmitted; the selection of the individual signal elements for each character then occurred automatically. Thus there was no inhibition imposed, on account of the operator, in the allocation of the various signal combinations to the different characters. The important feature from an operating point of view, as in the case of a typewriter, was that the keys on the keyboard should be in the most convenient juxtaposition for rhythmic manipulation and minimum fatigue. The closest possible approach to a normal typewriter keyboard layout was therefore aimed at, and for a three-row keyboard this entailed the association of the numerals 1, 2, 3, 4, 5, 6, 7, 8, 9, 0 with the characters Q, W, E, R, T, Y, U, I, O, P, respectively, in the top row of keys. Thus, the code combinations of the numerals have to be the same as the corresponding letter but, apart from this proviso, the codes could have been allocated indiscriminately. Murray appears to have allotted the codes so that those characters having the greatest frequency of

occurrence were given a combination which involved the least number of mechanical operations on the instrument mechanisms, thereby reducing wear. The letter-shift signal had to be allotted the "all-marking" signal, for reasons which will be made clear in Chapter 11, as this signal is employed with 32 in the case of the five-unit code. Thus it is clearly possible to fulfil all of the functions performed by a five-unit code, without using case-shift signals. This offers considerable advantages for traffic involving a mixture of letters and figures, as the elimination of the operations involved in the

TABLE 1.1
International Telegraph Alphabet No. 1

NUMBER OF SIGNAL	LETTER CASE	FIGURE CASE	No. OF IMPULSES 1 ST.	2 ND.	3 RD.	4 TH.	5 TH.	REMARKS
1	A	1		■	■	■	■	
2	B	8	■	■			■	
3	C	9		■			■	
4	D	0					■	
5	E	2	■		■	■	■	
6	F	SEE NOTE 1.	■				■	
7	G	7	■		■		■	
8	H	+			■		■	
9	I	SEE NOTE 1.	■			■	■	
10	J	6		■	■		■	
11	K	(		■	■			
12	L	=			■			
13	M	)	■		■			
14	N	SEE NOTE 1.	■					
15	O	5				■	■	
16	P	%						
17	Q	/		■				
18	R	—	■	■				
19	S	.	■	■		■		
20	T	SEE NOTE 1.		■		■		
21	U	4		■		■	■	
22	V	' (APOSTROPHE)				■		
23	W	?	■			■		
24	X	, (COMMA)	■		■	■		
25	Y	3	■	■		■	■	
26	Z	: (COLON)			■	■		
27	CARRIAGE RETURN	CARRIAGE RETURN			■	■	■	
28	FRESH LINE SEE NOTE 2	FRESH LINE (SEE NOTE 2)		■	■	■		
29	LETTER BLANK (SPACE)	LETTER BLANK (SPACE)	■	■	■	■		
30	FIGURE BLANK (SPACE)	FIGURE BLANK (SPACE)	■	■	■		■	
31	* (ERROR)	* (ERROR)	■	■	■			
32	INSTRUMENT AT REST	INSTRUMENT AT REST	■	■	■	■	■	

■ INDICATES POSITIVE CURRENT

□ INDICATES NEGATIVE CURRENT

NOTE 1. AT THE DISPOSAL OF EACH ADMINISTRATION FOR ITS INTERNAL SERVICE.

NOTE 2. FOR PAGE PRINTING INSTRUMENTS

for the purpose of erasing errors in perforated slip in automatic systems.

It will be observed from a study of Tables 1.1 and 1.2 that in both the International Alphabet No. 1 and No. 2 certain figure-case character combinations are left free for allocation in any manner desired by an administration for its internal services.

The Six-unit Code. The characteristics of the six-unit code are similar to those of the five-unit code except that the combination of signals for each character consists of six elements of equal duration. This therefore enables a total of 2^6, i.e. 64, combinations of signals to be obtained as compared

insertion of shift-signals saves time in the transmission of messages. An example of traffic of this type is Stock Exchange messages, and, in America, six-unit teleprinters are employed for certain services of this type. Also, for languages using more letters than the English alphabet, the international alphabets at present existing for five-unit codes do not provide enough characters in the primary case, and the authorities concerned have to employ one or more of the optional secondaries for use as additional letters. This arrangement is slightly inconvenient and wasteful of operating time as a result of the additional operations of the shift-signals which have to be

made to obtain the full range of letters required. To overcome this disadvantage a device for automatic case-insertion is sometimes used; this however involves undesirable mechanical complexities in the transmitting instruments.

In these cases a six-unit code would give some figures and letters respectively, so also can shift-signals be employed in a six-unit code to enable a greater number of characters to be transmitted. For example, if two of the available combinations are employed as shift-signals this leaves 62 combinations for upper- and lower-case characters.

TABLE 1.2
International Telegraph Alphabet No. 2

NUMBER OF SIGNAL	LETTER CASE	FIGURE CASE	No. OF IMPULSES							REMARKS
			START	1ST.	2ND.	3RD.	4TH.	5TH.	STOP	
1	A	—		■	■				■	■ INDICATES POSITIVE CURRENT.
2	B	?		■			■	■	■	□ INDICATES NO CURRENT IN THE CASE OF SINGLE CURRENT WORKING OR NEGATIVE CURRENT IN THE CASE OF DOUBLE CURRENT WORKING.
3	C	:			■	■	■		■	
4	D	SEE NOTE 4		■			■		■	
5	E	3		■					■	
6	F	SEE NOTE 1.		■		■	■		■	
7	G	SEE NOTE 1.			■		■	■	■	
8	H	SEE NOTE 1.				■		■	■	
9	I	8			■	■			■	
10	J	AUDIBLE SIGNAL		■	■		■		■	NOTE 1. AVAILABLE FOR THE INTERNAL SERVICE OF EACH ADMINISTRATION.
11	K	(		■	■	■	■		■	
12	L	)			■			■	■	NOTE 2. FOR PAGE PRINTERS
13	M	.				■	■	■	■	
14	N	,				■	■		■	NOTE 3. ALSO USED AS 'ERASURE' IN CASE OF AUTOMATIC WORKING. IN AUTOMATIC WORKING THE PERFORATED SLIP MUST CONTAIN THE PERFORATIONS INDICATED BY ■ IN THE COLUMNS FOR 1ST., 2ND., 3RD., 4TH. & 5TH. SIGNAL IMPULSES. TO INDICATE AN ERROR THE 'SPACE' SIGNAL AND THE LETTER X ARE REPEATED ALTERNATELY A FEW TIMES.
15	O	9					■	■	■	
16	P	0			■	■		■	■	
17	Q	1		■	■	■		■	■	
18	R	4			■		■		■	
19	S	' (APOSTROPHE)		■		■			■	
20	T	5						■	■	
21	U	7		■	■	■			■	
22	V	=			■	■	■	■	■	
23	W	2		■	■			■	■	NOTE 4. TO OPERATE THE ANSWER BACK UNIT OF THE CORRESPONDING INSTRUMENT IN THE INTERNATIONAL SERVICE BY START-STOP APPARATUS.
24	X	/		■		■	■	■	■	
25	Y	6		■		■		■	■	
26	Z	+		■				■	■	
27	CARRIAGE RETURN (SEE NOTE 2.)						■		■	NOTE 5. SIGNALS Nos. 29 & 30 (LETTERS & FIGURES) DO NOT AFFECT THE SPACING MOVEMENT
28	FRESH LINE (SEE NOTE 2.)				■				■	
29	LETTERS (SEE NOTES 3 & 5.)			■	■	■	■	■	■	
30	FIGURES (SEE NOTE 5)			■	■		■	■	■	
31	SPACE					■			■	
32	NOT USED								■	

Note. At the VIIth Plenary Assembly meeting of the International Telegraph Consultative Committee (C.C.I.T.) Arnhem, 1953, Signal No. 32 was also placed at the disposal of Administrations for use in their national service.

operating advantages. There are however objections to its use from other points of view, and, although the possibility of adopting a six-unit code has been discussed internationally (C.C.I.T. conferences at Berlin 1929, Berne 1931 and Geneva 1956), there has so far been no agreement, or general desire, to adopt a six-unit code for international services.

It will be clear that, in the same way as two shift-signals are employed in the five-unit code to enable the remaining code combinations to be employed for two purposes if desired; namely This immediately offers a possibility to provide for the full range of facilities (i.e. capital and small letters, numerals, fractions, etc.) given on a commercial typewriter keyboard and permits standardization of keyboard layout to conform with typewriter practice. This would undoubtedly have considerable appeal to the commercial world. In addition, specialized requirements involving a greater range of characters than can be offered from the five-unit code would be attainable. It therefore seems probable that in the future development of telegraph services there will inevitably arise a

demand for a six-unit code, more especially for private services. At the moment, however, the six-unit code is only employed, to a limited extent, in America.

stability of modern circuits has facilitated the adoption on a wide scale of direct printing telegraph systems employing the five-unit code. As already explained, the five-unit binary code gives

TABLE 1.3
Teletypewriter Code

NUMBER OF SIGNAL	START ELEMENT	CODE ELEMENTS 1	2	3	4	5	STOP ELEMENT	AMERICAN TELETYPE COMMERCIAL KEYBOARD	
1		●	●				●	A	—
2		●			●	●	●	B	?
3			●	●	●		●	C	:
4		●			●		●	D	$
5		●					●	E	3
6		●		●	●		●	F	!
7			●		●	●	●	G	&
8				●		●	●	H	£
9			●	●			●	I	8
10		●	●		●		●	J	'
11		●	●	●	●		●	K	(
12			●			●	●	L	)
13				●	●	●	●	M	.
14				●	●		●	N	,
15					●	●	●	O	9
16			●	●		●	●	P	0
17		●	●	●		●	●	Q	1
18			●		●		●	R	4
19		●		●			●	S	BELL
20						●	●	T	5
21		●	●	●			●	U	7
22			●	●	●	●	●	V	;
23		●	●			●	●	W	2
24		●		●	●	●	●	X	/
25		●		●		●	●	Y	6
26		●		.		●	●	Z	"
27					●		●	CARRIAGE RETURN	
28			●				●	LINE FEED	
29		●	●	●	●	●	●	LETTERS	
30		●	●		●	●	●	FIGURES	
31				●			●	SPACE	
32							●	BLANK	

1. ● = MARKING ELEMENT
2. AN AUTOMATIC MOTOR STOP FACILITY IS OPTIONAL IN PLACE OF THE SECONDARY OF LETTER 'H' ON THE TELETYPEWRITER

Error-detecting Telegraph Codes. When land-line or submarine cable circuits are employed for the transmission of telegraph signals it is possible to ensure very stable transmission conditions, provided the equipment and lines are well designed and constructed and properly maintained. Using such circuits, telegraph signals can be transmitted and received with ease and accuracy. The great

32 usable combinations, and, as in practice all of these are employed for printed characters or functions, the code is very economical in its use of the transmission path. If, however, the transmission path is not stable and any of the signal elements are changed during transmission, e.g. due to fading, atmospherics, interference and noise, so that a marking signal is received as a spacing

signal, or vice versa, then the combination received will be different from that transmitted.

The falsification of an element, or elements, will therefore result in the production of a different character, and, except for possible identification from the context in a limited number of instances, the error will be undetectable. In short, since there is no redundancy in the code, any falsification of any element will lead to the reception of a wrong character or function. In codes having a redundancy, e.g. Morse, certain errors in transmission have no alphabetical significance in the code used and therefore can be detected. Morse code, however, is not specifically designed for the detection of errors, although a skilled operator reading Morse slip can detect and correct errors to some extent. This is a useful feature of the code especially in the operation of radio circuits.

Radio circuits, unlike cable circuits, are in many cases subject to wide and rapid variations in propagation conditions. The effects of multipath, fading and noise will at certain times give rise to errors in transmission and, if severe, may render a circuit completely unworkable. On many long-distance radio circuits some degree of error in transmission must be accepted during certain periods, despite the use of modern radio techniques.

The standard of performance can be improved by the use of synchronous methods of telegraph working but any further improvement must be sought from the use of special protective codes, known as *error-detecting codes*, which enable certain errors in transmission to be detected automatically in the receiving equipment. In some systems the detection of an error results in the printing of a special error sign, whilst in other systems arrangements are made to correct the error automatically, as will be described later. An error-detecting code is one in which the signal combinations used to convey the message information are so chosen that the effect of the more common forms of mutilations which may be suffered in transmission is to produce an unused combination; the occurrence of an unused combination at the receiver serving to indicate the presence of an error.

It can be shown that for the transmission of 32 characters, any code with more than five elements can be derived so that a character error resulting from a single false element can always be detected and that at least nine elements would be required to detect all errors due to two false elements. It follows, therefore, that codes with numbers of elements per character between these values can be constructed so that all single element errors are detected and a proportion of the two element (or more) errors are detected.

Six-unit Error-detecting Code. One simple form of error-detecting code can be constructed by adding one element to the five-unit code, the polarity of the additional element being such as to make the total number of marking elements even (or odd, if preferred). The receiving equipment can be designed to detect for the presence of this characteristic in each six-unit code received. This code would ensure the detection of a single element error or any odd number of errors in each character. An even number of errors would of course be undetectable.

It should be noted that a six-unit binary code gives $2^6 = 64$ combinations and thus a six-unit code used for error detection for only 32 characters means that 32 combinations are redundant. A primary method of evaluating the efficacy of an error-detecting code is to calculate the probability of undetectable character errors in terms of the probability (P) of receiving a false signal element. Expressed in this manner, then using the six-unit code described above the probability of an undetectable error is approximately—

$$15P^2 - 60P^3 + 105P^4 - 90P^5 + \ldots .$$

Conversion from and to five-unit code is simple but there are no extra combinations available for use as supervisory signals in switching systems, e.g. Telex.

Seven-unit Error-detecting Codes. An improved performance can be obtained by the use of seven-unit codes and a number of codes of this type have been devised by various inventors. One of the earliest seven-unit error detecting codes used was devised by J. B. Moore and R. E. Mathes. In this code an acceptable combination has three marking and four spacing elements (or four marks and three spaces if preferred), thus giving $\frac{\underline{/7}}{\underline{/7-3}\,.\,\underline{/7-4}}$ = 35 usable combinations. Notice that a seven-unit binary code gives $2^7 = 128$ possible combinations, so that making a selection of only those combinations having three marks and four spaces results in a redundancy of $128 - 35 = 93$ combinations in the code and this accounts for its improved performance compared with the six-unit code already described.

The probability of an undetectable error using this code is approximately—

$$12P^2 - 60P^3 + 138P^4 - 174P^5 + \ldots$$

The extent of the improvement in performance is perhaps not so marked as might at first be

expected but it will be appreciated that as the number of elements in the code is increased so also is the probability of error on a character basis, for the simple reason that there are more elements in each character to go wrong.

A seven-unit code of the foregoing type using three marking and four spacing elements was employed at one time by the Radio Corporation of America (R.C.A.) for commercial circuits using a special printer which was arranged so that when a faulty combination was received a special error symbol was printed. Error-detecting systems of this type are suitable for use when the error rate is not very high but as the error rate increases the point is reached when a prohibitive number of RQ's (i.e. requests for repetition) have to be sent from the receiving to the transmitting operator and the value of the system is then questionable.

This limitation of a purely error-detecting system was overcome by an ingenious method invented by Dr. Van Duuren of the Netherlands. His system also employs a seven-unit error detecting code based on the principle of three marking and four spacing elements and thus having a probability of undetectable errors similar to the R.C.A. code, i.e. $12P^2 - 60P^3 + 138P^4 - 174P^5 + \ldots$ In addition, however, the sending and receiving equipment used in the Van Duuren system is so arranged that when an error is detected by the receiver it immediately prevents further printing for a period equal to four character periods and causes a special seven-unit RQ signal to be sent back automatically to the distant transmitting end to cause it to repeat, automatically, the transmission of the last three characters sent. Thus any errors in transmission of the telegraph signals which are detected are automatically corrected and therefore only good message copy is printed, apart of course from any undetectable errors which the code cannot detect for the reasons already explained.

The operation of this system obviously needs a send and receive channel to be available but both channels can be used simultaneously for carrying traffic, any transmission error in one channel interrupting the flow of traffic in the other whilst the RQ signal and the four character repetition cycle takes place. This arrangement covers all forms of detectable errors in either direction and the system has been proved in practice to be capable of dealing successfully with very high error rates. Naturally under such conditions the traffic-carrying capacity is still further reduced; furthermore, as the number of corrected errors increases the number of undetectable errors will unfortunately also increase. Nevertheless the system enables radio circuits to be operated when propagation conditions would be unworkable, using Morse or five-unit synchronous or start-stop codes.

Unlike the R.C.A. code, in which an arbitrary allocation of the seven-unit codes to different characters was made, the Van Duuren code was specifically designed to facilitate code conversion between it and the International Teleprinter Alphabet No. 2. The seven-unit code allocations therefore follow a logical law to facilitate the conversion process between the five- and seven-unit codes. It should also be observed that the 35 usable combinations employed in the Van Duuren system enable one combination to be used as an RQ signal, and two, known as signal alpha (α) and signal beta (β) respectively, for supervisory signals in teleprinter switching systems. Signal alpha corresponds to the start signal condition of a standardized start-stop apparatus and is used for "clearing," and signal beta corresponds to a stop signal condition, and is used for "calling."

Another interesting form of seven-unit error detecting code which is easier to convert from five-unit code than the Van Duuren code is the B.P.O. (Cook) code. In this code two elements are added to the five-unit code, one of which is assumed to have a "weight" of two. By giving these elements suitable polarities, 30 of the 32 five-unit characters can be converted to seven-unit characters in which the weighted total of marks is four. The five-unit all-space and all-mark signals have to be exceptions to this rule. These two characters and two others are obtained by having in the seven-unit code two characters with a weighted total of one mark, and two characters with a weighted total of seven marks. This arrangement gives 34 acceptable combinations. The probability of an undetectable error is approximately $8{\cdot}35P^2 - 34P^3 + 60P^4 - 52P^5 + \ldots$

Another very attractive form of seven-unit code is the B.P.O. (Wheeler-Fifield) code. This code is sometimes called a 5/2–2/5 code and is constructed very simply from the normal five-unit code by adding a sixth and seventh element of suitable polarity to form seven-unit combinations having either two marking and five spacing elements, or two spacing and five marking elements. The great attraction of this principle of constructing the code is that it simplifies the design of the code translating equipment, facilities maintenance and furthermore, unlike the other seven-unit codes, it does not involve exceptions in the code conversion rules for certain combinations. The Wheeler-Fifield code gives 42 possible combinations and the probability of an undetectable error is approximately $10P^2 - 40P^3 + 70P^4 - 60P^5 + \ldots$

If the characters are restricted to 34, which is the practical requirement, the probability of an undetectable error is—

$$8{\cdot}35P^2 - 33{\cdot}4P^3 + 57{\cdot}5P^4 - 48{\cdot}1P^5 + \ldots$$

Another advantage of the Wheeler-Fifield code is that it has less signal transitions per character than any other seven-unit code, being 3·14 as compared with 3·74 for the Cook code and 4·35 for the Van Duuren code.

In the practical employment of error-detecting codes an important application is that of providing interconnexion of teleprinters working at normal speeds via a synchronous channel in a radio telegraph system equipped with error detection and/or correction equipment. For such purposes it is desirable that the rate of flow of traffic throughout the circuit is uniform in the land line and radio sections. Thus the telegraph speed in the synchronous channel must be proportional to the number of elements in the character. For this reason the choice of seven-unit error-detecting codes is attractive for practical systems as more elaborate codes involve the use of higher signalling speeds and this increases the probability of error.

Error-correcting Codes. Codes having nine or more units can be arranged to give automatic error-correction of single errors (i.e. the element wrongly received can be identified and corrected by suitable apparatus) but this is achieved at the expense of the overall error-detecting efficiency. Thus, a nine-unit code can either detect all single and double element errors or it can correct single errors but fail to detect double errors. A ten-unit code can detect single, double and treble errors or it can correct single errors and detect double errors but fail to detect many treble errors.

Another form of error-correcting code is the "multi-character check" method in which, instead of checking elements being applied to each separate character they are applied to groups of characters. The advantage of this principle is that the check is more efficient, e.g. a four-element check on two-characters together detects more errors than a two-element check on each separate character. The main disadvantages however are—

(1) that a single error in a group of characters necessitates the repetition of the whole group, with a consequent waste of time, and

(2) that more characters have to be stored, ready for repetition if required, so making the equipment more complicated.

Codes of this type are of theoretical interest but it seems unlikely that codes having a greater number of elements than seven will have much practical application in telegraphy, as there are objections to their use, either on the grounds of loss of traffic-carrying capacity or the need for the use of a higher signalling speed in the synchronous link.

The extent of practical application of automatic error-detecting and/or correcting systems to radio telegraph services is still in the early stages of development and active experimental and design work is in progress in several countries. The use of electronic methods including the application of transistors and magnetic storage devices are of great interest in future equipment designs. At present most systems are electro-mechanical and the use of these has been spreading rapidly throughout the world during the last few years on long-distance radio teleprinter services. It seems clear

TABLE 1.4

Five-unit to Seven-unit Code Conversion Standardized for use on International Radio Teleprinter Circuits

	International Code No. 2	7-unit Code
A	Z Z A A A	A A Z Z A Z A
B	Z A A Z Z	A A Z Z A A Z
C	A Z Z Z A	Z A A Z Z A A
D	Z A A Z A	A A Z Z Z A A
E	Z A A A A	A Z Z Z A A A
F	Z A Z Z A	A A Z A A Z Z
G	A Z A Z Z	Z Z A A A A Z
H	A A Z A Z	Z A Z A A Z A
I	A Z Z A A	Z Z Z A A A A
J	Z Z A Z A	A Z A A A Z Z
K	Z Z Z Z A	A A A Z A Z Z
L	A Z A A Z	Z Z A A A Z A
M	A A Z Z Z	Z A Z A A A Z
N	A A Z Z A	Z A Z A Z A A
O	A A A Z Z	Z A A A Z Z A
P	A Z Z A Z	Z A A Z A Z A
Q	Z Z Z A Z	A A A Z Z A Z
R	A Z A Z A	Z Z A A Z A A
S	Z A Z A A	A Z A Z A Z A
T	A A A A Z	Z A A A Z A Z
U	Z Z Z A A	A Z Z A A Z A
V	A Z Z Z Z	Z A A Z A A Z
W	Z Z A A Z	A Z A A Z A Z
X	Z A Z Z Z	A A Z A Z Z A
Y	Z A Z A Z	A A Z A Z A Z
Z	Z A A A Z	A Z Z A A A Z
Carriage return	A A A Z A	Z A A A A Z Z
Line feed	A Z A A A	Z A Z Z A A A
Figures	Z Z A Z Z	A Z A A Z Z A
Letters	Z Z Z Z Z	A A A Z Z Z A
Space	A A Z A A	Z Z A Z A A A
Unperforated tape	A A A A A	A A A A Z Z Z
Signal repetition	- - - - - - - - -	A Z Z A Z A A
Signal α	- - - - - - - - -	A Z A Z A A Z
Signal β	- - - - - - - - -	A Z A Z Z A A

Note. Symbol A denotes the signalling condition corresponding to the start signal of a standardized start-stop apparatus.
Symbol Z denotes the signalling condition corresponding to the stop signal of a standardized start-stop apparatus.

that error detecting and correcting telegraph systems are destined to play an important part in the future development and operation of radio teleprinter services.

It is of interest to record that the International Consultative Committees for Radio and Telegraphy (i.e. the C.C.I.R. and the C.C.I.T.) recommended at their Plenary Meetings in 1956 that when the use of a five-unit code on a radio circuit results in an intolerable error rate and there is a return circuit, the use of a seven-unit automatic error correction system should be considered and in such cases the seven-unit code shown in Table 1.4 should be adopted.

Hellschreiber Code. The Hellschreiber system is a printing telegraph system developed primarily for use on radio links. The system is so named after its German inventor Dr. Hell and is commonly referred to in short, as the Hell system. The system is usually restricted to the transmission of the letters of the alphabet only, and is designed for the transmission of these characters in the approximate form of Roman Capitals. Each letter printed is synthesized at the receiver by printing a mosaic of black and white picture elements in a succession of parallel strips, which scan the character from top to bottom. The transmitter incorporates a signal cam for each character which produces a train of marking and spacing signals corresponding to the black and white mosaic elements of the printed character form when scanned in the manner described.

The Hell system is often described as a facsimile system but this is not strictly correct since the printed form of the received message is not a true facsimile of the message transmitted. It is therefore more accurate to describe the Hell system as being a Mosaic Printing Telegraph System.

The Hell system employed in the United Kingdom uses what is known as a seven-line system, that is to say, the character is analysed pictorially in seven vertical scanning lines. The duration of the shortest element of signal in any letter corresponds to a black element and is equal to $\frac{1}{49}$ of the total signalling time of one character. A 12-line Hell system has been used extensively in Germany and in this case the duration of the shortest signalling element is $\frac{1}{100}$ of the transmission time of a complete character.

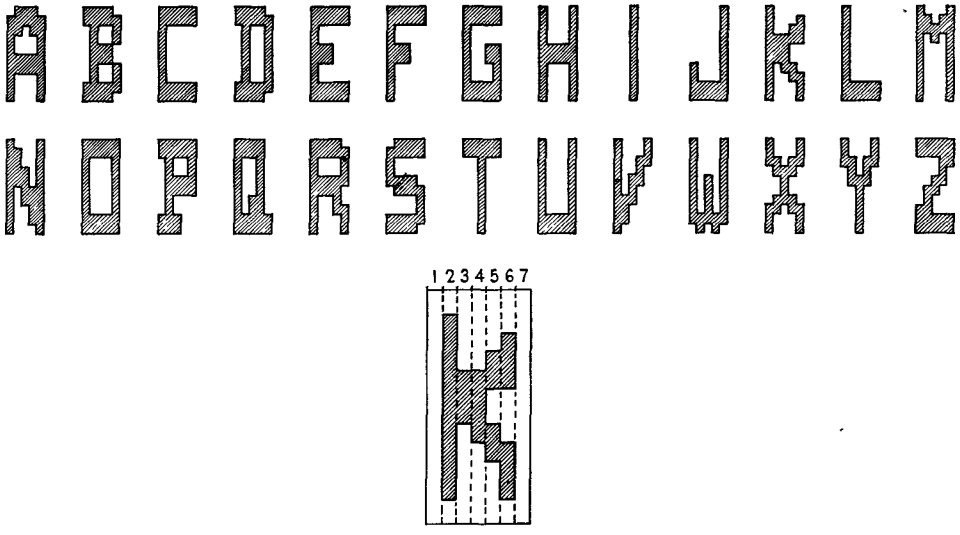


FIG. 1.2. CHARACTER FORMS USED IN 7-LINE HELLSCHREIBER SYSTEM

Fig. 1.2 indicates the form of characters employed in the case of the British type of seven-line system and this is found in practice to give good legibility in the receiving printer. The signalling code for each character may be derived from an examination of Fig. 1.2. Notice that the code is arranged so that the first and last vertical strips are left blank to form spaces between adjacent letters when printed; also that the first and last

code elements of each vertical strip will produce a marginal blank above and below each letter when printed.

The 12-line system will of course give a more exact representation of each letter, since the scanning is finer, but it has the disadvantage that it requires 100 signal elements per character as compared with 49 elements per character in the case of the seven-line system. The baud speed, and hence the band width of the transmission channel, required for transmission of a given number of words per minute, is proportional to the number of signal elements per character, and thus, a 12-line system requires more than twice the baud speed and band width of the seven-line system for a given word speed.

The normal speed of working a seven-line system is five characters per second, i.e. 300 characters per minute. Thus the baud speed equals $5 \times 49 = 245$ bauds (see page 16).

Facsimile and Picture or Photo-telegraphy. Facsimile telegraphy, as the name implies, refers to those systems employed for the transmission of intelligence and its reception in a form which provides an exact or similar reproduction of the original. Distinction is sometimes drawn between facsimile telegraphy and picture or photo-telegraphy, the latter referring to those systems employed for the transmission and reception of half-tone still pictures, whilst the former refers to those systems in which printed or written messages are reproduced as black and white copies of the original. The C.C.I.T. definition of facsimile telegraphy, however, is "A system of telegraphy providing reproduction in the form of fixed images (photographic or otherwise), of the form and possibly of the depth of tone or of the colours, of an original document, whether written, printed or pictorial," and this is preferred. The use of a code of signals in the literal sense is not employed in facsimile working.

The principle employed in these systems is that the original subject-matter to be transmitted is systematically scanned, line by line. Optical scanning is usually employed, e.g. a ray of light focused to a small spot and arranged so that the light transmitted through, or reflected from, the subject-matter, acts upon a photo-electric cell so varying the current flowing in it, in accordance with the variations in the intensity of the light falling on the cell. The current variations control the transmission of a carrier signal to the receiving equipment by modulating a carrier frequency.

In some systems the current variations are proportional to the whiteness of the subject-matter and, thus, are responsive to all intermediate tone values from white to black; such a system is therefore suitable for the transmission of pictures or photographs containing a range of tones. In other systems the photo-cell causes a current to be transmitted for white, and no current for black (or vice versa), half tones are not transmitted; a system of this type is therefore only suitable for printed or written messages, line drawings, etc.

The reception of facsimile transmissions is effected on a receiving instrument which is controlled to run in synchronism and phase with the transmitter; the incoming signalling currents control the recording of an image, which is built up line by line in accordance with the original scanning. Recording of the received image is effected in either of two ways, i.e.

(*a*) *Directly*, with a stylus or writing helix, which applies an electric voltage to produce a mark on a suitably treated paper. The heaviness of the mark is dependent upon the magnitude of the voltage produced by the demodulated received signals. Systems of this type are called "Direct Recording Facsimile Systems" and the received copy can be taken straight off the machine ready for use. A later development uses a percussion method of recording an inked impression on ordinary paper.

(*b*) *Photographically*. This is the method employed in "Photo-telegraphy," which is the most refined form of facsimile telegraphy; normal photographic materials and processes are used for developing and fixing the received copy, the overall object of which is to produce a photographic copy which is indistinguishable from the original.

It will thus be clear that the employment of facsimile techniques enables an almost infinite variety of forms to be transmitted and recorded, the degree of fineness of detail being determined by the fineness of the scan, the characteristics of the transmitting and receiving equipment and the recording method employed. Thus, the limitations imposed in this respect by the other types of codes discussed are overcome.

Telegraph Speed. The rate at which intelligence may be transmitted over a telegraph channel is an important factor from both a traffic and an engineering point of view. In the former case, the speed of operation will determine the number of communication channels and operators required to dispose of a given quantity of messages in any given time and may also have a bearing on the degree of skill required by the operators to transmit and receive the messages. From the engineering point of view, the speed of operation has an important influence upon the design characteristics of both the transmitting and receiving instruments and also that of the communication channel.

Any economic comparison of the relative merits of various systems of telegraphy, involves consideration of the operating speed. From a traffic point of view, it is natural and convenient to express the speed of operation in terms of the number of words per minute (W.P.M.) which may be transmitted or received. The use of W.P.M. as a unit of speed is, however, inadequate for engineering purposes, since it does not indicate with any exactitude the speed of signalling the elements of code and this is the factor of prime importance in engineering design. In Morse systems the number of dots and dashes varies for different characters but, for traffic purposes, it may be assumed that the average duration of the signals per character (in the case of transmission of plain English) is roughly equivalent to nine-dots. An average English word consists of five letters and when expressing the operating speed in W.P.M. an allowance of one space (equivalent to seven dots) between words is allowed. Thus a speed of N word/minute* in Morse is equivalent to $N[(5 \times 9) + 7] = 52N$ dots per minute. Thus the duration of the dot is $\frac{60}{N \times 52} \times 1{,}000 = \frac{1{,}154}{N}$ milliseconds (msec).

In the case of five-unit code systems the duration of the signals is the same for every character and the duration of the space between words is the same as that for a character. The minimum duration of the signal between characters varies with the type of five-unit system employed. Teleprinter systems, for example, operate on a start-stop principle, that is to say the transmitting and receiving mechanisms are started and stopped at the beginning and end respectively of each five-unit code signal combination transmitted. The Teleprinter No. 7, which is used extensively in Great Britain, has a start signal equal in length to one code element and a stop signal which is equal in length to one and a half code elements. Hence the total duration of the signals for each character is equivalent to seven and a half code elements. An operating speed of N words/minute in this case is therefore equivalent to $N \times 6 \times 7\frac{1}{2} = 45N$ code elements per min. The duration of one-code element is therefore equal to $\frac{60}{N \times 45} \times 1{,}000$ msec i.e. $\frac{1{,}333}{N}$ msec (approximately).

In the case of the Hell system employing 49 code elements per character, a speed of N w.p.m.* is equivalent to $N \times 6 \times 49 = 294N$ signal elements per min. Hence the duration of one signal element is $\frac{60}{294N} \times 1{,}000$ msec, i.e. $\frac{203}{N}$ msec (approximately).

The duration of the shortest element can be similarly calculated for any type of telegraph system. Enough has been said, however, to demonstrate that the duration of the shortest element of signal for a given W.P.M. speed varies considerably, depending upon the code employed and the speed in W.P.M. requires careful interpretation before the significance of the speed from an engineering point of view is understood. For this reason, it is the practice in engineering parlance to express the speed of operation of telegraph instruments and channels in terms of a unit which is related to the shortest element of signal. This unit is known as a *Baud*, and is so named after the famous French telegraph engineer Emile Baudot.

The definition of a baud is as follows—

"*Baud*—The unit of telegraph speed. Telegraph signals are characterized by intervals of time of duration equal to, or greater than, the shortest or elementary interval. Telegraph speed is, therefore, expressed as the inverse of the value of the elementary interval in seconds. A speed of one elementary interval per sec is termed one baud."

It should be noted that the baud speed is determined by the duration of the elementary interval, i.e. the shortest element of signal. Thus, in the Morse code, the elementary interval is the dot, whilst in the start-stop code it is one code element, e.g. in the case of the Teleprinter No. 7, the elementary interval is 20 msec, i.e. 0·02 sec; hence the telegraph speed is $\frac{1}{0{\cdot}02} = 50$ bauds.

The desired characteristics of the communication channel for the transmission of telegraph signals are determined by the time required for the current corresponding to a signal element to build-up in the channel. The shorter the signal element the faster the build-up must occur. This is why the duration of the shortest signal element is of such importance in relation to the characteristics required of the channel and is the reason for its use as the basis for expressing telegraph speed. It will be explained fully in Chapter 5 how the build-up time of a signal is governed by the available band-width of the channel and it will be shown that the higher the baud speed the greater is the band

* The speed N w.p.m. is here assumed to be such that there are no pauses by the operator during sending. If pauses do occur, then the duration of these pauses must be subtracted before the duration of the shortest signal element can be calculated, which further emphasizes the inadequacy of W.P.M. speed as an indicator of signalling speed. The Teleprinter No. 7 for example may be operated at any speed up to 66⅔ W.P.M. but the duration of each code element is constant and equal to 20 msec.

width required to enable telegraph signals to be satisfactorily transmitted.

Comparison of the Efficiency of various Telegraph Codes. The maximum speed of transmission of characters is obtainable from a code in which the average number of signal elements per character is a minimum. This is secured by employing a code in which the maximum possible number of combinations which may be derived from it is equal to the number of different characters required to be transmitted. For example, a five-unit code provides a maximum of $2^5 = 32$ combinations, all of which are employed for characters or other necessary functions. This code is therefore very efficient in its utilization of channel band width. In the case of a seven-line Hell system, a maximum of $2^{25} = 33{,}554{,}432$ possible combinations are available but only those combinations which cause the receiver to print a form having alphabetical significance are used. This system is therefore very wasteful in use of band-width. In the case of facsimile telegraphy the number of possible combinations that can be transmitted is practically infinite and if such a system were used merely for transmitting a limited number of alphabetical signs this would be grossly wasteful of band-width.

From the point of view of band-width required, the most economical telegraph code is obviously the one which involves the lowest baud speed for a given character rate and the relative efficiency of various systems of telegraphy in this respect are shown in Table 1.5.

TABLE 1.5

Telegraph System	Baud speed necessary for the transmission of 1 character per sec.
Cable Code	3·3
Multiplex (5-unit code)	5 to 6 (depending upon the method of speed correction)
Teleprinter (start-stop)	7 or 7·5 (depending whether the stop signal is 1 or 1·5 units)
International Morse	8·6
Hellschreiber	49 or 100 (depending whether a 7-line or 12-line system is used)
Facsimile Telegraphy	100 to 300 (depending upon the number of lines per in.)

If instead of speed, the criterion of comparison is made one of accuracy in the presence of interference and noise, etc., in the transmission circuit, then the order of merit of the above systems is almost the reverse of that shown in Table 1.5. Thus, for example, an incorrect element in the case of five-unit code will alter the printed character completely from one character to another, furthermore if the mutilation transposes the signal into a shift-signal of the opposite case, then all the following characters will be in the wrong case until the next case shift-signal is received.

On the other hand, in the Hell system an incorrect element will only result in a slight irregularity in the printed form and will not render the character illegible, whilst in photo-telegraphy an incorrect element will only cause a minor blemish and might well pass unnoticed.

Principles employed in Telegraph Signalling. The object of a telegraph system is to transmit intelligence from one point and receive it in a recognizable form at another point. We have seen that for this purpose the intelligence is conveyed in the form of a code of signal elements. It is now necessary to consider how these signal elements are formed and how the nature of these elements may be recognized and transformed into intelligence at the receiving end of the circuit.

The first requirement in a telegraph system is obviously a means for transmitting the code of signals and the device employed for this purpose is quite naturally called a "transmitter." The action required from the transmitter is that it shall cause a series of changes to occur in the electrical condition of the circuit at the sending end, the changes occurring in a definite time sequence and corresponding to the telegraph code of the character being transmitted. The changes in the transmitter will give rise to corresponding electrical changes at the receiving end of the circuit and, by recognition of these time intervals at the receiver, the character may be identified and recorded.

These operations performed at the transmitter have been given the name "telegraph modulation." The instants of time at which the characteristic changes in the electrical conditions occur at the transmitter, are called "characteristic instants of modulation," and the intervals between these instants are called "elements of modulation."

The simplest forms of signalling are those employed in direct current transmission systems, and of these the *single-current* system will first be described.

Single-current Signalling. This method of signalling, as the name implies, employs direct current signals which flow in a single direction in the circuit—they are unidirectional currents. For single-current working the transmitter may be arranged in either of the two following ways—

(*a*) It may be connected so that when it is idle no current flows to line but when operated to its other contact position the tongue of the transmitter completes an electrical circuit and allows current to flow from a battery, or other source of

signalling power, through the transmitter, the line and the distant receiving instrument.

Or conversely—

(*b*) The transmitter may be connected so that in the idle condition its transmitting tongue is connected to the line and permits a current to flow from a battery through the transmitter, the line

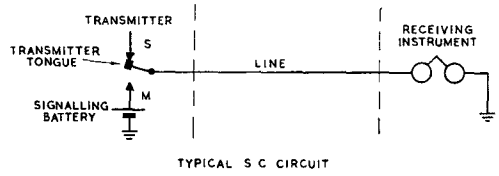


FIG. 1.3. TELEGRAPH CIRCUIT USING SINGLE-CURRENT SIGNALLING

and distant receiving instrument; whereas, when the transmitting tongue is operated to its other contact it breaks the line circuit and the current ceases.

Whichever method of signalling is adopted, the action of the transmitter controls the flow or cessation of current through the line to the receiving instrument, the current flow being unidirectional in each case. Thus the elements of modulation may be indicated either by the flow of current or its cessation, and this method of signalling therefore permits of two basic conditions of signalling to be indicated and these are called respectively "marking" and "spacing." A "marking" signal may thus be represented by no current and a "spacing" signal by a flow of current, or vice versa. Normal British single-current practice is to transmit no current for "marking" signals and current for "spacing" signals.

The signals resulting from telegraph modulation in this way are called single-current signals and circuits so operated are said to employ single-current working.

Fig. 1.3 shows a typical single-current operated circuit and Fig. 1.4 indicates graphically the nature of the single-current signals for typical characters both in the case of Morse code and five-unit start-stop code signals (International Alphabet No. 2, i.e. for Teleprinters).

Double-current Signalling. This method of signalling employs direct-current so that an element of modulation corresponding to the marking condition of signalling causes a current to flow in one direction in the circuit, whereas an element of modulation for the spacing condition of signalling causes a current to flow in the reverse direction in the circuit. Thus two current conditions are employed to differentiate between marking and spacing conditions of signalling, hence the expression Double-current Signalling. Systems employing this method of signalling are usually referred to as double-current signalling systems or are said to employ double-current working.

The transmitter may be arranged in one of two ways—

(*a*) So that a marking signal causes a current to flow from the transmitter into the line (this is often referred to as a positive current), and a spacing signal causes a current to flow in the reverse direction namely from the line into the transmitter (this is often referred to as a negative current).

Or.

(*b*) So that a marking signal causes a flow of current from the line to the transmitter and vice versa for a spacing signal.

Fig. 1.5 shows a typical double-current operated

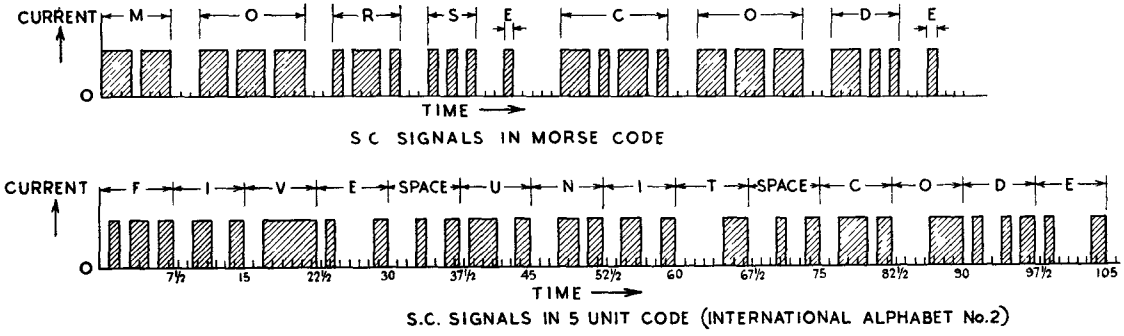


FIG. 1.4. SINGLE-CURRENT SIGNALS IN MORSE CODE AND 5-UNIT TELEPRINTER CODE

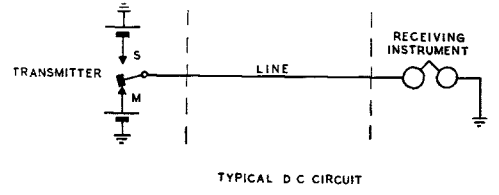


FIG. 1.5. TELEGRAPH CIRCUIT USING DOUBLE-CURRENT SIGNALLING

circuit and Fig. 1.6 indicates graphically the nature of the double-current signals for typical characters in Morse code and five-unit start-stop code.

Alternating Current Signalling

Simple Sine Function. The equation

$$e = E \sin \omega t \quad . \quad . \quad (1)$$

relates to a simple harmonic or sine wave where

e is the amplitude at any instant of time t;
E is the maximum amplitude of the wave;

curve to a sine function is illustrated by means of the rotating vector shown at the left. One complete rotation of the vector corresponds to one cycle of the sine wave. The figure shows how, for a given fraction of a revolution of the vector, 30° for example, the amplitude of the sine wave for the same fraction of its total period, is equal to the sine of the angle turned through by the vector. The vector is assumed to rotate in a counter-clockwise direction. It will be seen that any point on the sine wave corresponds to a given angular displacement of the rotating vector. This angle is reckoned in

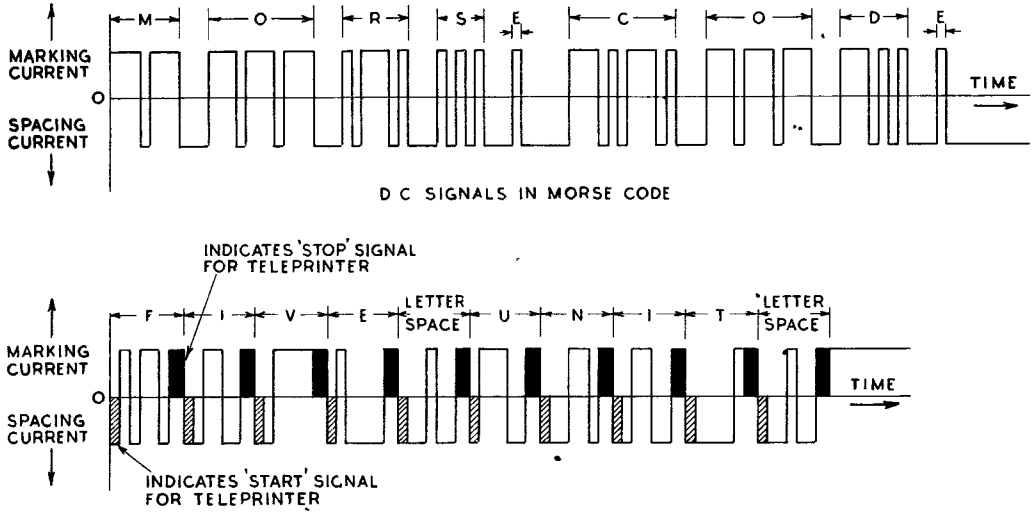


FIG. 1.6. DOUBLE-CURRENT SIGNALS IN MORSE CODE AND 5-UNIT TELEPRINTER CODE

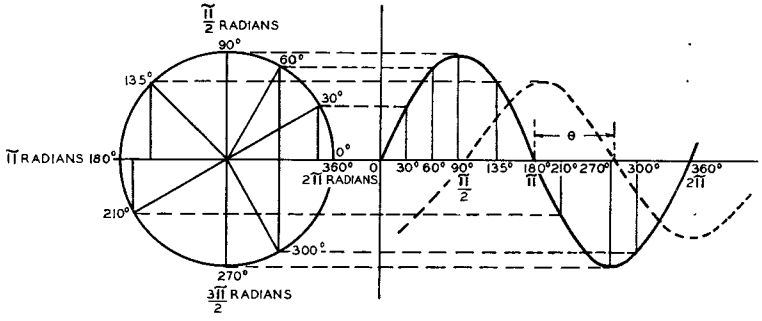


FIG. 1.7. SINE CURVES: $E \sin \omega t$ and $E_1 \sin (\omega t - \theta)$

and ω is a constant depending upon the frequency with which the wave repeats itself.

The curve of the foregoing equation is plotted in Fig. 1·7, the ordinates giving the amplitude of the wave or e.m.f. at any given time from the commencement of a cycle or period. The relation of the radians and in equation (1) this is given by the product ωt. Thus when ωt is equal to $\pi/2$ radians we have—

$e = E$ because $\sin \pi/2 = +1$. Also when $\omega t = \pi$, $e = 0$ because $\sin \pi = 0$. When $\omega t = 3\pi/2$,

$e = -E$ because $\sin(3\pi/2) = -1$, indicating that the e.m.f. has changed in direction.

When $\omega t = 2\pi$ the cycle is completed and a new cycle commences.

It will thus be seen that

$$t = 2\pi/\omega$$

is the period of one cycle, t being the time in seconds.

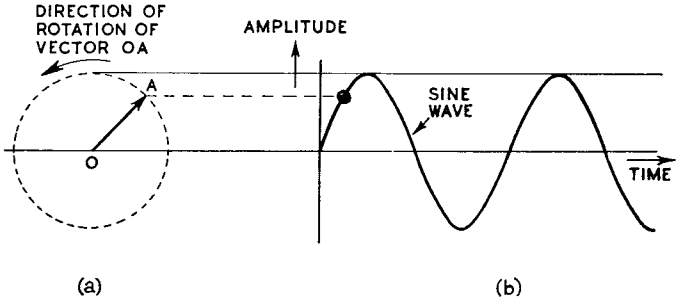


FIG. 1.8. UNMODULATED CARRIER FREQUENCY

Again, if f is the frequency, that is, the number of cycles per second, we have

$$f = 1/t = \omega/2\pi \text{ or } \omega = 2\pi f$$

In Fig. 1·7 a second sine curve is shown dotted. This curve is lagging behind the first by an angle θ, or a time of θ/ω sec. The curves are said to have a *phase difference* of θ radians. The equation to the second curve is

$$e_1 = E_1 \sin(\omega t - \theta)$$

where the time t is reckoned from the zero point on the first wave $e = E \sin \omega t$.

Thus it will be seen that an alternating current, voltage or electromagnetic wave possesses three main defining characteristics viz—

(*a*) Amplitude
(*b*) Frequency
and (*c*) Phase.

A variation (i.e. modulation) of any one of these three characteristics can be used for conveying intelligence from a transmitter to a receiver, provided that the receiving equipment is designed to be responsive to the particular type of modulation employed. Any alternating signal which is employed in this manner to carry intelligence is termed a "carrier signal."

There are thus three generic types of A.C. transmission systems depending on whether the mode of modulation of the carrier is by means of amplitude, frequency or phase. These three systems of modulation are therefore referred to as—

(*a*) Amplitude Modulation (A.M.)
(*b*) Frequency Modulation (F.M.)
and (*c*) Phase Modulation (P.M.).

Phase modulation is closely allied to frequency modulation.

Amplitude Modulation. An unmodulated carrier frequency can be represented either by a vector of length OA rotating at a constant angular velocity, see Fig. 1.8 (*a*), or else by a sine-wave form, see Fig. 1.8 (*b*), which shows the instantaneous amplitude of the carrier plotted against time. Consider now the effect of connecting such a carrier signal to a line in the manner indicated in Fig. 1.9 in which the connexion or disconnexion of the carrier signal to line is under the control of a Morse key. With the circuit arrangement shown, the carrier signal is transmitted to line during operation of the key to the marking contact (M) and is disconnected from the line when operated to the spacing contact (S). If the key is operated for signals in Morse code then the resulting carrier signals in the line will take the form indicated in Fig. 1.10 from which it will be seen that the carrier is transmitted for dot and dash signals, the duration of the carrier signal for a dash being three times the duration of that for a dot. For space signals the carrier is not transmitted to line. This form of signalling is an elementary form of amplitude modulation and is described as on-off keying or on-off signalling.

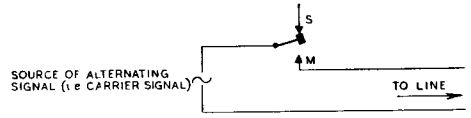
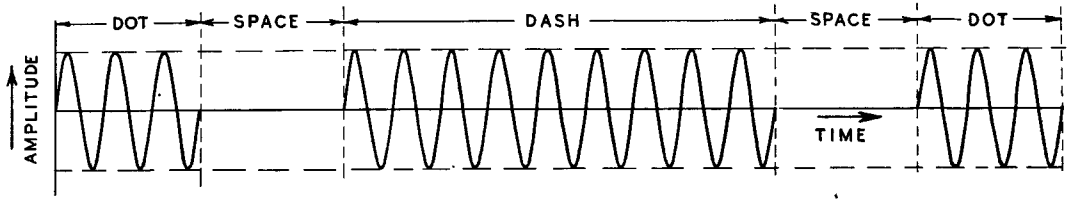


FIG. 1.9. ALTERNATING-CURRENT ON–OFF KEYING

In the case considered, transmission of carrier is employed to signify elements of signal corresponding to marking, whilst disconnexion of the carrier corresponds to spacing. The converse signalling arrangement can be employed if desired and the choice of the method used in any particular transmission system depends upon the line condition to be met.

If instead of on-off signalling in which the carrier is abruptly connected to and disconnected from the line for the different elements, we consider the effect of varying the carrier so that its amplitude is controlled by a signal consisting of a sine-wave,

then the resultant modulation may be represented as indicated in Fig. 1.11. In this Fig. the vector OA, rotating at a constant angular velocity, represents the unmodulated carrier and the effect of modulation is to cause the amplitude of the carrier to vary sinusoidally about its unmodulated value



ON-OFF KEYING OF CARRIER FOR LETTER 'R' IN MORSE CODE

FIG. 1.10. ON–OFF KEYING OF CARRIER FOR LETTER R IN MORSE CODE

OA, in accordance with the modulating sine wave. Thus, for one complete cycle of the modulating frequency, the amplitude of the carrier will vary between the limits OB to OC, where

$OA = E_c$ the maximum amplitude of the unmodulated carrier

$OB = E_c - E_m$ and $OC = E_c + E_m$ where E_m = the maximum amplitude of the modulating signal.

the unmodulated carrier. Thus the modulation factor

$$K = \frac{\frac{1}{2}[(E_c + E_m) - (E_c - E_m)]}{E_c} = \frac{E_m}{E_c}.$$

The maximum possible modulation depth is obviously produced when $E_m = E_c$ so that $E_c - E_m = 0$ and $E_c + E_m = 2E_c$.

The maximum attainable value of the modulation factor K is thus 1. The modulation factor is sometimes expressed as a percentage and is then termed the "modulation percentage." Thus when $K = 1$ the modulation percentage = 100 per cent.

It will now be shown that as a result of the modulation of the carrier wave by a single sine

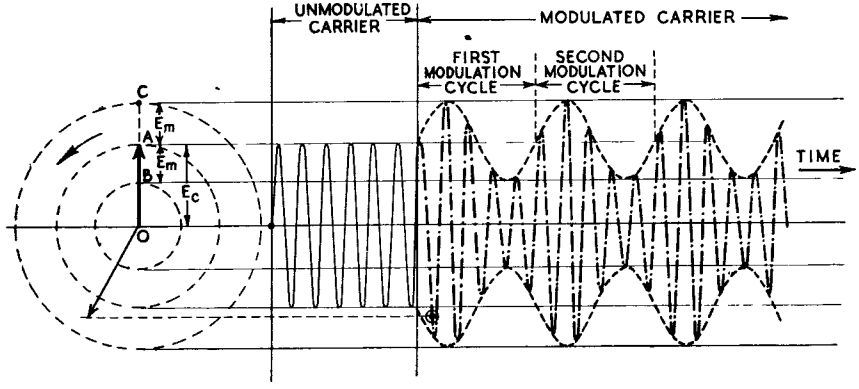


FIG. 1.11. AMPLITUDE MODULATION OF A CARRIER FREQUENCY

The corresponding cycle of the modulated carrier for one cycle of the modulating signal is called the "modulation cycle." E_m is called the "depth of modulation." The ratio E_m/E_c is a measure of the degree of modulation of the carrier and is called the "modulation factor" (K). The modulation factor may therefore be defined as the ratio of half the difference between the maximum ($E_c + E_m$) and minimum ($E_c - E_m$) amplitudes of the modulated carrier, to the amplitude (E_c) of wave, that three frequencies are present in the modulated wave, namely, the original carrier frequency and two other frequencies, one having a frequency equal to the carrier frequency plus the modulating frequency, and the other having a frequency equal to the carrier frequency minus the modulating frequency. This may be proved as follows—

The unmodulated carrier e.m.f. may be represented by— $e_c = E_c \sin 2\pi f_c t$

where e_c = the instantaneous value of the carrier e.m.f. at the time t;

E_c = the maximum amplitude of the carrier e.m.f.;

and f_c = the frequency of the carrier e.m.f.

The modulating e.m.f. may be represented by—

$$e_m = E_m \sin 2\pi f_m t$$

where e_m = the instantaneous value of the modulating e.m.f. at time t;

E_m = the maximum amplitude of the modulating e.m.f.;

and f_m = the frequency of the modulating e.m.f.

Hence the instantaneous amplitude of the modulated carrier may be represented as—

$$\begin{aligned} e_{mc} &= (E_c + e_m) \sin 2\pi f_c t \\ &= (E_c + E_m \sin 2\pi f_m t) \sin 2\pi f_c t \\ &= E_c \sin 2\pi f_c t + E_m (\sin 2\pi f_m t)(\sin 2\pi f_c t) \\ &= E_c \sin 2\pi f_c t + \frac{E_m}{2} \cos 2\pi (f_c - f_m) t \\ &\qquad - \frac{E_m}{2} \cos 2\pi (f_c + f_m) t \\ &= E_c \sin 2\pi f_c t + \frac{E_m}{2} \sin \left[2\pi (f_c - f_m) t + \frac{\pi}{2} \right] \\ &\qquad + \frac{E_m}{2} \sin \left[2\pi (f_c + f_m) t - \frac{\pi}{2} \right] \end{aligned}$$

The modulated carrier therefore comprises three alternating components, i.e.—

(*a*) $E_c \sin 2\pi f_c t$ whose amplitude and frequency are those of the unmodulated carrier;

(*b*) $\frac{E_m}{2} \sin \left[2\pi (f_c - f_m) t + \frac{\pi}{2} \right]$ whose amplitude is half the depth of modulation and whose frequency is less than the carrier frequency f_c by an amount equal to the modulating frequency f_m;

(*c*) $\frac{E_m}{2} \sin \left[2\pi (f_c + f_m) t - \frac{\pi}{2} \right]$ whose amplitude is half the depth of modulation and whose frequency is greater than that of the carrier frequency f_c by an amount equal to the modulating frequency f_m.

The frequency $f_c - f_m$ is known as the "lower sideband frequency" and $f_c + f_m$ is known as the "upper sideband frequency."

It is important to note that although the presence of the carrier is essential to the production of the sideband frequencies, the presence of the carrier when modulation has occurred serves no useful purpose in the transmission of the intelligence which was contained in the modulating signal. This intelligence is now carried in each of the sideband frequencies and may be extracted from either sideband at the receiving end of the circuit by a process known as demodulation.

It is of interest to note the distribution of energy in the sideband and carrier frequencies and this may be determined as follows. Power is proportional to (voltage)^2 thus—

Power in the carrier is $\propto E_c^2$

Power in the lower sideband is $\propto \left(\frac{E_m}{2} \right)^2$

Power in the upper sideband is $\propto \left(\frac{E_m}{2} \right)^2$

Or expressed in terms of the modulation factor K which is equal to $\frac{E_m}{E_c}$,

Power in the carrier is

$$\propto E_c^2$$

Power in the lower sideband is

$$\propto \left(\frac{K \,.\, E_c}{2} \right)^2 \text{ i.e. } \frac{K^2}{4} \,.\, E_c^2$$

Power in the upper sideband is

$$\propto \left(\frac{K \,.\, E_c}{2} \right)^2 \text{ i.e. } \frac{K^2}{4} \,.\, E_c^2$$

Thus with maximum modulation, i.e. $K = 1$, the power in each sideband is $\frac{1}{4}$ of the power in the carrier.

If the modulation factor $K = \frac{1}{2}$ then the power in each sideband is $\frac{1}{16}$ of the power in the carrier. The power in the sidebands for other values of K may be similarly calculated in relation to the power in the carrier.

The modulation effects demonstrated in the foregoing, in which the modulation was produced by a single sinusoidal frequency, apply equally when the modulation is caused by any number of frequencies. The resultant effect is that for each component frequency of the modulating signal, a pair of sideband frequencies is produced in the modulated carrier, these frequencies being displaced in the frequency spectrum on either side of the carrier frequency by an amount equal to the modulating frequency. Thus if the carrier frequency f_c is amplitude modulated by a signal which is comprised of simultaneous components having frequencies f_1, f_2, f_3 and whose amplitudes are such that they produce depths of modulation corresponding to the modulation factors 1, $\frac{1}{2}$, and $\frac{1}{10}$ respectively, then the resultant modulated carrier

will have a frequency spectrum as indicated in Fig. 1.12.

Amplitude modulation techniques are used very extensively in modern telegraphy, both for land-line and radio-telegraph transmission systems. Fuller details of the methods employed to effect modulation and the applications of this technique to various systems will be found in later chapters. At this stage it is sufficient if the reader has understood the principle of amplitude modulation and realized its intrinsic usefulness. Thus it should be a suitable selection of the carrier frequency. It has been explained how the intelligence after modulation is contained equally in both sidebands and therefore that the transmission of both is not essential for the purpose of receiving the intelligence. Use is made of this characteristic in some systems to effect an economy in the bandwidth required for the transmission; one sideband is suppressed after modulation and only the remaining single sideband is transmitted. The bandwidth required for the transmission is thus halved.

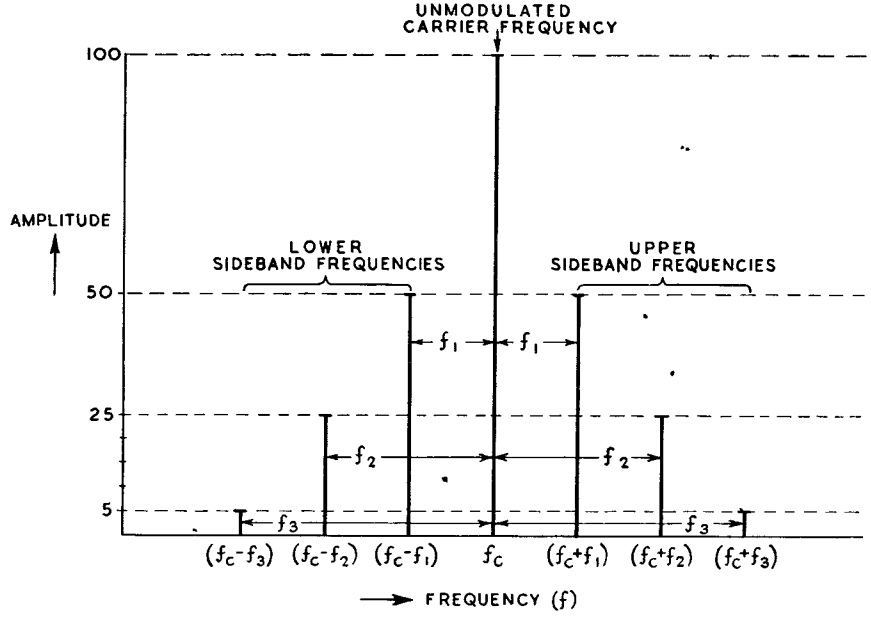


FIG. 1.12. FREQUENCY SPECTRUM RESULTING FROM AMPLITUDE MODULATION OF CARRIER f_c BY A SIGNAL HAVING COMPONENT FREQUENCIES f_1, f_2 AND f_3

clear that, as the modulating signal may be comprised of one or more sinusoidal frequencies of any amplitude, any modulating signal, however complex, may be transmitted by the modulation of a carrier by the signal. Thus, the modulating signal may take the form of either direct-current or alternating-current, as it can be shown that even direct-current signals can be analysed into a number of simultaneous and equivalent alternating current components. This technique thus offers great possibilities as it enables any telegraph signal generated by a telegraph transmitter, to be transmitted over any form of audio or high-frequency land-line channel and similarly enables transmission over radio links. Furthermore, in either case, the telegraph intelligence is able to be carried by the sideband frequency, or frequencies, over any desired band in the frequency spectrum by making

Frequency Modulation. In frequency modulation signalling systems the transmission of intelligence is effected by means of the modulation of a carrier frequency so that the modulating signal causes the instantaneous frequency of the carrier to vary (i.e. swing) by an amount proportional to the instantaneous amplitude of the modulating signal; the maximum amplitude of the modulated carrier, however, remains constant throughout. The effect can probably be appreciated better by the study of Fig. 1.13 (*a*) in which the modulated carrier frequency is plotted against time.

In this Fig. F_c represents the carrier frequency and if no modulation is present then this frequency will remain constant. If now a sinusoidal modulating frequency F_m is applied, then the frequency of the modulated carrier frequency will vary in the manner indicated. Thus at the instant of time t

shown in Fig. 1.13 (*a*), the frequency of the carrier is $F_c + \Delta F$, where ΔF (i.e. the frequency swing) is proportional to the amplitude e_m of the modulating signal at the instant of time t. From this it will be clear that the modulated carrier frequency is the same as the unmodulated carrier at those instants when the amplitude of the modulating signal is zero, that is to say, at times corresponding to the points *a*, *c*, *e*, *g*, *i*, and *k* in Fig. 1.13 (*a*). Also, the modulated frequency is maximum at those instants corresponding to times *b*, *f*, and *j* in Fig. 1.13 (*a*); the modulated frequency is minimum at times corresponding to *d* and *h*. Thus it will be seen that a modulation cycle occurs, in which the frequency of the carrier varies in a sinusoidal manner from F_c to $F_c + \Delta F_{max}$ back to F_c and then to $F_c - \Delta F_{max}$ and thence to F_c, for each cycle of the modulating signal.

Fig. 1.13 (*b*) indicates the effect on the instantaneous amplitude of the modulated carrier, plotted against time.

The effect of frequency modulation may also be represented vectorally, in which case the unmodulated carrier may be represented by vector E_c rotating at a constant angular velocity ω_c radians per sec and the effect of modulation is to cause the angular speed of rotation of the vector to vary from instant to instant in accordance with the amplitude of the modulating signal. Thus the instantaneous frequency varies above and below the mean carrier

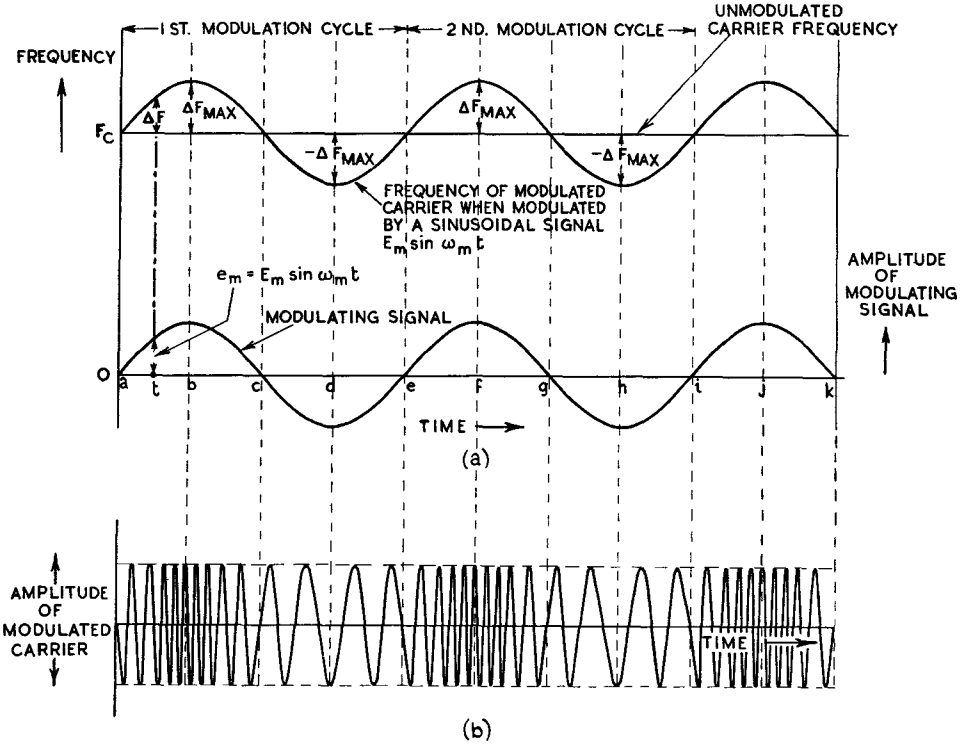


FIG. 1.13. FREQUENCY MODULATION

(*a*) Relationship between frequency of modulated carrier and amplitude of modulating sine-wave signal.
(*b*) Resulting modulated waveform.

frequency for each cycle of the modulating frequency. The extent of this variation, at any instant of time, is called the *frequency swing* (ΔF) and this may therefore be defined as "the variation (ΔF) of the instantaneous frequency F, above or below the mean carrier frequency F_c, due to the modulating signal amplitude at that instant."

Frequency Deviation (ΔF_{max}) is then defined as the value of the frequency swing ΔF corresponding to the maximum modulating signal amplitude.

Modulation Factor. In a frequency modulated transmission, the normal unmodulated carrier frequency F_c will be varied between the limits $F_c + \Delta F_{max}$ and $F_c - \Delta F_{max}$ at maximum

modulation depth. The ratio $\Delta F/F_c$ is termed the modulation factor and this ratio when expressed as a percentage is called the modulation percentage or percentage modulation.

Modulation Index. The modulation index of a frequency modulated wave is defined as the ratio of the frequency swing to the frequency of a specified sinusoidal modulation.

Deviation Ratio. The deviation ratio (D) is the value of the ratio of the frequency deviation $\Delta F_{\max}$ to the maximum modulating frequency $f_{\max}$. Thus $D = \Delta F_{\max}/f_{\max}$ and this factor is of particular value in enabling the frequency band

$$= 2\pi F_c t + \frac{\Delta F_{\max}}{f_m}(-\cos \omega_m t) + \frac{\Delta F_{\max}}{f_m}$$

$$\therefore\ \theta = 2\pi F_c t - \frac{\Delta F_{\max}}{f_m}\cos 2\pi f_m t + \frac{\Delta F_{\max}}{f_m}$$

Hence the instantaneous amplitude of the modulated carrier is—

$$e_c = E_c \sin \theta$$

$$= E_c \sin\left(2\pi F_c t - \frac{\Delta F_{\max}}{f_m}\cos 2\pi f_m t + \frac{\Delta F_{\max}}{f_m}\right)$$

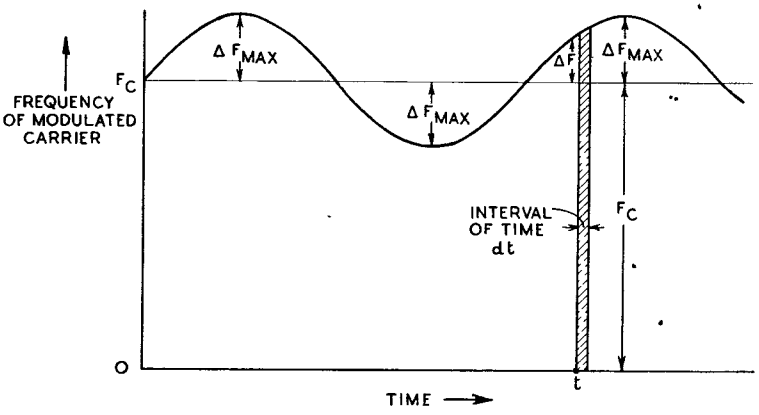


FIG. 1.14. FREQUENCY MODULATION: INSTANTANEOUS FREQUENCY OF MODULATED CARRIER PLOTTED AGAINST TIME

and signal-to-noise ratio associated with a given transmission to be estimated.

If the maximum frequency swing from the mean carrier frequency caused by a single sinusoidal signal ($e_m = E_m \sin \omega_m t$) is $\Delta F_{\max}$, then the frequency swing at any instant of time t may be represented by—

$$\Delta F = \Delta F_{\max} \sin \omega_m t$$

Thus the instantaneous frequency of the modulated carrier at time t will be $F_c + \Delta F = F_c + \Delta F_{\max} \sin \omega_m t$ (see Fig. 1.14).

Considering now an infinitely short time $\mathrm{d}t$, then the angle swept by the carrier vector between time t and $t + \mathrm{d}t$ will be $2\pi(F_c + \Delta F_{\max} \sin \omega_m t)\mathrm{d}t$. Thus the total angle ($\theta$) swept by the vector during the time from O to t is

$$\theta = \int_0^t 2\pi(F_c + \Delta F_{\max} \sin \omega_m t)\mathrm{d}t$$

$$= 2\pi\left[F_c t + \Delta F_{\max}\left(-\frac{1}{\omega_m} \cdot \cos \omega_m t\right)\right]_0^t$$

The mathematical expansion of this expression indicates that not only is the first pair of sidebands, namely $F_c \pm f_m$, generated as in the case of amplitude modulation, but in addition pairs of sideband frequencies are also generated at $F_c \pm 2f_m$, $F_c \pm 3f_m$, $F_c \pm 4f_m$ and so on to $(F_c \pm nf_m)$. Thus there is theoretically an infinite number of pairs of sideband frequencies, and the magnitudes of these sidebands are controlled by the ratio $\Delta F/f_m$ (the modulation index) but they are not directly proportional to it.

Fig. 1.15 shows a series of curves from which the amplitude variations of the carrier and significant sidebands can be determined for various values of modulation index.

Fig. 1.16 indicates the distribution of energy throughout the frequency spectrum for various values of modulation index and a constant modulating frequency. Although, theoretically, an infinite number of sidebands is possible, in practice only those sidebands containing a significant amount of energy relative to that of the unmodulated carrier are important, and it will be found

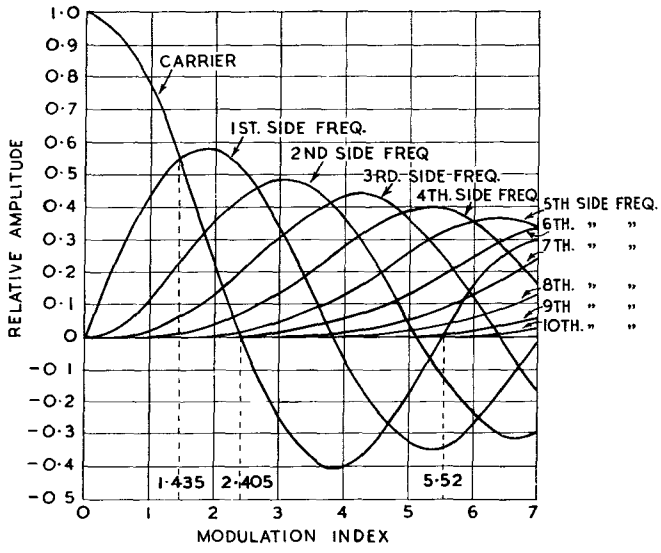


FIG. 1.15. FREQUENCY MODULATION: CARRIER- AND SIDE-FREQUENCY AMPLITUDES FOR SINGLE-FREQUENCY MODULATION

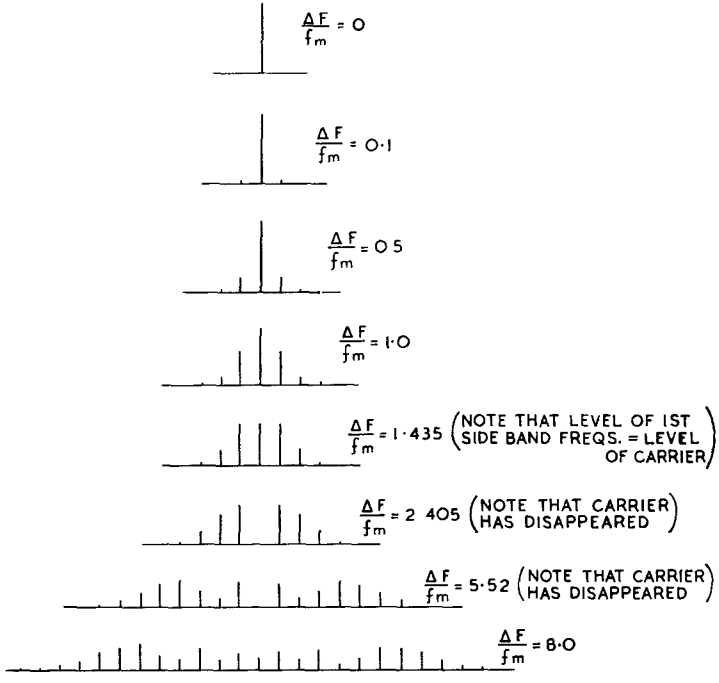


FIG. 1.16. FREQUENCY MODULATION: DISTRIBUTION OF ENERGY THROUGHOUT FREQUENCY SPECTRUM FOR VARIOUS VALUES OF MODULATION INDEX AND A CONSTANT MODULATING FREQUENCY

that the bulk of these are contained within the range—

$$\pm (\Delta F_{\max} + f_m)$$

This expression for the range is a useful general first approximation, but where it is necessary to keep the distortion to a very low figure a more accurate expression is

$$\pm (1{\cdot}1\ \Delta F_{\max} + 3f_m)$$

Essential Differences between Amplitude Modulation and Frequency Modulation. The essential differences between amplitude and frequency modulation should be carefully noted and these may be summarized as follows—

1. *Carrier Level.* In amplitude modulation the relative level (i.e. amplitude) of carrier and sidebands is such that at 100 per cent modulation by a single frequency each sideband is always half the carrier level, the carrier level remaining constant for all conditions of modulation. In frequency modulation, however, for certain conditions of modulation, the carrier may vanish entirely and so also may pairs of sideband signals. Fig. 1.15 indicates the conditions for these effects and as can be seen from the curves, the carrier level passes through cyclical variations of amplitude about zero as the modulation index is increased.

2. *Maximum modulation depth.* In amplitude modulation a limit to modulation depth is sharply set at 100 per cent. In frequency modulation theory sets no such definite limit but in practice a limit is fixed, either by an arbitrarily agreed maximum deviation (governed largely by the frequency band which is permissible for the transmission) or else by the bandwidth handling capacity of the equipment concerned.

3. *Distribution of intelligence.* In amplitude modulated systems, the whole of the modulation intelligence is borne by the sidebands; indeed in certain amplitude modulated systems the carrier is either eliminated or transmitted at a very reduced level. In frequency modulated operation, the modulation intelligence is spread over carrier and sidebands.

4. *Multi-tone modulation.* In an amplitude modulated system, each single modulation frequency applied to the carrier results in the production of a pair of sideband frequencies appropriate to that frequency. In frequency modulated systems no such simple relationship exists. Sidebands exist at intervals in the frequency spectrum corresponding to each modulation frequency.

5. *Energy distribution.* In a frequency modulated system, the sum of the energy contained in the carrier and sidebands is not a function of modulation conditions but is constant, since the amplitude is constant. The energy contained in the original unmodulated carrier is distributed by the modulation process over the portion of the frequency spectrum occupied by the transmission. This contrasts with amplitude modulation, where the intelligence is conveyed by variations in the power contained in the sidebands, in a manner corresponding to the variations in the modulation conditions. In frequency modulation, changes of modulation index do not affect the total power transmitted but only its distribution in the frequency spectrum.

Further treatment of amplitude modulation and frequency modulation and their application in telegraph transmission is dealt with in Chapter 5. The use of frequency modulation for telegraph transmission has so far only been employed to a limited extent, but under certain conditions, to be described later, it offers advantages over amplitude modulated systems and it is probable that much greater use of this transmission technique will be employed in telegraphy in the future, both for radio, submarine cable and land-line links.

CHAPTER 2

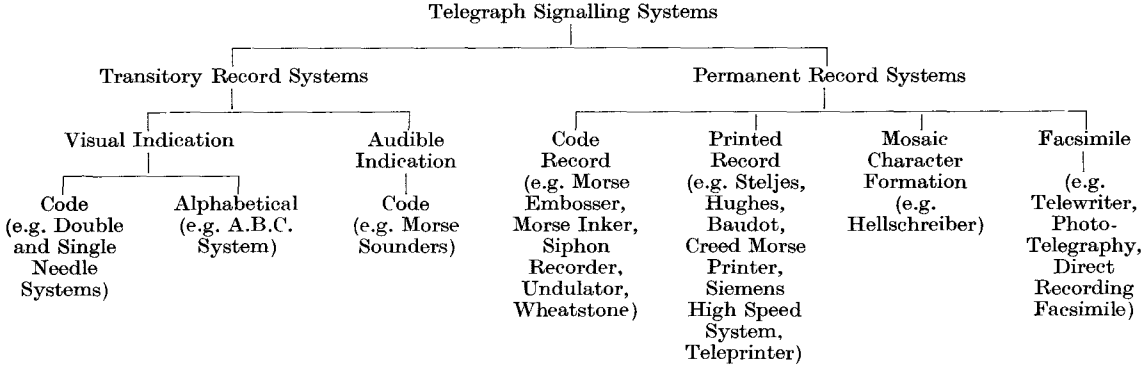
HISTORICAL SURVEY OF TELEGRAPHY

ALL systems of telegraphy may be classified broadly into one or other of two main divisions, namely—

(*a*) Transitory Record Systems, i.e. those in which the intelligence transmitted is made manifest at the point of reception in a transitory form, either by means of visual or audible signals, and

(*b*) Permanent Record Systems, i.e. those in which the intelligence transmitted is made manifest at the point of reception in the form of a permanent record, either in code form, as a printed or written character, or as a facsimile reproduction of the original copy.

TABLE 2.1



These two divisions may be further divided into the various categories shown in Table 2.1 which also indicates the names of various well known systems in each. Those readers requiring a more detailed record of the historical development of telegraphy than that which follows should consult other works of reference a selection of which is shown at the end of this chapter; the present treatment of such systems is mainly intended to indicate the general principles of operation only.

Transitory Record Systems of Telegraphy

In transitory record systems the reception of intelligence is effected by observing the visual or audible effects of the signals on the receiving instrument.

The first practical system of telegraphy was invented in 1837 by that pioneer of modern systems of telegraphy, Sir Charles Wheatstone, in conjunction with William Fothergill Cooke. This system was the "Five Needle System," an alphabetical signalling system in which five needles in combination, controlled from signals over five line wires were caused to point to the letter signalled. A telegraph circuit of this type was successfully demonstrated as a practical system on the 25th July, 1837, between Euston and Camden Town on the London–Birmingham Railway.

The five-needle system was clumsy to use and as it required five transmitting wires it was not long before this system of working was supplanted by the "Double Needle System" employing a code which only required two line wires; this in turn gave place to the "Single Needle System" using the Morse code.

The Single Needle System. This was one of the earliest systems of telegraph signalling in which a visual indication was employed for reception. The Highton Single Needle System was introduced in 1837, and employed the Morse code transmitted from a signalling device known as a commutator. This consisted of two keys, one of which was pressed to send a line current in one direction corresponding to a dot signal, and the other key, when depressed, reversed the direction of the line current and this corresponded to a dash signal. At the receiving end of the line these currents passed through a galvanometer, the deflexions of the needle to the left or right indicating dot and dash signals respectively. Fig. 2.1 shows a typical single needle instrument.

The single needle system was very simple and robust but the speed of sending was necessarily slow, since the receiving operator's attention was divided between observing the signals and writing

down the message. This disadvantage soon became evident in use and quickly led to the adoption of devices which rendered the signal indications audible to the receiving operator. The single needle instrument was constructed so that the deflexion of the needle to the left or right was limited by ivory stop pins and it was discovered that by replacing one stop pin by a piece of metal,



FIG. 2.1. A SINGLE NEEDLE INSTRUMENT
(By courtesy of H.M. Postmaster-General)

the needle deflexions could be identified aurally by the distinctive sound made when the needle struck either the ivory or the metal stop. Thus the single needle was soon used as an audible instrument and this enabled slightly higher speeds of working to be attained with less fatigue to the receiving operator. In noisy offices, however, the noise made by the needle on its stops was insufficient to be readily heard and this led to the introduction of the Double Plate Sounder System.

Double-plate Sounder System. In this system, two electromagnets having pivoted armatures were employed, one being operated by a dot signal and the other by a dash signal. Each electromagnet was constructed so that when current flowed through its coils its armature was operated and caused a hammer to strike a bell or a metal plate, thus producing a distinctive sound. The electromagnets were in consequence called sounders and each of the sounders produced a distinctive noise, thus enabling a dot to be distinguished from a dash. The sounders were connected as shown in Fig. 2.2

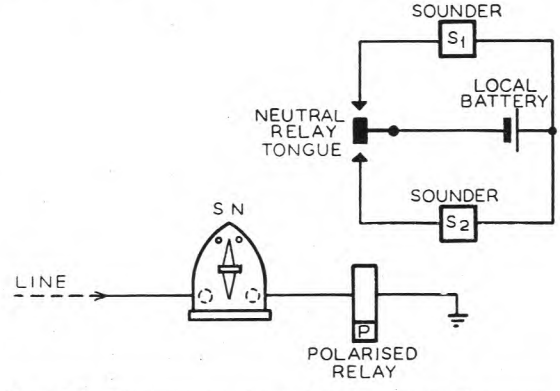


FIG. 2.2. CONNEXIONS OF A DOUBLE-PLATE SOUNDER

in the tongue and local contact circuits of a polarized relay, which was in series with the line and a single-needle instrument. The relay tongue was spring loaded so that it was neutral, i.e. resting in a neutral position between the relay contacts,

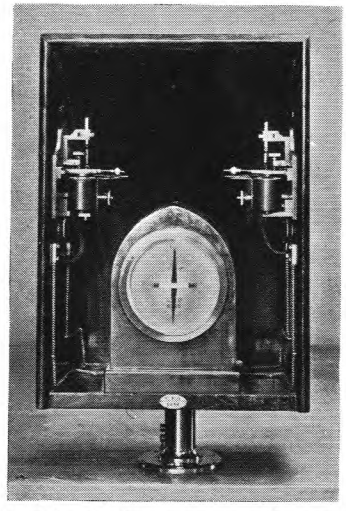


FIG. 2.3. A DOUBLE-PLATE SOUNDER
(By courtesy of H.M. Postmaster-General)

when the relay was not energized. A dot signal operated the polarized relay and caused its tongue to move over to one contact, whereas a dash signal reversed the current in the line relay coils and so caused the relay tongue to move to the other contact. Fig. 2.3 shows a view of a typical double-plate sounder set.

Single-current Morse Key and Sounder Working. Practical experience soon showed that it was possible for an operator to interpret Morse signals equally as well by noting the short or long time interval between the sounder noise caused by dot and dash signals as it was to read the distinctive deflexions of a single needle, or the sounder noises from a double-plate sounder. This soon resulted in the replacement of single-needle and double-plate sounder systems by the simple Morse sounder

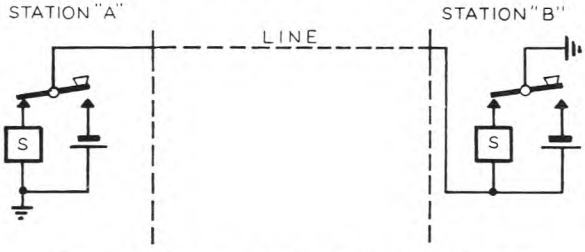


FIG. 2.4. A SINGLE-CURRENT MORSE KEY AND SOUNDER CIRCUIT

system and thus arrived the long period during which the ordinary Morse sounder held sway for carrying the large volume of traffic on main line circuits. A skilled operator in this system was capable of transmitting or receiving signals at a speed of at least thirty words per minute.

The simplest form of sounder circuit consists of a single-current Morse key and sounder connected to line, battery and earth as shown in Fig. 2.4. This arrangement is known as a Simplex Sounder Circuit and provides facilities for station *A* to speak to station *B* or vice versa but not simultaneously.

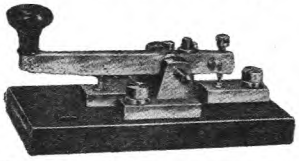


FIG. 2.5. A SINGLE-CURRENT MORSE KEY

The single-current Morse key illustrated in Fig. 2.5 consists of a pivoted brass lever fitted at its front extremity with a shaped operating handle. The lever has a contact on the front underside of the lever and this makes connexion with a fixed contact on the base of the instrument when the lever is depressed. At the rear of the lever an adjustable screw contact, which may be locked, is provided and projects through the underside of the lever. Normally, the lever is constrained by a spring, to rest in a position in which the rear contact on the lever is depressed so as to make connexion with a fixed contact on the base of the instrument. When the operating handle of the key is depressed, the lever is forced into contact with the fixed front contact and the connexion between the back contacts is broken. Conversely, when the operating handle is released, the lever is actuated by its control spring, causing the front contacts to open and the rear contacts to close. The operating travel of the lever is adjustable by means of the rear contact screw. Clearly the front and back fixed contacts on the base of the instrument act as limiting stops to the movement of the key and these contacts are in consequence normally referred to as the front and back stops respectively.

The A.B.C. System. The A.B.C. system was invented by Sir Charles Wheatstone in 1840 and was so named because it provides a means of telegraphic communication in which the alphabetical significance of the character signalled was shown directly by an indicator pointing to the appropriate letter and not by means of a coded signal which required transcription. The generation of the signals for a given letter was similarly simplified from an operating point of view. The system operated on a "step by step" or "sequence" signalling principle. Successive positive and negative half waves of alternating current each corresponded to a given character; thus starting from a given datum position, the first positive half wave of current corresponded to letter *A;* the next negative half wave corresponded to letter *B* and so on, as illustrated in Fig. 2.6. A total of 30 characters was catered for, namely, 26 letters of the alphabet, and comma (,) semi colon (;) full stop (.) and plus sign (+). Thus, 15 complete cycles of alternating current are required for transmission of all of the characters in sequence, i.e. step by step.

In a signalling system of this type the transmitter and receiver must pass progressively forward through the sequence of characters, to reach the appropriate ones. Thus, to pass from *A* to *B* only requires a negative half cycle, but *B* to *A* requires 14 complete cycles and a positive half cycle. This will be clear from a study of Fig. 2.6.

The A.B.C. system employed a transmitting instrument called a "Communicator." It consisted of a magneto-generator driven from a handle and employed to generate alternating current for the transmission of signals to line. Above this was mounted a circular dial, around the periphery of which, and equally spaced, were 30 keys, each key corresponding to a letter of the alphabet or other sign. Pivoted at the centre of the dial was a pointer which was geared to the hand generator.

The receiving instrument was called an "indicator" and consisted of a polarized electro-magnet having its armature coupled through an escapement to a pointer. Operation of the electro-magnet from line signals caused the pointer to be rotated

around a dial having lettering around its periphery identical to that on the dial of the communicator.

Fig. 2.7 shows a typical A.B.C. set consisting of a combined Communicator and Indicator. The signalling of a word was accomplished by turning the handle of the generator continuously and depressing, in turn, the keys corresponding to the letters of the word to be signalled. The pointer of the communicator was thus caused to revolve until it was stopped at the position corresponding to the depressed key of the first letter. At the same instant the generator was disconnected from the line until the key of the next letter was depressed and this caused the pointer to be released and the generator reconnected to the line. The pointer then rotated to the next letter and stopped, and so on for the successive letters of the word. Each word was always started from a key marked "Zero," so that a definite number of half cycles of alternating current was transmitted with reference to the zero position, for each letter signalled. The indicator electromagnet caused the pointer of the instrument to be stepped forward one letter for each half cycle of current received, so that as both the communicator and indicator were started from zero, the two pointers moved in step with each other and by noting the letters at which the pointer of the indicator stopped, the receiving operator was able to read off the message.

This system was simple and robust, and negligible skill was required for its operation; the operating speed was, however, comparatively slow, about 15 w.p.m. For lightly loaded circuits, however, it was a very useful system in its day; nowadays it is much more convenient and cheaper to use the telephone for such circuits.

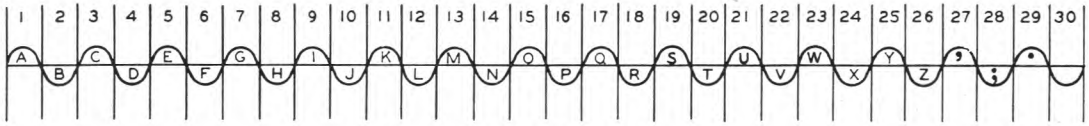


FIG. 2.6. THE A.B.C. SIGNALLING SYSTEM

Permanent Record Systems of Telegraphy

A system of telegraphy in which a permanent record of the received signals is obtained clearly offers many advantages over a transitory record system. For example, whereas a transitory signal indication requires the constant attention of an operator to enable reception to be recorded, this is not essential with a permanent recording system. This enables an economy to be effected in the staffing of lightly loaded circuits, and in the case of heavily worked circuits, it has the advantage that during periods of heavy traffic the speed of reception is not limited by the rate of transcription by the receiving operator. This reduces the fatigue of the operator and reduces the interdependence between the transmitting and receiving operators. The possibility of errors is also reduced and the permanent record of the signals provides a means of checking any queries arising. Under permanent recording conditions, the work of transcription of the received message may be divided between a number of operators and thus accelerate the speed at which traffic may be handled over the circuit.



FIG. 2.7. AN A.B.C. SET CONSISTING OF A COMBINED COMMUNICATOR AND INDICATOR

In permanent record systems in which a printed character or fascimile reproduction of the original information is received, the work and skill involved on the part of the receiving operator is still further reduced and this leads to greater ease and efficiency in operating circuits and reduces the possibility of errors to a minimum. Furthermore, the emergence

of the modern forms of telegraph instruments of this type, e.g. the teleprinter, has greatly enhanced the utility of telegraphy and made it possible for business firms to apply telegraphic methods to innumerable applications, with no more specialist knowledge on their part than that which is required to operate typewriters efficiently.

One of the earliest attempts made to obtain a permanent record directly from the received signals was the Morse Embosser. This instrument, invented by Samuel Morse in America, was first exhibited in 1837, but it was not until May 1844

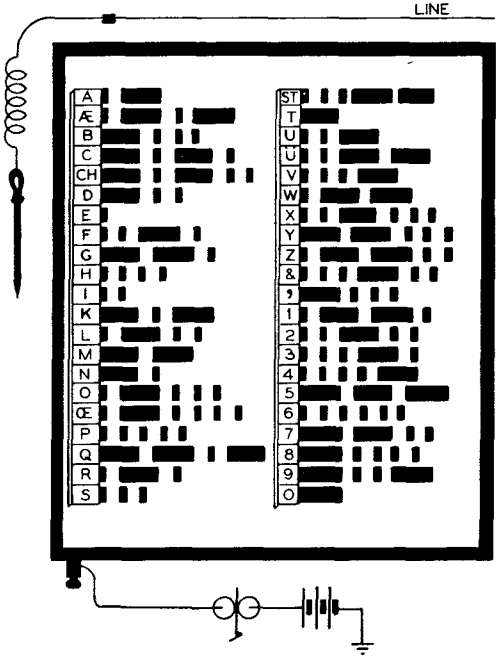


FIG. 2.8. TRANSMITTING PLATE USED IN MORSE EMBOSSER SYSTEM

that a Morse telegraph circuit employing this method was employed between Baltimore and Washington, a distance of 40 miles.

For the Morse embosser system, signals were transmitted from a transmitting plate on which each letter of the alphabet, and other signs, were represented by different combinations of long and short metal bars, as indicated in Fig. 2.8. The bars were connected to a battery and to transmit a letter the operator passed a pointer, which was electrically connected to the line, over the bars corresponding to the desired letter and this caused currents of long and short duration to be transmitted to line, in accordance with the code of the letter. Thus dot and dash signals, as they came to be called, were transmitted. Shortly afterwards, it was found that a telegraphist could just as simply, and with more convenience, learn to send dot and dash impulses by depressing a bar having suitable electrical contacts and this led to the introduction of the Morse key.

In the Morse embosser, the dot and dash signals actuated an electromagnet fitted with an arm which carried a stylus. When the armature was operated the stylus produced an indentation in a paper tape which was moved at a steady rate by clockwork mechanism past the stylus. Thus the dots and dashes were recorded as short or long indentations respectively in the paper tape. This system was cumbersome and as the indentations were often indistinct it was not entirely satisfactory from an operating point of view, and was first replaced by Alexander Bain's chemical recorder in 1845 and later, in 1854, by the better known Morse inker system invented by Thomas John of Vienna. In Bain's chemical recorder the line signal currents were passed through the stylus of the receiving instrument to the paper. The paper was treated with a chemical solution of potassium iodide in starch and the passage of the signal currents through the recording point of the stylus produced discoloration of the paper and so gave readable signals.

In the Morse inker, the received signals caused an inked wheel to be moved by the armature of an electromagnet and brought into contact with a steadily moving tape, thus producing a record of short and long inked lines corresponding to dot and dash signals respectively. For circuits operated at hand speed, the Morse sounder was generally preferred but the Morse inker was often employed in addition to the sounder, to provide a permanent record and check of the signals, especially on lightly loaded circuits where the operator might be otherwise engaged at the time a message was being received.

The main constructional features of the Morse inker will be clear from Fig. 2.9 which illustrates a typical instrument of this type.

Siphon Recorder. On long submarine telegraph cable circuits not only is the conductor resistance and capacitance very high but the signalling voltage employed for transmission has to be limited to reduce the risk of damaging the cable insulation, which on early cables, consisted of gutta percha. As a result, the signals received from such circuits are very weak and considerably distorted and require the use of a highly sensitive receiving instrument for their detection.

Johann Gauss and Wilhelm Weber invented a mirror galvanometer in 1833 by means of which

received telegraph signals were identified by the movements of a reflected spot of light, in a similar manner to the method employed in the reading of a single-needle system. This type of instrument was adopted in 1858 by William Thomson (later Lord Kelvin) for the purpose of telegraph working over an Atlantic cable. From this type of instrument Thomson developed his siphon recorder which, whilst retaining a high sensitivity, had the advantage that a permanent record of the received signals was traced in ink on a moving paper tape.

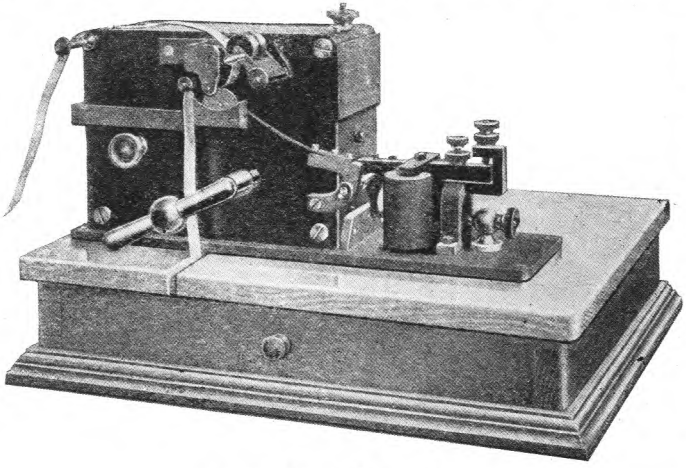


FIG. 2.9. A MORSE INKER

The siphon recorder consists essentially of a moving coil galvanometer of the D'Arsonval type, connected to the line and arranged so that the deflexions of the coil produced by the received signals control the movement of a stylus across a moving paper tape, the latter being driven at a constant speed from a clockwork or electric motor. The stylus is supplied with ink from a rubber tube connected to an inkwell from which ink siphons when the tape is in motion. The deflexions of the stylus produced by the line currents are proportional to the current received and the stylus therefore produces a visible trace on the paper tape corresponding to the magnitude of the line current received. Dots and dashes can therefore be identified by the upward and downward projections of the current curve traced.

Fig. 2.10 indicates the principle employed. The stylus S, consisting of a fine tube, is attached to a very light plate P, which is supported axially by the stretched wire W. The plate P is thus capable of angular rotation about the axis W under the control of the silk fibres a and b, which are attached to the left and right corners of the coil of the galvanometer. The movements of the coil thus produce corresponding angular movements of the plate P, which in turn causes corresponding sweeping movements of the stylus S over the surface of the paper tape T. One end of the wire W is very slightly but rapidly vibrated electrically, thus causing the stylus to make rapid and intermittent contact with the paper. This arrangement reduces the friction at the point of contact of the stylus and thus increases the sensitivity of the instrument. The current curve traced by the stylus on the paper consists of a series of fine dots, as illustrated in Fig. 2.10, and this curve represents the magnitude of the line current passing through the coil from instant to instant.

The Undulator. This instrument, although less sensitive than the type just described, is a robust form of siphon recorder which is eminently suitable for use on short submarine cable circuits, landlines or radio links, where it is desired to record signals on a paper tape in the form of undulations corresponding to the received signals. It is also a useful device for monitoring signals. Instruments of this type may be operated at speeds up to 300 w.p.m. and can be operated from either single or double-current signals. The paper tape is driven forward by an electric motor and a siphon-fed ink stylus is controlled directly from a moving coil galvanometer, so that its writing head moves across the paper. When no signals are being received the stylus traces a straight line longitudinally along the tape. When signals are received the

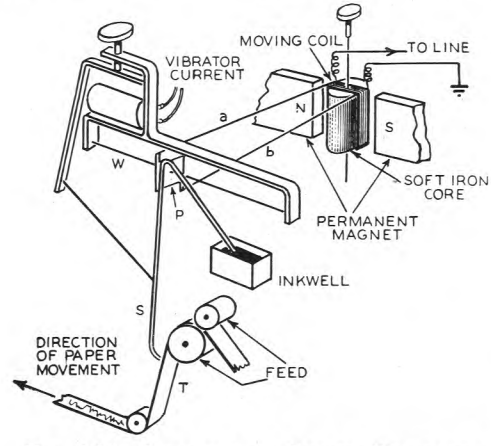


FIG. 2.10. PRINCIPLE OF SIPHON RECORDER

stylus is deflected across the paper in accordance with the magnitude and effect produced by the incoming signals on the galvanometer coils. Full details of this type of instrument are given in Chapter 12.

Printing Telegraph Systems. The advantage of a system of telegraphy in which the received intelligence can be directly printed, in the form of Roman

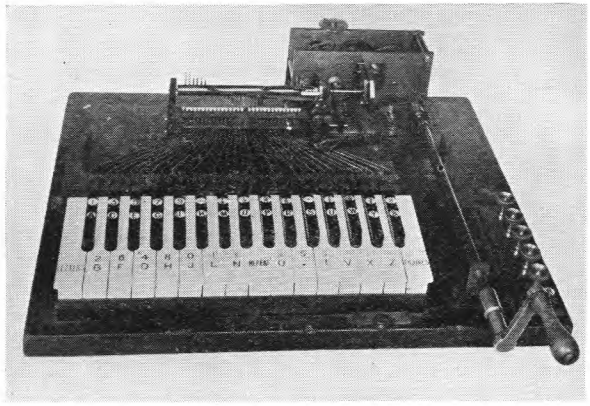


FIG. 2.11. EXCHANGE TELEGRAPH COMPANY'S TRANSMITTER—1873

(By courtesy of Exchange Telegraph Co.)

characters, on a paper tape or page, was obvious to inventors from a very early date. There are recorded attempts to design such systems from as far back as 1832. The first practical model of such an instrument was invented by Royal House, Jacob Brett and J. W. Brett in America, in 1845. This system had a pianoforte keyboard transmitter and a typewheel which printed Roman characters on a paper tape at the receiving station.

The typewheel moved step by step from one character position to the next. In 1855 Hughes produced an instrument with a continuously rotating typewheel and this type of instrument was extensively used both on the Continent of Europe and at a later date, in 1889, in the British Post Office service. The Exchange Telegraph Company was established in 1872 with an instrument devised by F. Higgins and which resembled the Hughes instrument. Fig. 2.11 and Fig. 2.12 show views of the Higgins transmitter and receiver.

The Hughes Printing Telegraph System. This system, which was invented in 1855 by David E. Hughes of Kentucky, operated on a single current impulse signalling basis and provided facilities for transmitting and receiving messages in printed form on a paper tape at speeds up to about 30 w.p.m. The transmitting and receiving instruments were run in synchronism and the signalling

of each character was effected by a single pulse c current, equal in duration for all characters, bu separated from each other by unequal interval depending upon the order in which characters wer transmitted and the speed of operating. Fig. 2.1 shows a typical Hughes transmitting and receivin set.

The transmission was effected by the operatio of a keyboard, consisting of 28 keys, arranged i pianoforte fashion. Each key was lettered t correspond to the characters on the typewheel c the receiving mechanism. The typewheel rotate continuously and carried on its periphery 56 typ pads corresponding to the letters of the alphabe alternated with figures and other secondar characters. The change from letters to figures, an vice versa, was effected by the transmission c special signals.

The principle of operation of the Hughes syste (see Fig. 2.14) is as follows. Each transmittin key K controls a spring loaded pin P. The pir

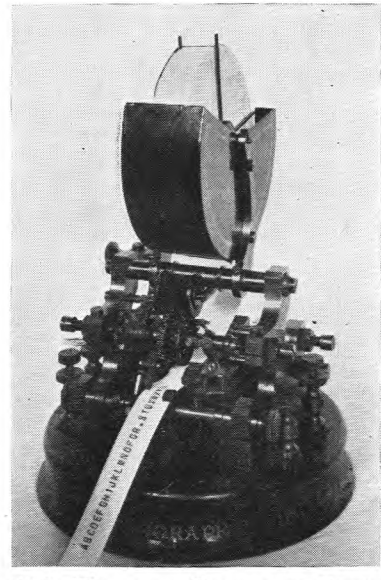


FIG. 2.12. EXCHANGE TELEGRAPH COMPANY'S RECEIVER—1873

(By courtesy of Exchange Telegraph Co.)

corresponding to the various keys are symmetri ally positioned around a circular plate. When key is depressed, the associated pin is raised in the path of a rotating chariot C. This chariot driven from the typewheel spindle via the spind S by a governed motor; the typewheel a chariot rotate at the same speed and are arrang so that their mechanical phase position is such tha

when the revolving chariot encounters a raised pin, the corresponding character on the typewheel, both on the transmitting and receiving instruments, is causing the sliding collar *SC* to be depressed momentarily, and then rejects the pin out of the subsequent path of the chariot, thus ensuring that

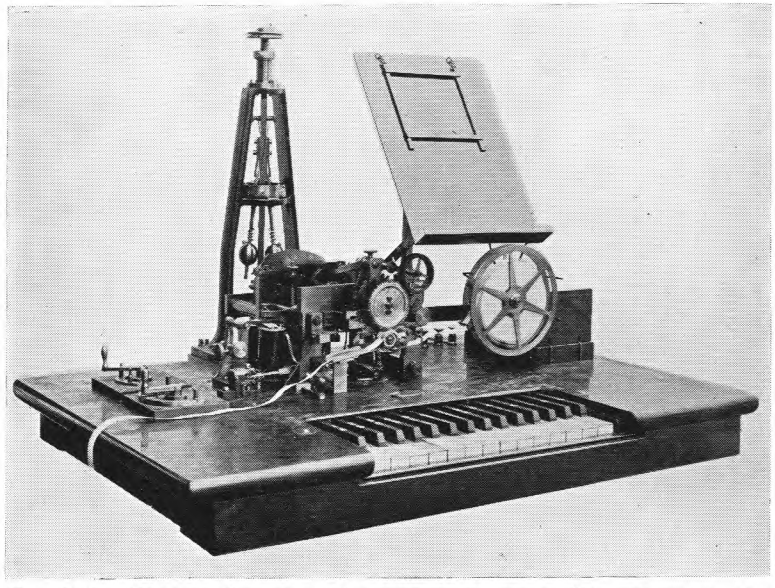


FIG. 2.13. HUGHES PRINTING TELEGRAPH SYSTEM: TRANSMITTING AND RECEIVING SET

(By courtesy of H.M. Postmaster-General)

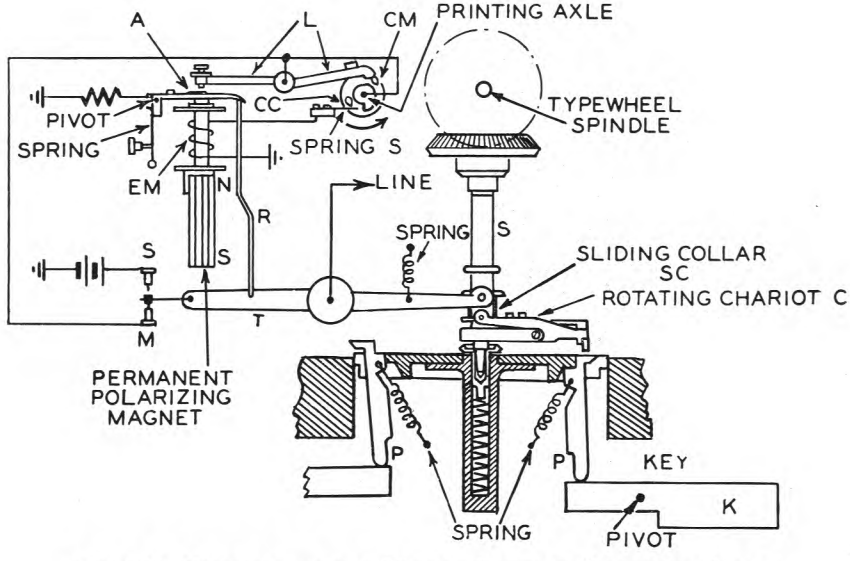


FIG. 2.14. PRINCIPLE OF THE HUGHES PRINTING TELEGRAPH SYSTEM

then in the correct position over the paper tape for printing. A local record of outgoing signals can be printed if required. The action when the chariot *C* encounters a pin *P* is that it rides over the pin, the character corresponding to the key depressed is only signalled and printed once, no matter how long the key is kept down. When the transmitting key is released, the corresponding pin *P* is restored

by its spring to its unoperated position. Depression of the collar SC, as a result of the chariot encountering a pin P, operates the transmitting tongue T to the battery contact S, thus transmitting a short current impulse to line. This current operates the distant receiving instrument and causes the transmitted character to be printed.

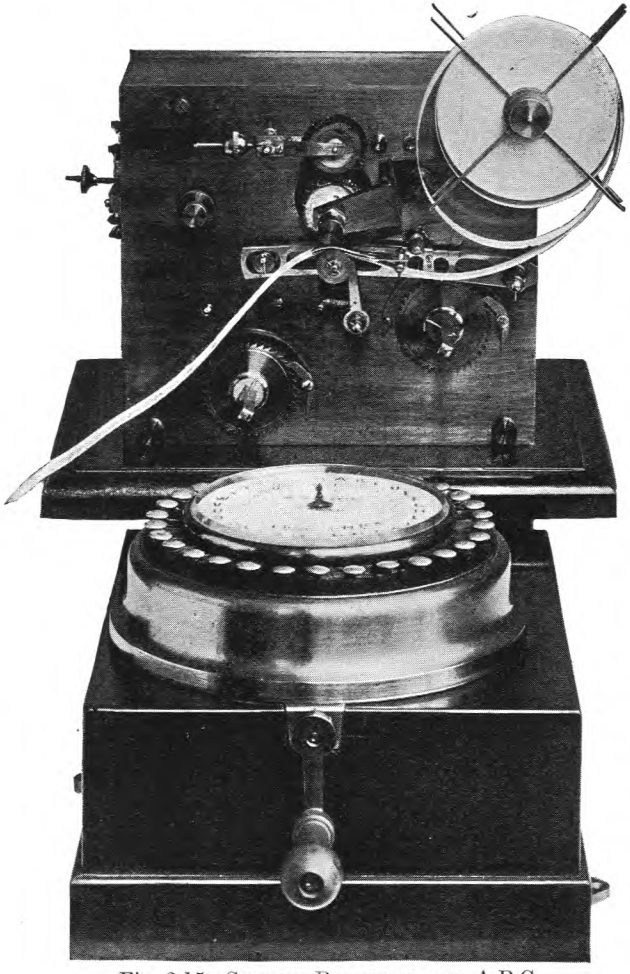


Fig. 2.15. Steljes Recorder and A.B.C. Communicator

The action of the receiving mechanism may be understood from reference to Fig. 2.14. Normally armature A is attracted to the yoke of the line electromagnet EM by the permanent magnet NS. The reception of a signal impulse from line passes via T, M, CM, CC and thence through the line coils of the electromagnet EM to earth. This produces an $M.M.F.$ in the electromagnet EM, in opposition to the permanent magnet flux, so reducing the force of attraction sufficiently to allow the armature spring to move the armature A upwards, this in turn operates lever L, so depressing its right-hand end, which allows the printing axle which carries cam CM to make one revolution and print the character. Mounted on the same spindle as CM is a correcting cam CC, which immediately it rotates, breaks the circuit of the relay EM at contact S; this circuit is remade when armature A restores, causing cam CM to come to rest after one revolution, whereupon contact between CC and S is remade. During the rotation of CM, it resets lever L to a position to arrest the rotation of the cam after one revolution and also causes the armature A to be restored, against the action of its spring, to its unoperated position, where it is held attracted to the polarized yoke of EM, in readiness for the next line signal. The correcting cam CM besides performing the function already described, acts on a correcting wheel which corrects the position of the typewheel at each revolution, so maintaining synchronism between the transmitting and receiving instruments. The spindle of cam CM carries a cam for striking the paper tape against the typewheel for printing, and another cam then steps the tape forward one letter space, in readiness for the printing of the next character.

When a local record of transmissions is required, this is obtained by the action of the rod R operating the armature A by a direct mechanical action from lever T, each time a key is depressed.

The Hughes instrument served its day and generation well. It was very stable and accurate in operation and was used extensively over short submarine cable circuits, e.g. those between Great Britain and Europe. The instrument did however require considerable operating skill, as, unlike the Wheatstone A.B.C., it had to be operated rhythmically. For inland telegraph work the Hughes system was little used in this country, apart from circuits carrying large quantities of code messages for which purpose an alphabetical keyboard with printed reception was preferred to operation with a Morse sounder system.

The Steljes Printing Telegraph System. The Steljes system was a development of the Wheatstone A.B.C. designed to enable the received signals to be recorded as printed characters on a paper tape. The printing instrument, known as a "Steljes Recorder" (see Fig. 2.15), was operated from signals received from an A.B.C. communicator and contained a polarized electromagnet connected in series with the line. The incoming line signals actuated the electromagnet and caused an inked typewheel to rotate, step by step, until the letter corresponding to the signals received was in a position opposite the paper tape. The typewheel

was momentarily arrested in this position and a non-polarized electromagnet, also connected in series with the line, released immediately the signals for a letter ceased, and caused the type-wheel to be struck by the paper, thus printing the desired letter. The printing mechanism then restored to normal and at the same time stepped the paper forward one letter space, ready for printing the next character. The motive power for the Steljes Recorder was provided by weights acting through a pulley system. At a later date, Steljes developed a typewriter type of keyboard transmitter and named it the "Rebesi."

The arrival of a typewriter type of keyboard in telegraphy was an important milestone, as this offered the prospect of reducing the art of operating to the simplest mechanical form. At this stage the use of typewriters for business purposes had already reached an advanced stage of development and the compact keyboard layout of this type of instrument had already established itself in commerce as capable of easy, accurate and speedy operation after a comparatively short period of training of the operator. Thus the use of such a keyboard for a telegraph instrument offered most attractive possibilities for the future and was the forerunner of very considerable mechanization of telegraph services.

The Steljes system was extensively used on private wires in the United Kingdom. The instruments were very easy to operate, robust in construction, easy to maintain and rendered good service. However, for many years now it has been completely ousted by the teleprinter which is much easier to operate and considerably faster.

The Baudot Printing Telegraph System. This system of printing telegraphy was invented by Emile Baudot of the French Telegraph Service, after whom it is named. The system is a time division system and utilizes (*a*) certain printing details of the Hughes instrument, (*b*) the distributor arrangements invented by Bernard Meyer in 1871, and employed in a Morse multiplex system, and (*c*) the five-unit code of Gauss and Weber. These devices were combined by Baudot with original mechanical arrangements to produce a practical form of multiplex system.

The first Baudot receiver was produced in 1874 and in the following year the invention was accepted by the French Administration and after further development work it was adopted in France in 1877. Thereafter its use in France was extensive and to some extent it was adopted in other countries. The B.P.O. adopted its use on a simplex circuit between London and Paris in 1897 and subsequently considerable use of duplex Baudot systems was made in the inland telegraph services of the B.P.O. and on some continental circuits. From 1930, its use in the United Kingdom began to decline as a result of the introduction of multi-channel voice-frequency telegraphy and the arrival of the teleprinter instrument in telegraphy. By 1935 the teleprinter had completely ousted the Baudot in B.P.O. services, apart from a few continental circuits which were converted a few years later. A similar transition has also occurred in France in more recent years.

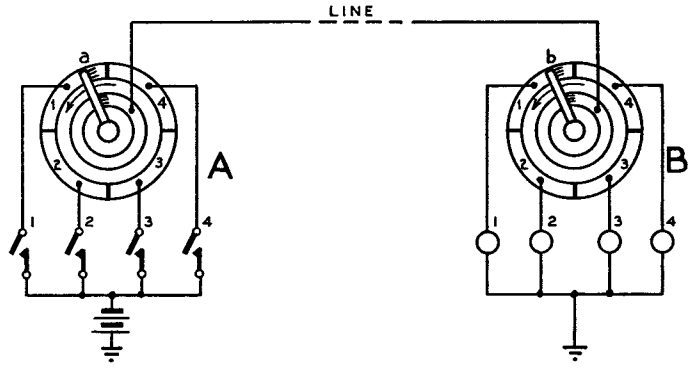


FIG. 2.16. BASIC PRINCIPLE OF 4-CHANNEL (QUADRUPLE) MULTIPLEX SYSTEM

Multiplex Principle. The ordinary Morse telegraph system requires that the operator shall have full and uninterrupted use of the line, whereas in the Baudot multiplex system several operators, in turn, use the line for an interval of time sufficiently long for the transmission of the five-unit code combination forming one letter. The line is successively connected to the set of each operator, in turn, for a similar period, by means of a distributor placed at each end of the line.

The basic principle employed is illustrated in Fig. 2.16, which indicates a four-channel multiplex system. The operation is as follows. The arms *a* and *b* are electrically connected to the line via the solid rings of the distributor at stations *A* and *B* and are rotated at a uniform speed by means of suitable driving mechanisms. They are fitted with metal brushes which sweep over and make contact with the sections 1, 2, 3, and 4 during each revolution and thus momentarily connect them successively to the line. Provision is made, as will be described later, to ensure that the brush arms at both stations maintain the same phase position throughout their rotations and so that signals

transmitted from sector 1 at station A arrive on sector 1 at station B. Similarly, sectors 2, 3, and 4 are connected through the line to their corresponding distant sectors. Each sector is divided into five segments to produce the conditions indicated in Fig. 2.17, thus forming 20 segments which are B, when the arm successively touches the segments named. The other electromagnets connected to segments 6–20 at B, are similarly selectively operated from A; thus four channels of communication may be worked in one direction from A to B.

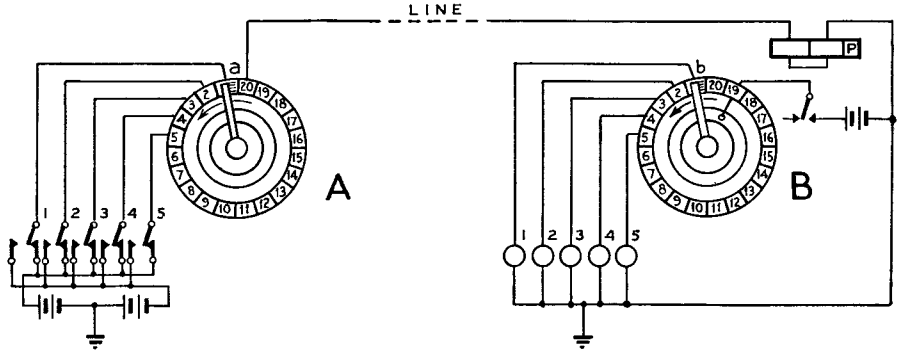


FIG. 2.17. PRINCIPLE OF 4-CHANNEL BAUDOT DISTRIBUTORS SHOWING THE CONNEXIONS OF ONE SENDING AND RECEIVING OPERATOR'S EQUIPMENT

connected in sets of five, to operators' sets. Only the connexions of one operator's set are shown in Fig. 2.17, for the sake of clarity but the other three operators are similarly connected to segments 6–10, 11–15 and 16–20 respectively. The depression of a key at A reverses the line current, operates a polarized relay at the receiving end, and closes the

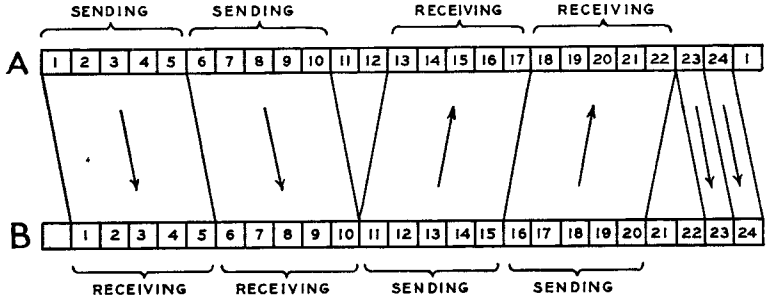


FIG. 2.18. PHASE RELATIONSHIP BETWEEN BAUDOT DISTRIBUTORS IN DUPLEX WORKING

circuit of the local battery through the non-polarized electromagnet of the receiver associated with the corresponding receiving segment at B.

The signalling conditions employed in Baudot working are that negative battery is connected for Marking signals and positive battery for Spacing signals. Thus if keys 1, 3 and 5 are depressed at A, the signals pass to line in the following order $- + - + -$, and a current passes from the marking contact of the relay, via arm b and segments 1, 3 and 5, to the corresponding electromagnets at

With the simple arrangement shown in Fig. 2.17, it is not possible to operate two channels in each direction, as a short time interval, dependent upon the electrical characteristics of the line, is required for the signals to traverse the line from one station to the other, and thus necessitate some corresponding phase correction of the relative brush positions at the two stations. For this reason, and also for the purpose of speed correction, it is necessary to increase the number of segments from 20 to 24. Two of the additional segments are required to compensate for the time of propagation of signals through the line, and two segments for speed correction.

Assuming that the transmission time of a signal is equivalent to the time taken by the brush arm to traverse one segment, the ring of the distributor at B (Fig. 2.18) is displaced one segment to the right as compared with that at A. The signals from the two sending channels at A should thus arrive correctly at B on similar segments, namely, 1–10. After the arrival of these signals, B may send on segments 11–20. Allowing for a similar transit time, the signals from $B11$ should arrive on segment $A13$, and that from $B20$ on $A22$. Segments $A23$ and $A24$ are required for the negative and positive correction currents, which should arrive on $B23$ and $B24$. The brush at A then passes once

more to segment $A1$. There are thus two idle segments at each end, viz. $A11$ and $A12$, and $B21$ and $B22$. In practice, the receivers at A are not connected to segments 13–22, but to 11–20, and these are made movable to take up the position 13–22, or any other that might be required, according to the signalling speed of the line in use.

Maintenance of Phase. Effective electrical connexion between successive segments at each end of the line depends upon the accurate rotation of the distributor brush arms and therefore upon the preservation of phase relationship, i.e. synchronism.

The early type of Baudot apparatus was weight driven and one of the distributors was arranged to run at from 0·25 to 0·5 r.p.m. faster than the other. A periodical check was applied to the brush arm of this distributor at approximately each revolution, to preserve correct phase relationship with the brush arm of the slower distributor. This check, or "Correction," in no way disturbed the uniform running of the driving mechanism of the distributor.

Correcting Currents. Fig. 2.19 shows diagrammatically the method of applying the periodical check. Once in each revolution a correcting impulse is sent out from segment 23 on the slower distributor at A—known as the "Correcting station"—and if through its higher speed, the brush arm at B—known as the "Corrected station"—has reached the corresponding segment MC and receives that impulse, the correcting magnet CM is energized. When this occurs, the armature of CM brings mechanism into operation which causes a momentary retardation of the brush arm, sufficient to retain it within the margin of allowable variation. The brush at B again commences to gain on the brush at A, but perhaps not sufficiently during the next revolution to bring into action the mechanical retarding gear. The cumulative advancement during the succeeding revolution, or a later one, causes the brush arm to reach the correcting segment before the brush at A has left segment 23; the correcting magnet then acts and again retards the brush. Segment 24 is connected to spacing voltage to restore immediately the relay at the receiving end. The correcting segment is adjustable and is termed the "movable contact." This feature was a necessity when primary batteries only were available and as a result current strengths were variable, but using secondary cells, with practically constant voltage, the current is sufficiently stable to render almost unnecessary any adjustment of the movable contact.

The retarding action of the brush arm, produced by the correcting mechanism, maintains the distributor speeds sensibly constant and the phase relationship between the two stations is preserved with sufficient accuracy for communication between the various channels to be maintained.

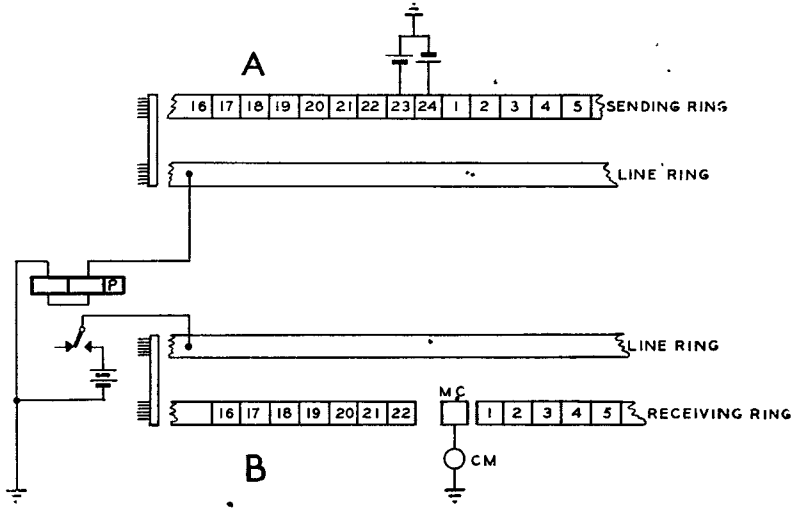


FIG. 2.19. SPEED CORRECTION ARRANGEMENTS FOR BAUDOT DISTRIBUTORS

The Baudot Distributor plays a fundamental role in the operation of the Baudot system. It provides the means of distributing the outgoing and incoming signals from, and to, the relative transmitters and receivers respectively; it keeps the local receiving apparatus in phase; it transmits a cadence signal to the transmitters and controls the maintenance of phase between two stations. Earlier Baudot distributors were driven by heavy weights acting through clockwork mechanism. As the weights descended, the mechanism drove the distributor, and a foot treadle, or electric motor, was provided to raise the weights. At a later date a phonic motor, driven from a vibrator, was employed to drive the distributor and this was later replaced by an electric motor fitted with a refined form of centrifugal friction governor of the Mendonca type. Fig. 2.20 shows a typical weight driven distributor and Fig. 2.21 shows a distributor fitted with a Mendonca governor.

Operator's Keyboard. Fig 2.22 shows a typical Baudot keyboard, and Fig. 2.23 indicates the



FIG. 2.20. WEIGHT-DRIVEN BAUDOT DISTRIBUTOR

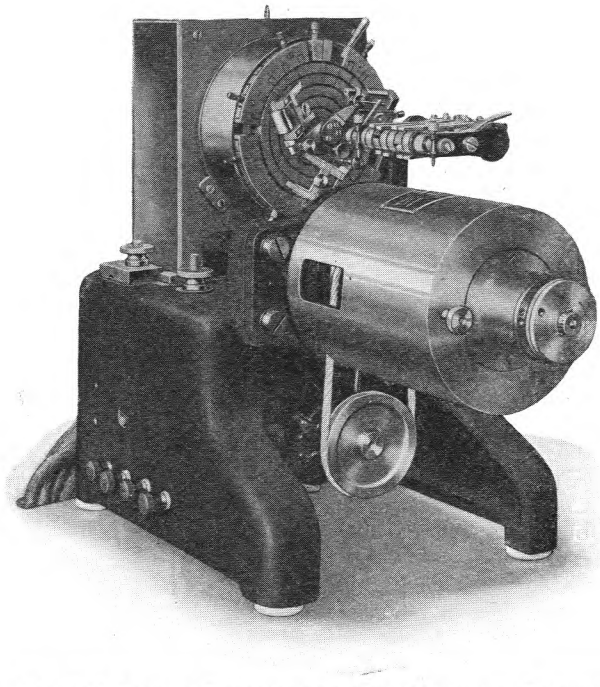


FIG. 2.21. BAUDOT DISTRIBUTOR WITH A MENDONCA GOVERNOR

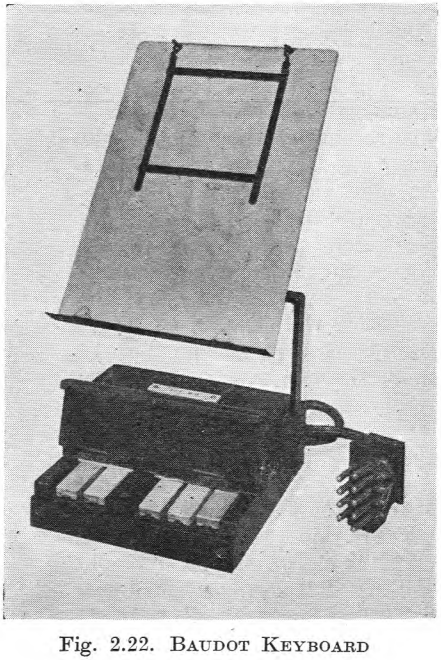


Fig. 2.22. BAUDOT KEYBOARD

V	IV			I	II	III	V	IV			I	II	III
		A	1	●			●	●	P	%	●	●	●
	●	B	8			●	●	●	Q	/	●		●
	●	C	9	●		●	●	●	R	-			●
	●	D	0	●	●		●		S	;			●
		E	2		●		●		T	!	●		●
		E	&	●	●				U	4	●		●
	●	F	≠		●	●	●		V	'	●	●	●
	●	G	7		●		●		W	?		●	●
	●	H	≡	●	●		●		X	,		●	
		I	≈		●	●			Y	3			●
	●	J	6	●			●		Z	:	●	●	
●	●	K	(	●			●		≠	.	●		
●	●	L	=	●	●		●	●	✕	✕	Erasure		
●	●	M	)		●			●	Figure Blank				
●	●	N	№		●	●	●		Letter Blank				
		O	5	●	●								

Letters	Figures	V	IV	I	II	III	Letters	Figures	V	IV	I	II	III
A	1			●			-	.		●		●	
E	2				●		X	9/		●			●
Y	3					●	S	7/		●			
/	1/			●	●		Z	:		●		●	●
I	3/				●	●	W	?		●			●
U	4			●		●	T	2		●		●	
O	5			●	●	●	V	1		●		●	●
							Letter Blank			●			
J	6		●		●		K	(	●	●	●		
G	7		●			●	M	)		●	●		●
B	8		●				R	-		●	●		
H	1		●	●	●		L	=		●	●	●	●
F	5/		●			●	N	£		●	●		●
C	9		●		●		Q	/		●	●	●	
D	O		●	●	●	●	P	+		●	●	●	●
Figure Blank			●				✕	✕		●	●		

FIG. 2.23. THE BAUDOT CODE AND MANIPULATION TABLES

allocation of the five-unit code which was employed in the B.P.O. for continental and for inland services. It will be observed that a number of characters in the continental code are replaced by fractionals in the inland code, as these are of greater service for commercial purposes. The code Tables in Fig. 2.23 have been prepared so as to indicate the keyboard manipulation adopted, thus code elements 1, 2 and 3 are transmitted by keys 1, 2 and 3 and these are operated by the first three fingers of the right hand; code elements 4 and 5 are transmitted by keys 4 and 5 and these are operated by the first two fingers of the left hand. Each of the five keys corresponds to one unit of the five-unit code and controls the signalling current transmitted for that element. Normally, each key is connected to positive battery and this corresponds to the spacing condition; when a key is depressed it is connected to negative battery and this corresponds to the marking condition of signalling; thus to send a character, the operator depresses those keys corresponding to the elements in the code for which it is desired to transmit marking signals. The five segments of the distributor serving that operator are thus connected to positive or negative battery, depending upon the code of the character being transmitted; when the arms of the distributor sweep over these segments the appropriate code signal combination for the character will be transmitted to line. The keyboard is so arranged that when any key is depressed it is mechanically locked until the distributor brush has passed over the five segments of the distributor connected to the keyboard and has thus transmitted the signal. The keys are then unlocked, in readiness for the transmission of the next character.

The operator is given an audible indication of the unlocking of her keyboard, by means of what is known as a "cadence signal." The cadence signal is controlled from the distributor, which causes a current to flow through an electromagnet in the keyboard, the operation of this electromagnet removes the lock from the depressed key and produces an audible click as an indication to the operator that the next combination of keys should be depressed for the transmission of the next character. The manipulation of a Baudot keyboard calls for a high degree of operating skill, since a definite, unvarying, rhythmic speed of signalling is necessary (180 letters per minute was the normal speed employed).

The Baudot Receiver. The action of the receiving mechanism consists firstly of electrical reception of the five-unit code in the manner already described, which results in the operation of five electromagnets. The armatures of these electromagnets reproduce the positional settings corresponding to the five sending keys at the transmitter. The second action of the receiver is a purely mechanical one and results in the translation of the armature settings for the selection and printing of the appropriate character. The movement of the armatures is communicated to five selectors, beneath the feet of which the 31 working combinations of the five-unit code are passed in succession. When the combination corresponding to the setting of the selectors is reached, an engagement takes place which results in the release of the printing mechanism. The appropriate character is then printed on a gummed paper tape and the tape fed forward in readiness for printing the next character. Resetting cams restore the moving parts to normal, ready to repeat the process for the next combination set up.

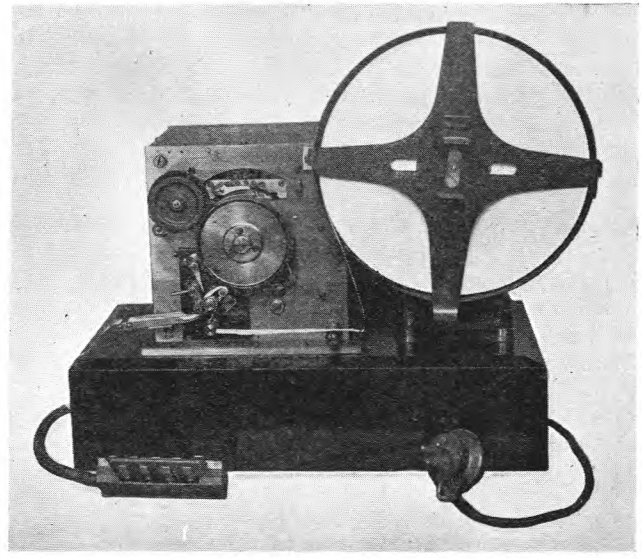


FIG. 2.24. BAUDOT RECEIVER

Fig. 2.24 shows a front view of a typical Baudot receiver.

It will be clear that it is essential to maintain accurate control of speed of the receiver for correct printing and this is arranged as follows. The receiver which is driven either by weights or electric motor is geared so that it runs slightly faster than its associated distributor and speed correction is obtained from a mechanical brake, which is controlled from a synchronizing current fed from the distributor during each revolution. The brake is controlled by an electromagnet, the circuit of

which is so arranged that a cam on the typewheel axle of the receiver closes a contact at one point for a fraction of each revolution; the distributor also closes a second contact in the same circuit for a fraction of each revolution. When these operations coincide, the circuit of the electromagnet is closed, the brake is thereby brought into action, engages the flywheel of the receiver, and so reduces the speed, thus preventing the receiver from over-running the distributor. The duration of the current in the brake circuit varies in accordance with the time the two contacts are simultaneously closed.

Owing to the fact that the various mechanical operations involved in the printing of a character impose a varying mechanical load on the driving motor, it is necessary to provide an additional refinement in the speed control arrangements for securing uniformity of running. These variations are catered for by means of a centrifugal type of friction governor, which is regulated so that when the receiver is not printing the governor applies its maximum frictional load. During the rapid fluctuations of load during a printing cycle the friction load is automatically varied to compensate for the load variations on the receiver.

The Baudot system enables from two to six operators to work over a single line connecting two stations, the arrangements being respectively termed Baudot double, triple, quadruple, quintuple, and sextuple. On a simplex installation, channels may be worked in each direction according to the incidence of traffic, e.g. two in each direction or three in one direction and one in the other on a quadruple simplex set. The system can also be applied to extended circuits, e.g. a single wire connecting stations A, B, and C can be used to give two channels each, between A and B, B and C, and A and C.

Duplex Baudot working was introduced in Great Britain by A. C. Booth in 1905, giving double-duplex, triple-duplex, quadruple-duplex, quintuple-duplex and sextuple-duplex. With sextuple-duplex there were six channels provided in each direction, thus enabling 12 messages to be transmitted over a single wire simultaneously.

For the purpose of standardization, the quadruple-Baudot was adopted as the standard installation for use in the Inland Telegraph Service of the B.P.O.

Automatic Telegraph Systems

It will be evident that a system of telegraphy in which the formation and transmission of signals is controlled by successive manual operations for each signal element imposes a limitation on the speed and accuracy of signalling. The speed is also clearly dependent upon the manipulative skill of the transmitting operator. The operator may be capable of transmitting at maximum speed for short periods, but if any attempt is made to maintain that speed it is probable that mis-operations will result and produce errors in transmission. Operators therefore always tend to work at an average speed which they can maintain for long periods with accuracy. Since this speed is less than the maximum speed of which the apparatus is capable, line time is wasted and this is obviously uneconomic, particularly in those cases where the line costs are high, e.g. long submarine cables. To overcome the limitations and disadvantages of manual telegraph systems various automatic instruments and systems have been evolved which not only simplify the operator's work but also enable the traffic-carrying capacity of circuits to be more fully exploited. Some notable examples of automatic telegraph systems will now be briefly described.

Note: The generic term "Automatic Telegraph System" is usually employed to denote all systems of telegraphy in which the signals are transmitted by mechanical means, as opposed to those in which the signals are sent by manual operation of a key for individual signal elements.

The Wheatstone Automatic System. The earliest practical form of automatic telegraph system was that invented by Wheatstone in 1867 in which the message to be transmitted was first transposed by an operator into the form of perforations in a paper tape, the perforations corresponding to the dot and dash Morse signalling code of the message. The perforated tape, "slip" as it is sometimes termed, was then passed through an automatic transmitter which examined the individual perforations in it and caused corresponding dot and dash signals to be transmitted to line.

At the receiving end these signals were recorded upon a paper tape by a Wheatstone receiver which reproduced an inked record of the message in the form of Morse dots and dashes. Figs. 2.25 and 2.26 illustrate typical early forms of Wheatstone transmitter and receiver.

The receiver was usually connected in the local circuit of a sensitive line relay. The use of the Wheatstone system permitted a number of operators to be employed simultaneously in the preparation of messages, so that the total output of messages when fed through the automatic transmitter completely utilized the full traffic-carrying capacity of the line. A long and urgent message could therefore be divided between a number of operators for preparation of perforated tapes which were then transmitted, in turn, at high speed.

Similarly the received tape could be divided for transcription between a number of operators, thus effecting a considerable saving in time as compared with manual transmission and reception of the message by one operator.

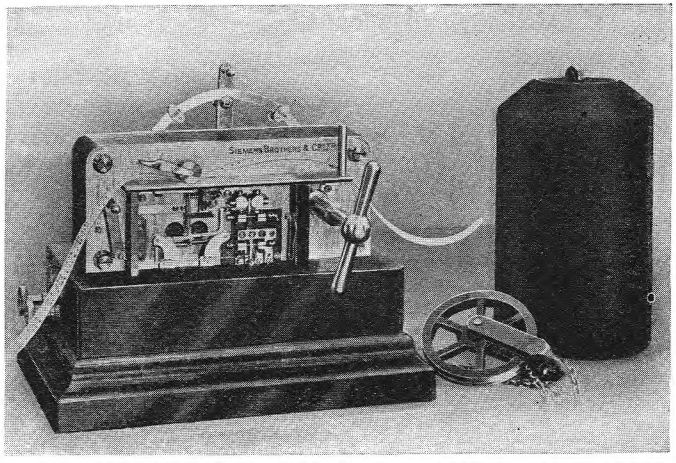


FIG. 2.25. WHEATSTONE TRANSMITTER (WEIGHT DRIVEN)

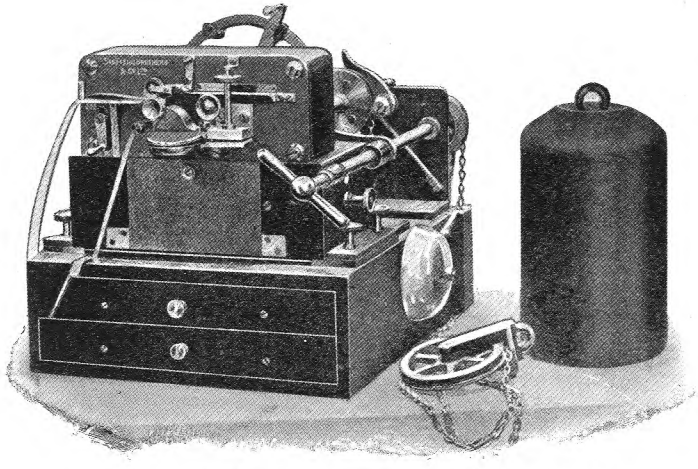


FIG. 2.26. WHEATSTONE RECEIVER (WEIGHT DRIVEN)

It will be noted that the use of automatic methods of this type involved the additional operation of feeding tape into the automatic transmitter and distributing the received tape between a number of operators for transcription, calling for the employment of additional staff not necessary with systems in which the transmission was effected directly from a sending to a receiving operator. Such a method is only justified when the additional operating costs are more than offset by the financial saving resulting from the more efficient use of line plant or, alternatively, when the shortage of line plant renders it essential to use existing lines to their maximum traffic-carrying capacity.

The original type of Wheatstone perforator (1867) illustrated in Fig. 2.27 was a purely mechanical device. The three keys shown at the front of the instrument were employed for the perforation of dot, space and dash respectively. These keys were struck by the operator by means of two rubber-tipped punching sticks, held one in each hand. The principle employed in the perforator was as follows—the three operating keys controlled the selection and operation of five punches spaced in the relative positions illustrated in Fig. 2.28 (*a*) at 1, 2, 3, 4 and 5. The punches 1, 3 and 5 produced perforations corresponding to code elements dot and dash, whilst punches 2 and 4 produced perforations of smaller diameter along the centre line of the tape and these were employed for feeding the tape forward. Operation of the dot key actuated punches 1, 2 and 3; the space key actuated punch 2 only; whilst the dash key actuated punches 1, 2, 4 and 5. The resulting perforations in each case were as indicated in Fig. 2.28 (*b*). The dot and dash keys were struck once for each dot and dash signal, whilst the space key was struck once for letter-space and twice for

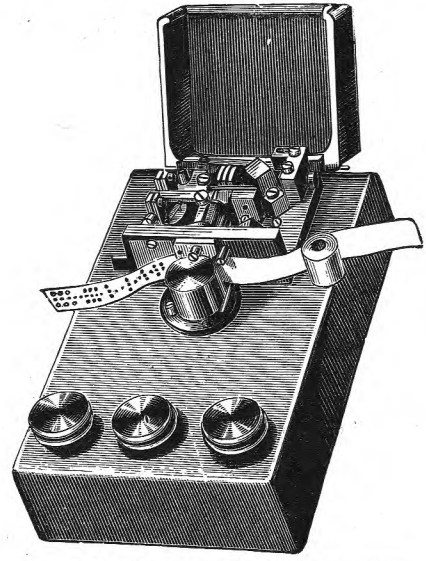


FIG. 2.27. WHEATSTONE PUNCH-STICK PERFORATOR

word-space. Arrangements were provided whereby a small spoked wheel, known as a "star-wheel," engaged the feed-holes of the paper tape and moved it forward by the appropriate amount, in readiness for the next perforation, when each depressed key was released.

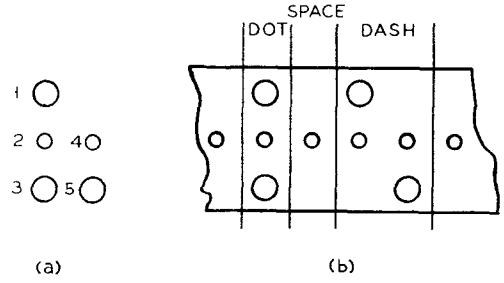


FIG. 2.28.

(*a*) Arrangement of Perforator Punches
(*b*) Perforations produced for Dot, Space and Dash

A modified keyboard was developed, in which pneumatically-operated punches were controlled by the operation of three light pianoforte keys and this allowed as many as eight tapes to be perforated simultaneously. This arrangement was employed for cases where the same message, such as news items had to be transmitted to a number of stations with consequent reduction of operating costs. A touch typist, that is, one who has been trained to type without looking at the keyboard and who can therefore give her whole attention to the matter being transmitted, is able to maintain an average operating speed of 40 w.p.m., as against 25 w.p.m. which was a good average speed on the "stick perforator," and furthermore with considerably less fatigue.

A typical form of modern Morse keyboard perforator is described in Chapter 12. In all types of Wheatstone-Morse perforators, the type of perforations produced for dot, dash and space signals are as indicated in Fig. 2.28 (*b*) and Fig. 2.29 shows a typical length of tape for the word "and."

The Wheatstone Transmitter. The automatic transmission of the message from the perforated tape is effected by the use of a Wheatstone transmitter. This instrument is essentially equivalent to a small and extremely light double-current Morse key, the movements of which are controlled automatically from the nature of the perforations in the perforated slip. The code holes in the perforated tape control the movements of a centrally pivoted divided lever. The divided lever consists of two portions, insulated from each other but rigidly clamped together. Each half functions as a transmitting tongue and at its extremities carries contacts which play between fixed battery

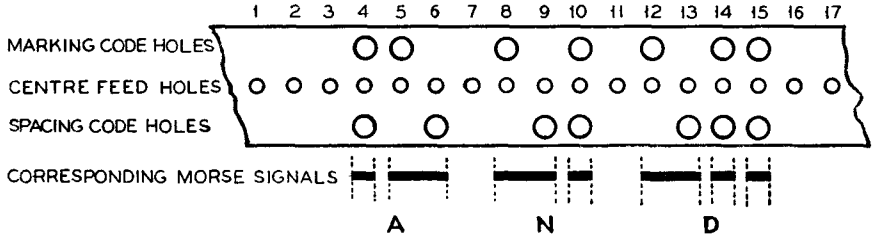


FIG. 2.29. WHEATSTONE MORSE PERFORATED TAPE (SLIP) AND CORRESPONDING MORSE SIGNALS

and so avoided delay from the need to make consecutive transmissions from the same tape; at the same time the possibility of errors occurring due to mutilation of the tape owing to repeated use was eliminated.

At a later stage, various typewriter keyboard perforators were produced by Allan, Siemens, F. G. Creed, Kotyra, Kleinschmidt, Gell and others. These instruments automatically produced the Morse code combinations for each character, in the form of perforations in a paper tape, by the depression of the appropriate key on the keyboard. This arrangement saved operating time and labour and enabled higher speeds of operating to be attained, contacts. For loop working with commutated battery signalling the electrical connexions employed are as shown in Fig. 2.30 (*a*). From consideration of this figure, it will be clear that the signalling battery is connected in series with the distant receiving equipment via the line loop and operation of the divided lever controls the direction of current flow. This arrangement thus provides double-current signalling facilities, without the necessity for a centre-tapped battery and overcomes the problem which arises in the latter case of maintaining equality of voltage either side of the battery centre-tap.

Where it is desired to use a centre-tapped battery

over a looped circuit the circuit arrangement employed is as indicated in Fig. 2.30 (*b*).

Fig. 2.30 (*c*) indicates centre-tapped battery working on a circuit operated with an earth return.

In the case of circuits operating as in Figs. 2.30 (*b*) and (*c*), it will be seen that the lower half of the divided lever is not in use.

The operation of the divided lever is controlled by the perforated tape as follows—two code peckers, corresponding to marking and spacing signals respectively, are caused to reciprocate up and down so that their tips touch the underside of the perforated tape and examine it for the presence of code-holes. If a code-hole is found by the pecker then it passes momentarily through the hole and in so doing the movement causes the divided lever to be operated to marking or spacing, depending upon the pecker which operates. Thus when no tape is passing through the transmitter the peckers, in turn, operate the divided lever alternately to marking and spacing. When either pecker in its upward searching movement finds that it is obstructed by the paper, due to no hole being perforated in that position, the divided lever remains operated to the contact to which it had been previously operated. The tape is propelled through the transmitter by means of a star wheel, engaging the centre holes, and at a rate conforming with the rate of reciprocation of the peckers.

Considering the action of the transmitter in relation to the tape shown in Fig. 2.29, it will be seen that assuming the last pecker which had operated the divided lever before the tape was inserted was the spacing pecker, then the divided lever will remain operated to spacing during the reciprocation action of the peckers corresponding to the centre holes 1, 2 and 3. When the marking pecker rises to examine the tape at a point opposite the fourth centre hole, it passes through the code-hole in the paper and so causes the divided lever to be operated to the marking contact. Next, the spacing pecker rises and passes through the spacing code-hole and this re-operates the divided lever back to the spacing contact. Thus, the divided lever causes a short element of marking current to be transmitted, corresponding to a dot signal. At the next centre hole, i.e. 5, the marking pecker again rises and operates the lever to marking, then the spacing pecker rises but as no code hole is punched in this position the pecker cannot pass through the paper, so the lever remains on the marking contact. At centre hole 6, the marking pecker cannot rise through the paper but the spacing pecker can, and the rising of this pecker terminates the marking signal by operation of the lever to spacing.

The foregoing action thus transmits a dash signal, and since the reciprocation of the peckers is a simple harmonic motion and the peckers are 180° out of phase with each other, the time intervals between the successive upward movements of the

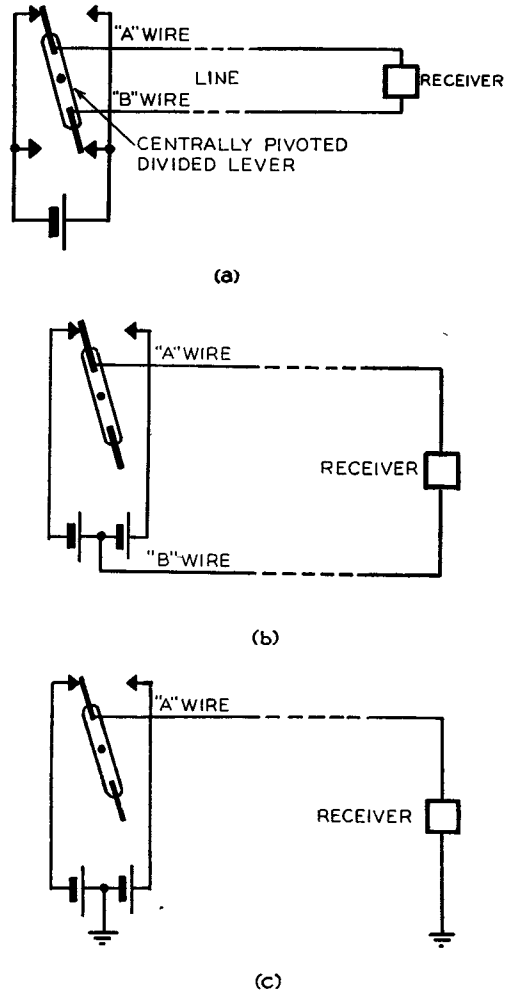


FIG. 2.30.

(*a*) Wheatstone loop working with commutated battery signalling
(*b*) Wheatstone loop working with centre-tapped battery signalling
(*c*) Wheatstone single-wire earth-return working with centre-tapped battery signalling

peckers are equal, and the duration of a dash signal is therefore three times the duration of a dot. The duration of a space signal between code elements is equal to that of a dot: the duration of a letter-space is equal to that of a dash.

Note that the duration of a dot signal is equal to the time it takes for the marking pecker to move

from its fully operated position upwards to its fully operated position downwards; this also corresponds to the time interval in which the spacing pecker moves from its fully operated downward position to its upward position.

Reconsidering Fig. 2.29, it will be seen that after the operation of the divided lever to spacing by the spacing code-hole opposite the sixth centre hole, that the spacing signal will continue until the eighth centre hole is reached when the marking pecker restores the lever to marking, thus terminating the letter-space. The marking signal will now continue until the spacing pecker rises and terminates the dash at 9. At 10, a dot is transmitted and the spacing current again continues until 12 is reached, when the dash in "d" is transmitted, followed by the two dots corresponding to centre hole positions 14 and 15. The lever is finally operated to spacing at the termination of the dot at 15 and remains on spacing for centre holes 16 and 17.

In the foregoing description it was assumed that at the commencement the divided lever was on the spacing contact. In practice, of course, it is equally probable that the lever will be on the marking contact at the moment when the tape is inserted and in the case illustrated in Fig. 2.29 this would have resulted in a continuous marking signal until the spacing pecker rose at four. In perforating a tape for transmission, a few A's are usually punched to precede the actual message, in order that the first signal of the message will not be merged into a continuous mark.

The utility of the Wheatstone system was considerably enhanced by a series of outstanding inventions by F. G. Creed, who founded the present well-known firm of Creed & Co., of Croydon, England. Creed developed, by 1901, a receiving perforator, known as a reperforator, which enabled the signals received from the line to be recorded in the form of perforations in a tape, at speeds up to a maximum of 200 w.p.m. Thus a perforated tape was produced at the receiver which was identical to that employed at the transmitter and could therefore be used to retransmit, automatically, the message to another office without transcription, thus effecting a considerable saving of operating time on retransmitted traffic. A later development was the Creed printer, which used the perforated tape from the receiver to cause the printer to reproduce automatically the message in Roman characters on a paper tape, which was then gummed on to a telegraph form for delivery. A model of the Creed printer suitable for page printing was also developed.

Full details of the construction and operation of modern types of Wheatstone transmitters, Morse keyboard perforators, reperforators and printers are given in Chapter 12.

In the B.P.O. Inland Telegraph Service, the Wheatstone system has been entirely replaced by the teleprinter, but Wheatstone is still employed in a few cases on radio circuits.

It is of interest to note, that the speed of operation of the Wheatstone system which in 1870 was only 70–80 w.p.m., was subsequently increased, as a result of developments, to 600 words per minute in 1890.

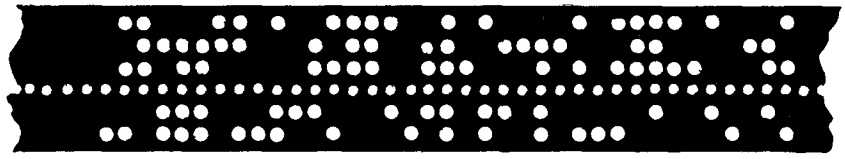


FIG. 2.31. KEYBOARD PERFORATOR 5-UNIT TAPE

Automatic Baudot. The operation of the Baudot keyboard was limited to a practical speed of 30 w.p.m. Attempts were made to increase this speed by the direct substitution of the five key type of keyboard by a typewriter keyboard. This gave some advantage but the necessity to observe a cadence signal still remained and this restricted the speed and tended to produce operator fatigue. The Baudot system was therefore automatized by the use of perforators which employed a typewriter keyboard, and caused five code punches to be selected in accordance with the code of the character depressed and the punches then produced the corresponding perforations in a paper tape. Fig. 2.31 indicates the nature of the perforated record so produced in the tape. It will be seen that the perforations for the code elements are punched transversely across the tape; a hole corresponds to a marking element of code whilst a blank represents a spacing element. The smaller holes punched between the positions of the second and third code-hole perforations are called "centre holes" and are employed for the purpose of driving the tape through the perforator and subsequently through an automatic transmitter, by means of a star-wheel

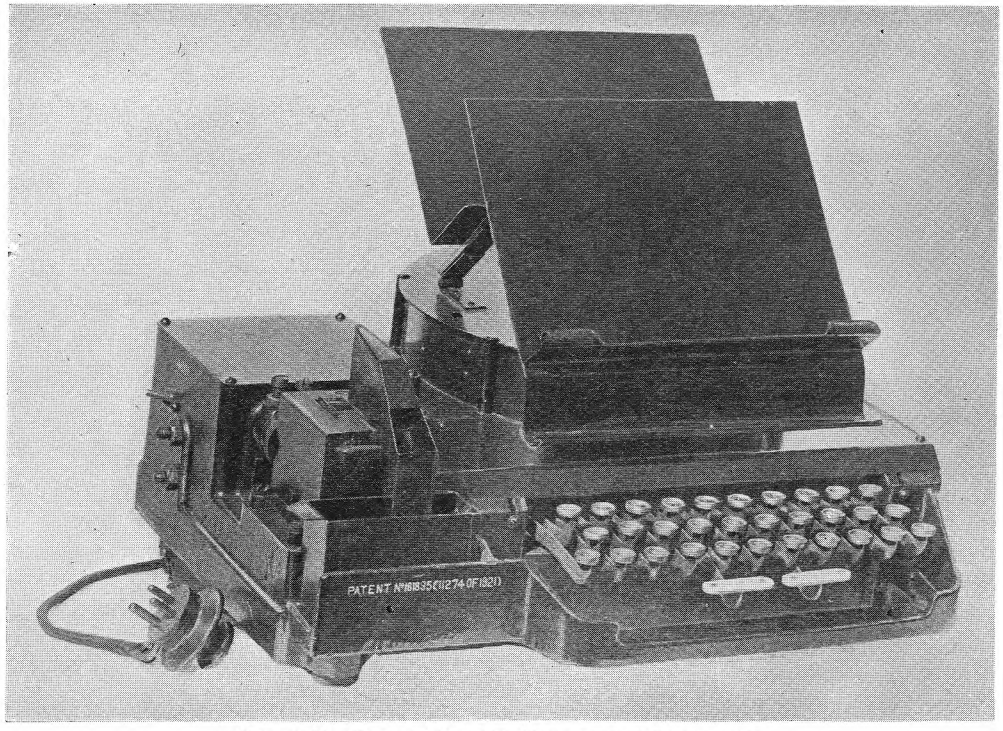


FIG. 2.32. BOOTH-WILMOT KEYBOARD PERFORATOR

similar to that already described in the case of the Automatic Wheatstone system.

This arrangement removes the inhibitions imposed upon the operator by the cadence signal so that tape can be perforated at any speed, as determined by the character of the copy and the psychological conditions of the moment.

A typical keyboard perforator of this type, which was employed in the B.P.O., was the Booth-Wilmot perforator which is illustrated in Fig. 2.32. This type of perforator was subsequently modified for use in the preparation of perforated tape for five-unit teleprinter code which employs a different alphabet from Baudot. The mechanical principle of operation of the perforator is, however, similar in each case and is described in Chapter 11. The perforated tape was used in conjunction with a Western Electric transmitter, which was controlled from the Baudot distributor, and converted the intelligence stored in the form of perforations on the tape into the corresponding signals for transmission to line via the Baudot distributor.

Fig. 2.33 shows a Western Electric transmitter of the type used and Fig. 2.34 shows the principle of the mechanism employed. The operation of the transmitter was as follows—there were five selector pins *SP*, one being shown in its raised position. When *EM*, the operating electromagnet, was energized by the cadence-signal from the

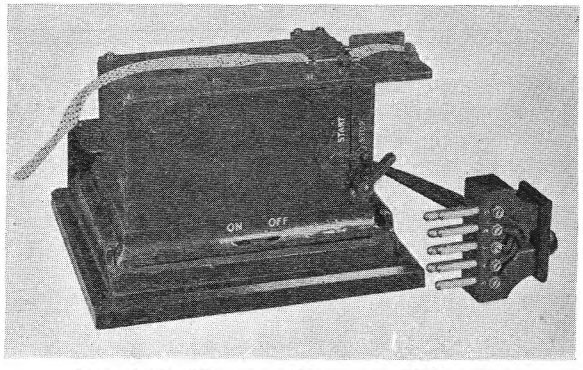


FIG. 2.33. WESTERN ELECTRIC MULTIPLEX TRANSMITTER

distributor, the armature *A* was attracted and any pins which had risen through the tape were retracted by the action of a pin retractor, *PR*, carried by the armature. The five contact levers *CL* were then returned to their spacing contacts,

SC, by the action of spring *RS*, when the armature acted upon the lever *L*, depressing it and so raised the feed rod *FR* which terminated in a pawl *FP*. The pawl engaged a ratchet wheel behind the star-wheel *SW* and at each upward thrust of *FR* the slip was carried forward one centre hole. The armature was returned to normal by the spring *AS*. The tension lever *TL* exercised an upward pressure on *SP*, which, when a perforation allowed, passed through the tape. The extension arm *EA* of *CL* was lifted so that *CL* moved to the marking contact *MC*. Where a selector pin was prevented from rising by unperforated tape the corresponding contact lever remained on the spacing contact. In this way, the movement of the selector pins, governed by the tape, was communicated to the contact levers and determined whether a spacing or marking current was sent to line. The battery circuit from *CL* was made through the spiral spring *BS* to the instrument cord. The star-wheel was steadied by a jockey roller carried by the lever *JL*, which was controlled by a spiral spring *JS*. By means of the screw *GS* the play of the armature was regulated.

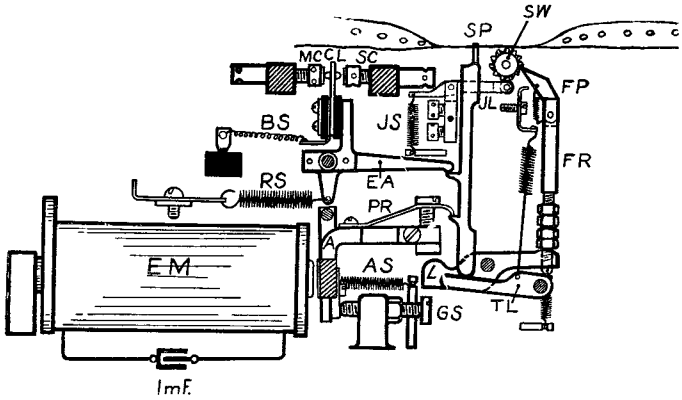


FIG. 2.34. PRINCIPLE OF WESTERN ELECTRIC TRANSMITTER

The five contact levers of the automatic transmitter were connected to the Baudot distributor, in a similar manner to the five keys of a normal manually operated Baudot keyboard; thus it will be seen that the code perforations of the perforated tape controlled the currents which were transmitted to line by the distributor.

The Murray Type-printing Multiplex System. This system was devised in 1901 by Donald Murray, as a combination of the best features of the Baudot multiplex and the Murray automatic systems. Murray employed a five-unit code, but the allocations of the signal combinations to the various letters differed from that in the Baudot code as is shown in Fig. 2.35.

The Murray perforator produced a tape in which the code was perforated transversely, the feed holes being in line with the front edges of the perforations so that the direction in which the letters should be read was at once apparent. A typewriter keyboard was employed and the principle of operation of the perforator may be understood by reference to Fig. 2.36 and the following description.

		1	2	3	4	5			1	2	3	4	5
A		●	●				Q	1	●	●	●		●
B	?	●			●	●	R	4		●		●	
C	(		●	●	●		S	'	●		●		
D	2	●			●		T	5					●
E	3	●					U	7	●	●	●		
F	½	●		●	●		V	)		●	●	●	●
G	¾		●		●	●	W	2	●	●			●
H	⅝			●		●	X	£	●		●	●	●
I	8		●	●			Y	6	●		●		●
J	⅞	●	●		●		Z	.	●				●
K	9	●	●	●	●		FIG SPACE	FIG SPACE	●	●		●	●
L	/		●			●	LTR SPACE	LTR SPACE			●		
M	,			●	●	●	LINE PAGE	LINE PAGE				●	
N	−			●	●		✳	✳	●	●	●	●	●
O	9				●	●	COL	COL		●			
P	0		●	●		●							

#12345 gives invisible correction on page printers & ✳ on slip printers.

FIG. 2.35. MURRAY 5-UNIT CODE

The keybars *K* were poised above six selector plates *SP*, extending across the machine. The upper side of the selector plates was serrated, and when a key was depressed a wedge shaped projection on its underside selectively engaged the teeth of the selector plates, in accordance with the code of the key depressed, and moved them to the right. Each selector plate had a bell crank lever *BL* at its left extremity, the horizontal arm of which engaged a notch in a vertical rod *IR*. In its normal position, *IR* was between one of the punches *P* and the punch hammer *PH* carried by the armature *A*. When *SP* was operated, *BL* pulled down *IR*. Each time the punch electromagnet *EM* was operated, *PH* struck the rods that had not been withdrawn. The blow was communicated to *P*, which perforated the tape shown at *T*. The third of the six selector plates, counting from the rear,

was operated by every key. Instead of a bell-crank lever, this selector plate had a contact lever CL at its right-hand extremity which, by means of a small block SB, closed the circuit of the punch electromagnet through contact PC. When the key-bar was released the circuit was broken; A was restored by a spiral spring, and by means of a pawl rotated a ratchet and star-wheel SW. The feed-hole punch FP was struck by the lower punch hammer PL every time the armature operated, thus preparing the small feed-holes engaged by the star-wheel. The feed-holes were thus perforated before the tape reached the star-wheel, and the signal holes were perforated after the tape had passed up from the star-wheel. By this arrangement every letter perforated was visible immediately it had been punched.

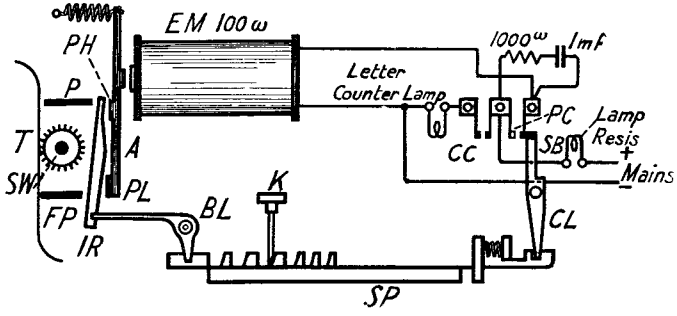


FIG. 2.36. PRINCIPLE OF MURRAY KEYBOARD PERFORATOR

The perforator was designed for use with a page printing-receiving instrument and for this purpose it was fitted with a letter-counting device. The operation of the punch magnet armature fed a rack along, letter by letter, and on completion of a line of printing caused the contacts CC to close and light a red warning lamp, as an indication to the operator to signal a new line by the operation of carriage-return and line-feed. The letter-counter thereupon returned to the zero position, in readiness for counting the next line.

A back-space key was provided on the perforator for use in conjunction with the erasure key, which enabled any errors to be obliterated in the perforated tape by punching the combination "all-space." The receiving instrument was arranged so that the receipt of the "all-space" combination did not print or feed the paper; thus the original error in the tape was erased.

The Murray Transmitter. Murray designed his transmitter and perforator to give the minimum possible distance between the perforating and transmitting mechanisms and so facilitated operation of a transmitter directly from an adjacent perforator. This was done by having the punch-block on the perforator in the extreme left-hand position on the instrument and the transmitting-block of the transmitter on the extreme right of the transmitter. This is illustrated schematically in Fig. 2.37 and with this arrangement the distance between the perforating and transmitting points was reduced to 16 centre holes.

The operation of the transmitter was as follows (Fig. 2.37 refers). Five contact levers CL were mounted, side by side, on a spindle SP and insulated one from the other and the upper part of them played between the battery contacts S and M. The contact levers were connected to the sending ring of the distributor as in a Baudot set. A spiral spring SG acting on CL tended to hold it on the spacing contact. The contact levers were operated by a horizontal projection on the control lever CN. An insulating stud IS prevented electrical contact. A strong spring SS attached to CN overpowered SG and pressed CL firmly against the M contact when in the operated position. The transmitter electromagnet EM was actuated by a current from two segments of the local ring of the distributor, the current being timed to operate immediately after the line brush had passed

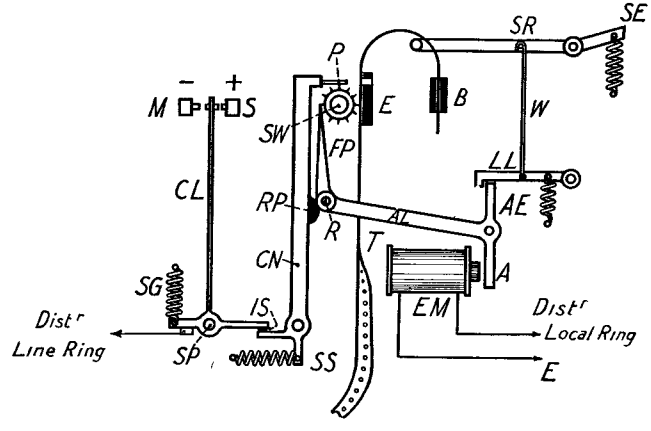


FIG. 2.37. PRINCIPLE OF MURRAY TRANSMITTER

the segments connected to the five contact levers. The attraction of A, raised the lever AL which carried a roller R and a feed pawl FP. The control lever had a rounded projection RP in the path of R. At every actuation of A, the roller travelled upwards, throwing CN back, so that the pin P was withdrawn from the tape. At the same time, FP engaged a ratchet behind the star-wheel SW, feeding the tape T down, by one letter space. When A was restored, R travelled down and the

pins were pressed by the spring SS against the tape. If a pin was accommodated by a perforation, the horizontal arm of CL was thrown up, and its contact passed over from S to M. The next combination is thus prepared in readiness for transmission by the distributor.

A novel feature provided on the transmitter was an automatic start and stop device, which was under the control of the paper tape and operated in the following manner. The tape in passing from the perforator punch block B, formed a short loop before passing into the transmitter at E. A rod SR projected at right angles under the loop and its extension SE had a spring which tended to elevate SR. The locking lever LL, and spring, was placed above an armature extension AE. A wire link W, coupled LL and SR. When perforating lagged behind transmission the tape was tightened and SR depressed, thus removing the upward pull exerted via W on LL; thus the spring on LL now takes control and tends to depress LL; LL however could only drop when the armature A was attracted. This occurred after the contact levers had been restored to the spacing contact. When A was thus locked by LL, five spacing currents were sent to line until further perforated tape was prepared and caused the tape to become slack and allowed SR to rise, so lifting LL. Mutilation of the tape, or a disconnexion in the transmitter, was thus avoided.

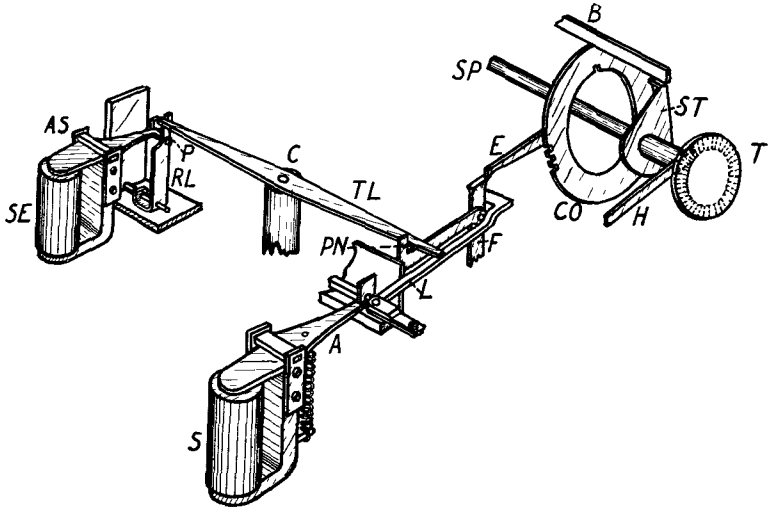


FIG. 2.38. PRINCIPLE OF CREED MULTIPLEX PRINTER

The Murray Reperforator. This instrument was designed to enable received signals to actuate a perforating mechanism to produce a perforated tape, corresponding to the original sending tape, which could then be used for retransmitting the message to another office. This facility was necessary in those cases in which the operation of a direct circuit between the office of origin and the destination office was impracticable, either from reasons of excessive line distortion or insufficient traffic to justify a direct circuit. The reperforator was also very useful in the case of "multiple-address traffic," i.e. where the same message had to be transmitted to more than one office.

The reperforator was employed either in parallel with a printing receiver or switched into circuit as an alternative to a printing receiver when desired. The construction of the reperforator was generally similar to a perforator, except that the selection of the punches to be actuated was controlled from the operation of five electromagnets, actuated from the line signals via the distributor. The distributor controlled a cadence signal, which operated the punching magnet after the code selection of the punches had been set up, and thus caused the tape to be perforated in the appropriate manner.

The Creed Multiplex Printer. This printer was used in connexion with the Murray multiplex and its principle of operation will be followed readily by the aid of Fig. 2.38. Five selector electromagnets were connected to the distributor ring and a sixth electromagnet was connected to the local ring of the distributor. Fig. 2.38 shows only one of the five selector electromagnets S. When S was operated, its armature A tilted the near end of the latch L and lowered the selecting finger F, attached at right angles to the extremity of the latch. In this position, a spring beneath L acted and F was slid beneath the comb extension E. A projection PN on L operated the long trip lever TL, which was pivoted at C. The remote end of TL engaged in a slot in the release lever RL. A projection P on the armature AS of the sixth electromagnet SE, also engaged a slot in the upper end of RL. While the selector electromagnets were in their rest position, TL prevented the armature of SE operating; when a latch was actuated however, its movement rotated TL and RL, freeing the armature AS, so that the detent was operated when the local impulse was received. The release of the detent resulted in the cam-shaft making one complete revolution. The cam had four tracks; as it commenced to rotate, it first moved the tape forward

the space of one letter and set the mechanism for restoring the code selection fingers F to normal. It should be noted that the printing of a letter took place one revolution later than the setting of the electromagnets. The printing hammer H was next operated and recorded the character on the tape. The bell-crank levers were then lifted, and the combination-combs freed from their last setting. Lastly the fingers were raised and those which had passed under the extensions shifted their respective combs.

The five combs CO having been set in a given combination caused a longitudinal slot to be opened at one point around their periphery, and this allowed a spring-controlled bell-crank lever B to drop into the slot. The five combs CO were mounted side by side on a drum and their movement limited to a fraction of a revolution. Passing through the axis of the drum was a spindle SP, which rotated the typehead T and its associated stop piece ST. When B dropped, its outer end projected into the path of rotation of ST and arrested the typehead; H struck the typebar and printed it on the tape. The discrimination between primary and secondary characters was made by means of a sixth comb. This comb was actuated by either of two bell-crank levers, operated respectively from the figure- and letter-shift signals. The comb was set into one of two possible positions and this determined whether a figures or letters bell-crank dropped, when any code selection was set up on the code rings.

The Western Electric and Morkrum Multiplex Systems. These systems were developed in America from the Murray system. The interesting development of the American systems was the Morkrum Typebar Printer which was a page printer capable of working at speeds up to 65 w.p.m. This printer was also suitable for use with Murray multiplex equipment and was so used to a limited extent in Great Britain.

The Morkrum Typebar machine had a typebar basket similar to a typewriter. The typebars were thrown up against a platen, printing the particular letter, through an inked ribbon, on to a paper roll. The selection of a typebar depended upon the setting of five code bars, whose movements were governed by five electromagnets connected to the segments of a Baudot distributor. The code bars

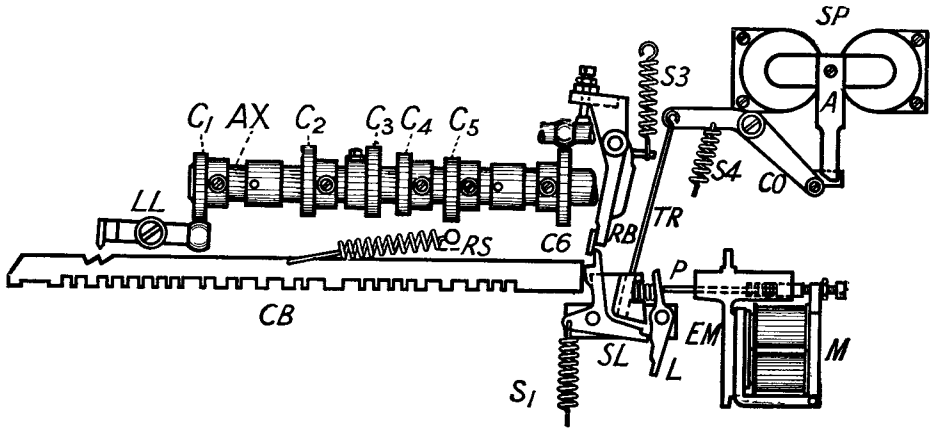


FIG. 2.39. PRINCIPLE OF MORKRUM TYPEBAR PRINTER

were notched on their under edge. A given combination permitted a particular push rod to rise through a channel made by the aligned notches into the path of a hammer lever. The hammer operated a push-bar and set the typebar in motion. The necessary movements to secure letters or figures, carriage-return, line-feed and space were made by mechanical means. The electrical apparatus consisted of five selector electromagnets, and a sixth whose function was to start the cycle of operations of the machine.

The train of movements may be followed in Fig. 2.39. When the armature M of the selector electromagnet EM was operated, the plunger P pushed the upper end of latch L, so that its lower extension disengaged the selector lever SL. The vertical arm of SL, by means of a spring S_1, then brought pressure to bear upon the code bar, moving it to the left. L and M were restored to the rest position by spring tension, immediately the signal ceased. While EM was being operated, the lock lever LL was raised from CB and the reset bail RB was freed from SL, but as soon as shaft AX rotated, cam C_1 allowed LL to be pulled down into one of the notches in the upper edge of CB, holding

the latter steady, while printing took place. Immediately afterwards, cam C_6 came into action, allowing spring S_3 to operate RB, so that the selector lever was restored.

When the code bar combination had been set, the sixth pulse electromagnet SP was operated. The movement of its armature A set the main shaft in motion and started the operating cycle of the printer. The shaft made one complete revolution each time the armature of SP was operated.

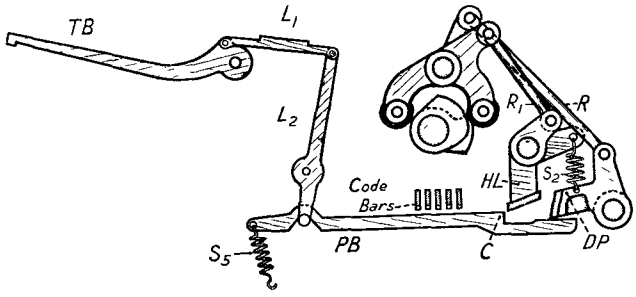


FIG. 2.40. PRINCIPLE OF MORKRUM TYPEBAR PRINTER

Each typebar TB (Fig. 2.40) was linked to its push-bar PB, by two levers L_1, L_2. In its rest position PB was depressed by DP against the tension of S_5. When the printing magnet SP had been operated, C_5 on the main shaft operated DP by means of rod R. This allowed the push-bars to rise and enter the slots lined up in the code bars according to the selection made. The corner C of the push-bar was then in line with a hammer lever HL. At a particular point in its revolution a cam C_3 released the pull on HL exerted by rod R_1, allowing spring S_2 to push PB, through the medium of HL and C. PB transmitted its motion to TB, resulting in an upward thrust to the platen. A safety cam C_4 ensured that the movement of TB was not excessive. When PB had been restored by the depression of DP, CB was returned to the normal position by a replacing spring RS. Spacing after printing was effected by means of cam C_2 operating a rack and pinion movement. When spacing only was required, the combination received actuated the code bars but no push-rod was associated with the spacing parts, so that a revolution of the shaft was made and all the operations were performed except printing.

A single-stroke bell-signal could be given in response to the code combination corresponding to the secondary of letter A. The push-bar in this case operated a bell-hammer connected to L_1 in place of a typebar. Where the printer was connected to a distributor, SP was energized every revolution of the brushes by a local current. This would cause a continuous action of the printer, unless some method was adopted to prevent SL operating except when signals were actually received from line. The difficulty was overcome by means of a cut-out lever CO, the lower end of which was held up by a spring S_4, so that it obstructed the armature A of SP. TR was a thin rod resting upon the selector levers. When SL was operated, TR received an upward thrust from the horizontal arm and CO moved downward, leaving the path of A clear.

The printer was driven by a small electric motor.

The Siemens and Halske Automatic Type-printing System. This system is based upon the use of a five-unit code but the allocation of the code combinations to the characters differs from the Baudot and the Murray codes. The system operates at high speed; a keyboard perforator is employed to prepare a perforated tape which is then passed through an automatic transmitter and at the receiving end of the circuit the signals are received directly on a tape printing machine which records the signals in the form of Roman characters on a gummed paper tape at a speed of 166 w.p.m.

The perforated tape is perforated transversely with the code holes and each outer edge of the tape has a row of guide holes like a cinematograph film and these are employed to propel the tape through the perforator and the automatic transmitter by means of two star-wheels. The passage of perforated tape through the automatic transmitter controls the operation of five-code pins, which, in turn, control the operation of five contact levers which are connected to five segments forming one ring of the transmitting distributor. The contact brushes of this distributor traverse the rings at 1,000 r.p.m. thus giving a transmitting speed of 166 w.p.m. At the receiving end, the signals pass from line through another distributor, which passes the signals to one of two sets of five relays, which are used alternately.

As the receiving distributor brush arm rotates, there is one particular position in its revolution where an electrical circuit is completed, through the five tongues of these relays, for each letter of the alphabet. In this position a capacitor is discharged through a magnet, which lifts a paper tape against a revolving type-wheel thus printing the required character. It is remarkable that the action of the magnet is so rapid that it is able to press the tape against the revolving type-wheel and to obtain an unblurred impression, although the wheel is revolving at such a high speed.

The type-wheel has one row of letters and another of figures, etc., and is shifted along its axle by a particular signal, depending on whether letters or figures are required. Two sets of five relays are required: as one set is used for reception of the impulses of one character combination, the other set, already actuated, is in use for completing the circuit of the printing magnet. Thus the printed character is one revolution behind the incoming signals. The distributors at the two ends of a circuit have to be kept in correct phase relationship and this is effected by the incoming signals controlling an auxiliary motor for speed correction, which rotates as required to introduce, or cut out resistance in the circuit of the driving motor.

Arrangements can be made so that incoming signals actuate a perforator, so as to produce a perforated tape, as well as a printed tape, for messages which have to be repeated to another circuit. As the received signals actuate the printing mechanism without the necessity of preparing a perforated tape the system is superior in this respect to either the Wheatstone-Creed combination, or the Murray automatic.

Fig. 2.41 shows a typical Siemens transmitter and Fig. 2.42 a Siemens receiver. The Siemens-Halske high-speed system was at one time considerably used in Germany, Norway and elsewhere, and until 1939 was employed by the B.P.O. on the two single-core Anglo-Norwegian cables which worked between London and Oslo. This service has since been replaced by teleprinter circuits and this is the tendency in other countries where the system has been used.

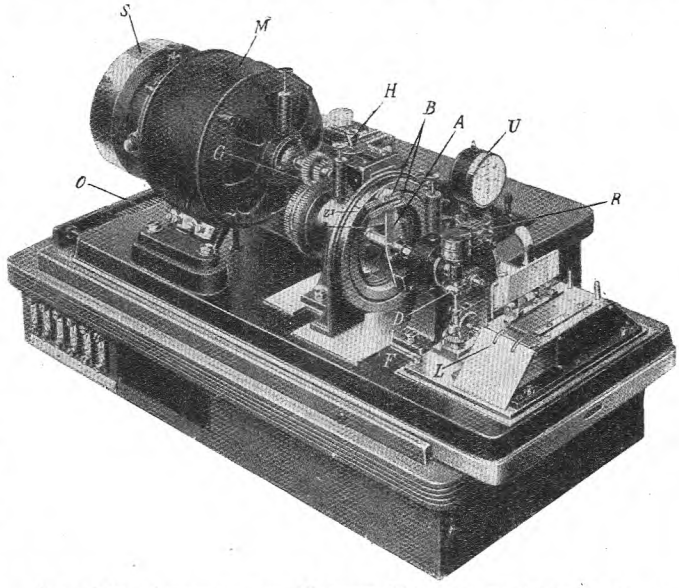


FIG. 2.41. SIEMENS AND HALSKE HIGH-SPEED AUTOMATIC TRANSMITTER

Start-stop Telegraphy. Synchronous printing telegraph systems employing even-length codes, e.g. the Baudot and the Murray, were a great advance in telegraphy. They suffered, however, from the disadvantage of lack of flexibility and required very accurate means for maintaining synchronism between the transmitting and receiving instruments. Skilled attention was also required at frequent intervals to ensure fault-free service.

To overcome these disadvantages a number of inventors experimented with the ingenious idea of starting and stopping the receiving instrument for each character and for this purpose the transmitting instrument was arranged to send special "start" and "stop" signals. The start signal was transmitted immediately preceding the code signals, and the stop signal was transmitted immediately the code signals were completed. The code employed was a five-unit code and the start signal was equal in duration to one code element, the stop signal being in some cases equal to one element and in other cases more than one, e.g. 1·5 elements.

Both the transmitting and receiving instruments were arranged so as to have a definite position of rest. In these positions the transmitter and the receiver were precisely in phase with each other in readiness for their respective timing cycles of operation, when released. The transmitter in the rest position sent a continuous signal corresponding to the signalling condition used for the stop signal, namely, marking. When a character was transmitted the transmitter first emitted a spacing signal to signify the "start-signal," followed by the code elements of the character (marking and/or spacing depending upon the character code) and finally the "stop-signal," i.e. marking. The transmitter then stopped, but continued, nevertheless, to maintain the same signal condition to line, i.e. a marking signal, until the start signal of the next character was transmitted. Thus it will be seen that, although the stop signal has a definite minimum duration, the duration of the marking signal after the completion of the transmission of the five-unit code signals depends upon the speed with which successive characters are selected for transmission. Thus, when a manually-operated keyboard is employed for controlling the transmitter the stop-signal condition will vary in duration, depending upon the speed of the typist.

When however an automatic transmitter is employed for transmission of the signals the start signal for each successive character commences immediately the stop signal of the preceding character ends. The transmitting cam which is used for timing the duration of the signal elements in this case either rotates continuously or stops only for an instant, depending upon the mechanical design employed.

incoming signals the required five-unit code combination is selected. The actual instants at which the selections occur are controlled by the cam, so that they are made at what should be the middle period of each element as timed from the instant at which the receiver is started by the reception of the start signal. Having selected the combination, the receiver then terminates its cycle of operations during the stop signal; the selecting mechanism is

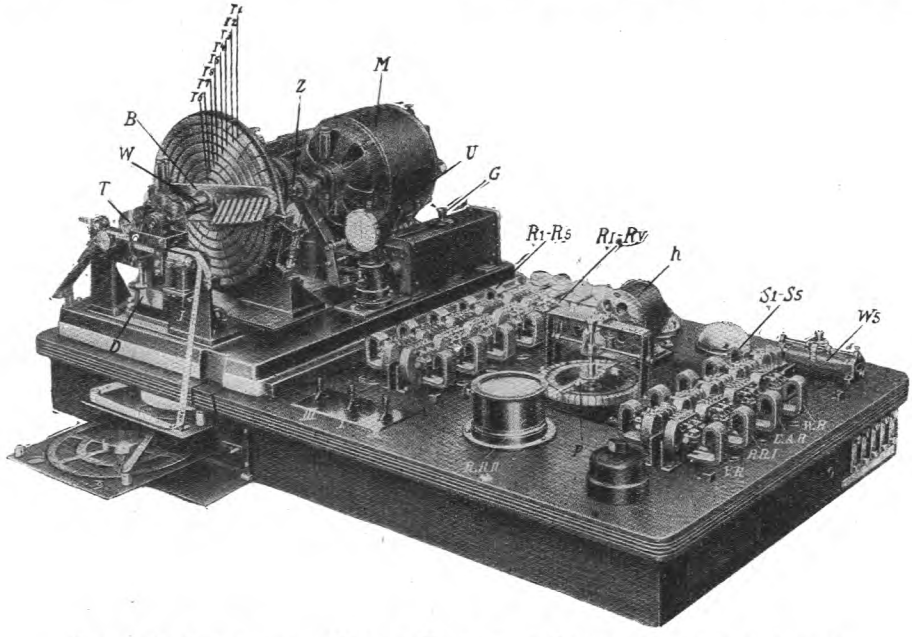


FIG. 2.42. SIEMENS AND HALSKE HIGH-SPEED RECEIVER (COVER REMOVED)

The transmitting and receiving instruments are each driven from an electric motor, usually fitted with a centrifugal type of governor, which maintains the speeds constant within close limits, usually of the order of 0·5 per cent.

To cater for the reception of signals which are automatically transmitted and which, in consequence, include stop signals of minimum duration, it is essential that the receiver must complete the selection of each character and then stop in its rest position before the arrival of the start signal of the next character. The receiver will otherwise get out of phase with the transmitter and erroneous selection of the characters following will result.

When a start signal is received it causes the selecting mechanism of the receiver to start its cycle of operations. These occur in a precise time sequence, which is determined by accurately cut cams in the receiving mechanism driven from a governed motor. Acting in conjunction with the thus brought to rest in readiness for the reception of the next character.

It should be noted that since the transmitter and the receiver always start from fixed rest positions and the sequence of timing operations for any character takes place at instants which are timed from the moment at which the transmitter and the receiver are respectively operated to their start positions, the actual time which the signals take to traverse the circuit is therefore of no importance, so long as it is the same for all the signals of each character.

In practice, distortion of the various signal elements occurs during their transmission through the circuit and this results in corresponding displacements of the signal transitions from their true theoretical positions in relation to the beginning of the start signal. Similarly, since the speed of the transmitter is not absolutely constant, this also produces distortion of the signal elements.

In the same way, slight variations can occur in the speed of the receiver, also resulting in a displacement of the selecting operations by the receiver from their true theoretical positions. It is essential, despite circuit distortion and variation of speed of the transmitting and receiving instruments between the extremes of their controlling governors (e.g. one instrument may be 0·5 per cent fast whilst the other is 0·5 per cent slow), that perfect registration of the desired character should be made over the widest possible limits.

The effect of distortion of the signals will cause the signal transitions to occur either early or late with respect to their true theoretical positions; similarly the timing operations in the receiver will be early or late, depending on whether the speed of the receiver is faster or slower than the theoretically correct speed. The optimum performance of the receiver is secured by designing it so that the selecting action caused by the code signals takes place during a very short period at the middle of each element. Thus, providing the signal transition for the element concerned is not later than the beginning of the selection period for that element, then it will be selected correctly, provided also that the signal transition of the following element is not so early that it occurs before the end of the selecting period appropriate to the previous element. The capacity of a receiving instrument to accept distorted signals and yet still produce perfect registration of the desired character is called the "margin" of the instrument. The maximum theoretical margin which it would be possible to attain in a receiver if perfectly designed is 50 per cent, and this implies that the selection of each character element in the receiver would have to occur in an infinitely short time at the middle of each element. In practice start-stop instruments of modern design give a margin of 40–45 per cent. Fuller information on this subject will be found in Chapter 5 and Chapter 11.

Since any signal transition may be advanced or retarded with respect to its true theoretical position as a result of speed errors and distortion, it is clearly desirable that the receiver be arranged so that under all circumstances its selecting cycle is completed during the stop signal, i.e. before the next start signal arrives to start the next cycle of operations. This is done by making the receiver complete its cycle in a time which is at least half an element shorter than that of the transmitter cycle, e.g. where the transmitter has a start and stop signal each equal to a code element, the receiver completes its cycle in a time equivalent to six and a half elements. This is a very important feature in the design of the receiving mechanism and is essential for satisfactory operation when the maximum permissible distortion is present and the signals are being received at automatic transmission speed.

Start-stop telegraph instruments have revolutionized modern telegraphy, as they have made it readily possible for any such instrument to work together with any other similar instrument with ease and accuracy and minimum maintenance attention. Telegraph systems can, as a result, be made much more flexible and complex switching systems can be operated in which any number of start-stop instruments can be connected to manual or automatic exchanges with means for interconnexion between any of the instruments so connected. When connexion has been established between any two points in such a network, the instruments can be worked one to another, either simplex or duplex as desired, with the same facility as if the connexion was, in fact, a point-to-point circuit.

The majority of modern telegraph circuits are now operated with start-stop instruments and in fact much of the development of modern telegraphy would not have been possible without the benefits derived from this type of instrument.

Full details of the types of start-stop instruments employed in the B.P.O. services are given in Chapter 11.

It is of interest that the earliest start-stop type of instrument was introduced in 1907 by Charles L. Krumm and his son H. Krumm. It was subsequently manufactured by the Morkrum Co. of America and began to find practical application about 1920. This instrument, known as the teletype, comprised a typewriter keyboard for direct sending, employed a five-unit code with start and stop signals, and printed the received messages directly from line signals on to a paper tape. This instrument was capable of working at a speed of 40 w.p.m. and it could be operated either simplex or duplex.

In 1922 F. G. Creed of England designed a start-stop receiver and a few years later produced a combined transmitter and receiver having a typewriter keyboard. This machine, known as a teleprinter, printed the messages on a paper tape. In 1931, a page printing machine was introduced and this has proved extremely popular for private services as in this case it is usually preferred to obtain messages in page form and avoid the gumming-up operation which is necessary in the case of tape printers. For certain applications the use of a tape printer is usually preferred, e.g. the Public Telegraph Service.

The Creed teleprinter No. 7 operates at a speed of

400 characters per minute (i.e. 66 w.p.m. approximately) and may be operated either simplex or duplex. When simplex working is employed, the teleprinter will provide a local record of the transmitted signals as well as a copy of the messages received. The machine can be fitted with either a page or tape printing unit.

There are a number of associated instruments used for automatic transmission or re-transmission of messages. Thus, a perforator is available, having a typewriter keyboard, which produces a perforated



FIG. 2.43. TELEWRITER

tape when a key is depressed. The perforations in the tape correspond to the five-unit code of the character and this tape is suitable for passing through an automatic transmitter, which converts the perforated record of the message into the corresponding start-stop signalling code for transmission of the message to line and thence to a distant teleprinter or other start-stop receiving instrument. In some cases it is required to record the received signals in the form of a perforated tape for re-transmission and for this purpose a receiving perforator (i.e. a re-perforator) is available. A more recent development is an instrument in which a perforated record is obtained directly from line signals and in addition, a printed record is superimposed on one and the same tape, thus enabling the correlation to be seen between the perforations and the printed message. This arrangement considerably simplifies the handling of the message tapes for re-transmission as it enables the tape to be checked for accuracy and messages are much more readily identified.

Chapter 11 indicates the basic principles employed in various types of start-stop instruments and describes, in detail, the operation and design characteristics of the British types of instruments employed by the B.P.O. and manufactured by Messrs. Creed & Co., Ltd., Croydon, England.

Mosaic Printing Telegraphy. The best known example of a mosaic printing telegraph instrument is the Hellschreiber which has already been described in principle in Chapter 1 and which is dealt with in greater detail in Chapter 12.

Facsimile Telegraphy. Facsimile telegraphy is the generic name employed to describe those systems of telegraphy in which the object is to reproduce at a distance a more or less faithful copy of an original document. Handwriting, drawings and pictures can thus be transmitted and received. In the U.K. the expression "Direct-recording facsimile" is used to describe facsimile telegraph systems in which the object is merely to produce a readable copy of a written, typed or printed message or a line diagram or chart. Facsimile telegraph systems are also employed to produce a photographic copy of an original, which for all practical purposes is indistinguishable from a direct photographic copy. This latter is the most refined form of facsimile telegraphy and is called "Phototelegraphy" or "Picture telegraphy"; the system employs normal photographic materials and processes for developing and fixing the received copy.

One of the oldest forms of direct-recording facsimile instruments employed was the telewriter, or teleautograph, which was designed for the purpose of transmitting handwriting or sketches.

The question of transmitting handwriting was pursued by several inventors and Ralph Wedgewood appears to have been the first to invent a stylographic system in the year 1814 but failed to receive official encouragement. E. A. Cooper made a handwriting model in 1840 and was followed by Lenoir, Arlincourt, Jordery, J. H. Robertson and others. It was not until 1878, however, that Cooper produced an apparatus called the teleautograph or telewriter for public use.

Fig. 2.43 shows a view of a typical form of telewriter used at one time in the B.P.O. public telegraph service and which was suitable for operation over short physical lines. The transmitter consists of a pencil connected to the arms of a pantograph and the arms regulate the electrical currents transmitted over the two line wires when the pencil scribes the message to be transmitted on the writing desk. At the receiver the two line currents

control the movements of two moving coil galvanometers, which, in turn, control pantograph arms which carry a recording pen. Thus movements of the transmitting pencil cause corresponding movements of the receiving pen and thus reproduce a facsimile copy of the message at the receiver. Arrangements are made so that when the transmitting pencil is lifted from the paper the pen at the receiver performs a corresponding movement. The movements of the transmitting pencil must be confined between given parallel lines on the writing desk and when this area of paper has been used up the paper can be automatically fed forward by pressing the transmitting pencil against a contact at the side of the writing desk. This action produces a corresponding forward movement of the paper at the receiver and in addition causes the pen to replenish its ink supply from an inkwell.

The telewriter was at one time considerably used for short distance connexions on point-to-point circuits and also for switched connexions between a number of stations connected to private exchanges. At one time a number of these instruments were in use in the B.P.O. Central Telegraph Office in London for receiving and transmitting telegrams to certain private firms in London.

The instrument has a slow transmission speed and although its use by the B.P.O. was abandoned many years ago, certain private firms still find it useful for some forms of internal communications.

The development and operation of other forms of facsimile equipment including phototelegraph equipment are described in detail in Chapter 13.

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CHAPTER 3

METAL RECTIFIERS, THERMIONIC VALVES AND COLD-CATHODE GLOW-DISCHARGE TUBES

RECTIFIERS and thermionic valves are among the most important electrical devices employed in modern telegraphy and the valve, in particular, has undoubtedly made the most important contribution in the advance of the art in the last hundred years. The cold-cathode glow-discharge tube is finding increasing applications in recentyears.

Constitution of Matter. An elementary knowledge of the constitution of matter assists in understanding the nature of electric current flow and the difference in behaviour of conductors and insulators in the presence of an electromotive force. It is also essential for understanding the action of rectifiers and valves and will therefore be briefly explained.

All matter, whether in the solid, liquid or gaseous state consists of molecules built up from atoms of one or more of the various elements. A *molecule* is the smallest particle of any substance which can exist independently and retain the characteristics of that substance. The majority of substances available are *compounds* which means that they consist of two or more different simple substances in close chemical combination. The simple substances referred to are known as *elements* as these cannot be broken down chemically into different substances. They can, however, be broken into constituent atoms, an *atom* of an element being the smallest particle of that element which can take part in a chemical change. An atom cannot usually exist alone for any length of time as it will immediately combine with different atoms present to form a molecule of a chemical compound or else unite with similar atoms, usually in pairs, to form molecules of an element. Exceptionally, however, the molecules of some substances, e.g. copper, contain only one atom and in such cases the molecule and the atom are identical.

Modern theory explains the atom as being itself comprised of minute constituent particles termed *electrons, protons* and *neutrons* and although other constituent particles such as the *positron* and the *mesotron* are known to exist, consideration of these is unnecessary for the present purpose. The differences between the various elements is considered to be due to the number and arrangement of their constituent electrons, protons and neutrons, and their behaviour is determined by their electronic configuration, particularly in the outermost shell. All atoms are believed to consist of a positively-charged *nucleus* surrounded by one or more electrons which are negatively charged and the electrons rotate at high speed in orbits of various sizes around the central nucleus. The atom may thus be likened to an extremely minute solar system. The negative charge of the electron, which is considered to be the fundamental electric charge, is extremely small and the mass of the electron is only 9×10^{-28} gramme. The number of planetary electrons in an atom varies for different elements, for example, hydrogen, which is the lightest element, has only one electron; helium has two, lithium has three, copper 29, lead 82 and so on up to uranium which has 92. A number of elements heavier than uranium are known to exist, e.g. plutonium which has 94 electrons. The number of electrons in an atom of an element is known as the *atomic number* of the element and in a complete atom the negative charges carried by these electrons is exactly counterbalanced by an equal number of protons in the nucleus, each carrying a charge which is equal but opposite to that of an electron. A complete atom is therefore electrically neutral.

Although the positive charge carried by a proton is of the same magnitude as the negative charge on an electron, its mass is about 1,840 times greater. Furthermore, except in the simple hydrogen atom which consists of one proton and one electron, the nucleus is made up of protons and neutrons in practically equal numbers, the *neutron* being a particle having zero charge but of mass approximately equal to that of a proton. The total weight of an atom is therefore mainly accounted for by the weight of its nucleus. It is of interest to note that a chemically pure element may consist of a mixture of different forms of atoms known as *isotopes* which, although having the same atomic number, have different atomic weights caused by the presence of different numbers of neutrons in their nucleus. The isotopes of an element, although identical chemically, have different physical properties.

Current Flow. It has been explained that an atom is normally electrically neutral and that the electrons rotate in orbits around the nucleus, being maintained by the electrostatic forces between them. It is possible, however, to detach an orbital electron from an atom so leaving the atom with an

excess positive charge. Similarly, an electron can be added to an atom causing the atom to exhibit a negative charge. Atoms or molecules which exhibit an electrical charge externally are called *ions*, a *positive ion* being deficient of one or more electrons and a *negative ion* having an excess of electrons. In either state the ion has a strong tendency to return to a neutral atom by attraction or loss of electrons as required and this phenomenon underlies electric current flow. Electrons in the outer orbits of an atom are held more loosely as they are farther from their nucleus, and in certain substances called *conductors*, transfer of these electrons between adjacent atoms is continually occurring. In such cases a drift of orbital electrons throughout the material can be made to occur by the application of an external electrical force, and movement of electric charges in this manner constitutes an *electronic current*. In an *insulator* the electrons are very tightly bound to their parent nuclei which thus prevent, or severely restrict, any electron flow.

It should be noted that in addition to current flow resulting from movement of electrons in a conductor, it is also possible to obtain electron current flow through a vacuum or a gas at low pressure, and also by movement of ionized molecules through a gas or a liquid. The normal convention in practical electricity assumes that current flows from a region of positive to negative potential but it will be clear from the foregoing explanations that the current flow may be due to either (*a*) negatively-charged particles, i.e. electrons, or negatively-charged ions, moving from a negative to a positive potential, or (*b*) positively-charged ions moving from a positive to a negative potential.

It should also be noted that as an atom has much greater mass than an electron, an ionized atom will have a much slower speed than an electron when caused to move by the application of a given external electric force.

Linearity and Non-linearity. For pure resistances Ohm's law applies; that is to say, the ratio of applied e.m.f. to the resultant current in a resistor is constant, this constant being known as the resistance. Thus $\frac{V}{I} = R$. All electrical conductors have resistance, which is constant for each conductor at a given temperature, and if a graph is plotted for different values of applied e.m.f. and the resultant current, a straight line will be produced. This type of relationship between e.m.f. and current is therefore called "*linear*." Certain substances, e.g. the red cuprous oxide used in copper oxide metal rectifiers, do not conform to Ohm's law because the relationship between applied e.m.f. and resultant current is not constant and when plotted produces a curve. Similarly, if the output current is plotted against input voltage in a thermionic valve the graph produced is found to be a curve. This type of relationship is known as "*non-linear*."

Metal Rectifiers

A metal rectifier is a non-linear device which has the important property of being electrically asymetrical, that is to say, it passes current much more easily in one direction than in the opposite direction. This property is of considerable value as a means of rectification of alternating currents into direct currents and such devices have numerous and diverse applications in telecommunications.

The action of the rectifier is dependent upon the properties of *semi-conductors* which are materials having intermediate characteristics between those of a conductor and those of an insulator. Such materials have more free charges than an insulator but unlike a conductor their number is several orders smaller than the number of atoms in the material. The free charges in a semi-conductor may arise from local imperfections in the crystal structure or may be the result of a very small proportion of an impurity substance distributed throughout the semi-conductor. If there is a deficiency of electrons from the stable state, the material is known as a *p* (*positive*) *type* semi-conductor, whilst if there is an excess of electrons present it is known as an *n* (*negative*) *type* of material. If a conducting material is brought into contact with a semi-conductor the resistance to current flow is found to be greater in one direction than the other. In the case of a *p*-type semi-conductor the resistance to electron flow from metal to semi-conductor is much less than the flow in the reverse direction, whilst an *n*-type material has a reverse characteristic. If a single portion of semi-conductor is partly *p*- and partly *n*-type, the interface between the two types will exhibit rectification characteristics, the electron flow being much easier in the direction *n* to *p* than *p* to *n*. Silicon (*p*-type) rectifiers employing a wire contact, basically similar in form to the familiar cat's whisker crystal detector of the early radio receiver but made much more stable by improved techniques, were developed and used during the 1939–45 war for very high frequency radar equipment for which purpose the rectifier is required to have high forward conductance and low self-capacitance. *Germanium crystal diodes* based on the same principle and hermetically sealed in a glass envelope were subsequently developed for use at lower frequencies, e.g. in the modulators of carrier telephone systems, and more recently *fused*

junction types have been evolved. The self-capacitance of the ordinary metal rectifier, due to its relatively high contact area is higher than is desirable for high frequency uses and germanium rectifiers are much better for such applications. In recent years much effort has been concentrated upon the development of germanium and silicon power rectifiers and satisfactory designs are now

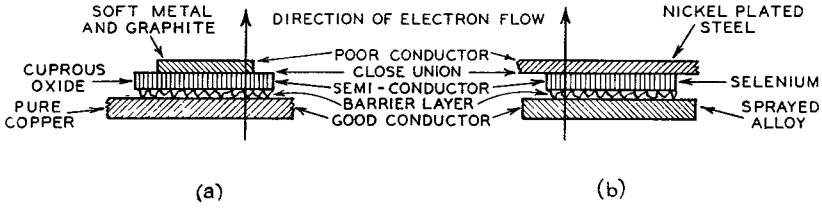


FIG. 3.1. PRINCIPLE OF METAL RECTIFIER
(*a*) Copper Oxide Rectifier (*b*) Selenium Rectifier

becoming available. At the present time, however, the main types of metal rectifiers employed in telegraph equipment are copper oxide and selenium types and the following descriptions are therefore confined to these types.

The basic principle of the copper oxide rectifier is illustrated in Fig. 3.1 (*a*). It consists of a metal *back-electrode* in the form of a copper disc upon

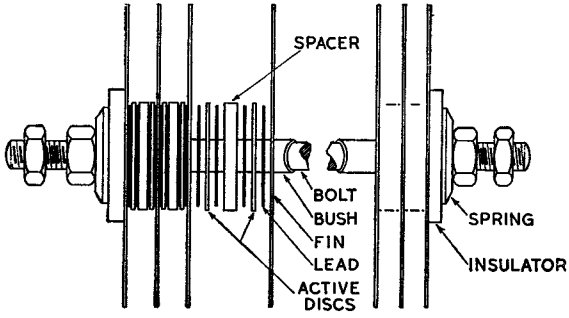


FIG. 3.2. TYPICAL CONSTRUCTION OF COPPER OXIDE RECTIFIER

which a layer of red cuprous oxide (Cu_2O) is formed on one face by heat treatment A second electrode, called the *counter-electrode*, is pressed firmly in contact with the face of the cuprous oxide to provide good electrical contact with it. The intimate junction between the copper back-electrode and the cuprous oxide which is a semi-conductor, forms what is known as a *barrier layer* and the seat of the rectifying action resides in this junction which exhibits the property of low resistance to current flowing from the oxide to the copper but extremely high resistance to current flowing in the opposite direction. The direction of low resistance is called the *forward direction* of the rectifier.

In the selenium rectifier a layer of selenium (Se) is formed on a nickel-plated steel disc and the free face of the selenium is then sprayed with a low melting point tin alloy to form the counter-electrode. This arrangement provides a robust mechanical and electrical unit and avoids the need for high mechanical pressures to ensure good electrical contact between the component layers. The barrier layer exists between the selenium and the counter-electrode and the low resistance to current flow, i.e. forward direction of the rectifier, is from the back-electrode to the counter-electrode, i.e. from steel to selenium. The basic principle of the selenium rectifier is illustrated in Fig. 3.1 (*b*).

Construction of the Copper Oxide Rectifier. A copper oxide rectifier element consists essentially of a disc of pure copper, about 1 mm thick and having an annular or rectangular form, upon one side of which a layer of red copper oxide, i.e. cuprous oxide (Cu_2O), is formed by a series of heat treatments.

To complete the rectifier element, it is necessary to make an efficient electrical contact to the cuprous oxide so colloidal graphite is painted on the surface of the oxide and then dried. Contact may be made with the graphite either by a soft metal under pressure or by spraying, vaporizing or cathode-sputtering a metal electrode which gives good contact without the use of heavy pressures.

A typical rectifier assembled from several discs is illustrated in Fig. 3.2. A number of oxidized copper discs are arranged alternately with lead discs and mounted on a common spindle but insulated from it by means of a bush. To ensure a firm series connexion between the rectifier elements they are compressed together on the spindle by means of nuts. Radiating fins are inserted between the active discs to assist the dissipation of heat from the rectifier, since it is important with the copper oxide rectifier to prevent the temperature rising in service to more than 55°C, as above this temperature the rectifying action falls off rapidly. In the

U.K. the highest continuous level of air temperature is about 25°C, with occasional peaks of short duration up to 35°C; but in tropical climates air temperatures up to 55°C may be reached which renders the copper oxide rectifier unsuitable for use in the tropics.

Construction of the Selenium Rectifier. The selenium rectifier consists essentially of a disc of nickel plated steel or aluminium on one face of which a thin layer, approximately 0·1 mm, of selenium is applied so as to form an intimate contact with the disc. Selenium may be obtained in three forms namely, the vitreous form which is almost an insulator, a crystalline form which has a high resistance, and another crystalline form which has a lower resistance. The special heat treatment used in the production of the rectifier is such that the third form of selenium is produced.

Fig. 3.3 shows a selenium rectifier element. Comparing this with Fig. 3.1 (*b*), the poor conductor is the nickel plated steel, the selenium layer forms the semi-conductor and the barrier layer is formed at the surface of the selenium which is in contact with the alloy counter-electrode which is the good conductor. In the manufacture of the disc element, the whole face is covered by the counter-electrode with the exception of a narrow ring at the periphery and centre which is covered with an insulating varnish. The central hole is provided for mounting the elements on an insulating spindle and Fig. 3.4 shows a typical rectifier unit made up from a number of rectifier elements.

Several methods of assembly have been used but the one illustrated is the one most favoured. A metal washer, usually of brass, makes contact with the back of each disc while a second metal washer makes contact with the sprayed metal counter-electrode. Referring to Fig. 3.3, the centre ring of selenium which is insulated from the sprayed metal by a coat of varnish is the annular area where the pressure is exerted in the assembly by the washers, when the nuts are tightened. From Fig. 3.4 it will be seen that the electrical connexions are made to the unit by means of tags inserted between the contact washers.

In this type of rectifier assembly the electrical characteristics are not affected by the degree to which the nuts on the ends of the centre spindle are tightened and this type of rectifier can be taken to pieces and re-assembled without its operation being affected in any way.

The selenium rectifier can be worked at quite high temperatures so that cooling fins are generally unnecessary and it is therefore particularly suitable for use in tropical climates.

Electrical Properties. The electrical properties of rectifiers can be varied considerably at the will of the manufacturers but those described below are typical of those found most generally useful. The resistance of a metal rectifier in either the forward or the reverse direction is dependent on the applied voltage. In addition, the resistance varies with temperature and age of the rectifier. Fig. 3.5 (*a*) gives typical voltage/current characteristics of a

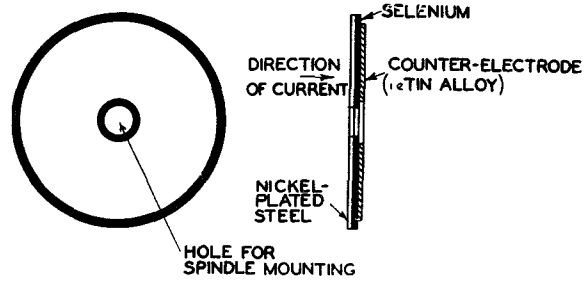


FIG. 3.3. A SELENIUM DISC ELEMENT

copper oxide rectifier at various temperatures and this should be compared with Fig. 3.5 (*b*) which gives a similar family of curves for a typical selenium rectifier. In both cases it will be evident that the resistance in the reverse direction is very high and that it reduces with increase of reverse voltage and of temperature. In the copper-oxide rectifier element it may be considered to pass appreciable reverse current above 8 V per element, whilst the corresponding value for the selenium rectifier is about 18 V per element. For higher

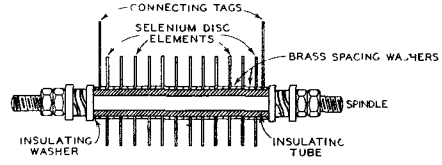


FIG. 3.4. TYPICAL CONSTRUCTION OF SELENIUM RECTIFIER

voltages it is therefore necessary to use two or more elements in series.

In practice, periodical routine tests are made to ensure that the rectifiers delivering direct current to telegraph apparatus are functioning at their correct values and any changes due to ageing, etc., can be corrected by adjustment of the applied voltage by means of tap changes on the mains transformer.

Applications of Metal Rectifiers. There are numerous applications of metal rectifiers in telegraphy. For example, they are employed extensively for deriving direct current supplies from a.c. mains for the purpose of driving the motors of

telegraph instruments and other machinery and also for providing signalling supplies. They are also used for polarizing the operation of relays and in modulator and demodulator devices employed in carrier current telegraphy.

Full details of the various modern applications of rectifiers in telegraphy are included in later chapters.

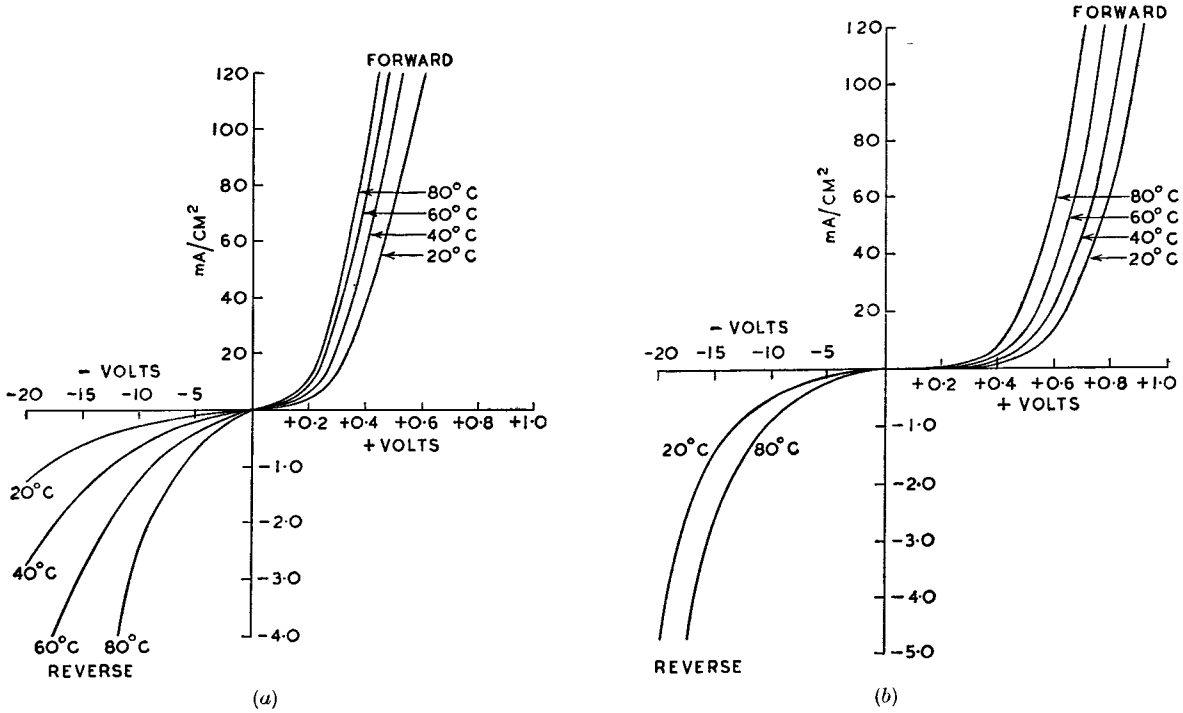


FIG. 3.5. VOLTAGE/CURRENT CHARACTERISTICS OF METAL RECTIFIERS
(*a*) Copper Oxide Rectifier (*b*) Selenium Rectifier

Thermionic Valves

The molecules of a body are in a continual state of motion at all temperatures other than at absolute zero (— 273°C) and as the temperature is progressively increased this motion increases until at a certain temperature, which varies for different materials, the molecules are thrown off from the surface and *evaporation* is said to occur. In a similar manner free electrons in a conductor can be caused to escape from the surface of the material at very high temperatures and the operation of thermionic valves depends on this phenomenon, which is called *thermionic emission*. An essential requirement if a heated electrode is to be employed as a source of electrons is that it must be enclosed in an evacuated envelope otherwise oxidation of the emitting surface will occur. Furthermore, if air, or any other gas, were present ionization would occur due to collisions between the emitted electrons and the molecules of the gas and this would produce undesired results.

If the heated body is situated in a vacuum, then, as an electron escapes, the body is left positively charged and the electrostatic field so formed tends to draw the electron back to the body. The greater the number of electrons escaping the greater is the force urging them to return, and, at any given temperature, equilibrium is established when the number of electrons leaving and returning to the body are equal. Under these conditions the electrons form a sort of cloud, known as the "space charge," round the heated body and there is a constant interchange of electrons between them.

If now a cold non-emitting conductor is brought close to the emitting surface, which is assumed to be still in the vacuum, and is maintained at a positive potential with respect to the latter, it will exert a force of attraction on the electrons and therefore oppose the force urging the electrons to return to the cathode. If the potential of the non-emitting conductor is sufficient there will be a continuous flow of electrons from the emitting

surface to the non-emitting conductor thus constituting a current of electricity. If the non-emitting conductor is maintained at a negative potential, it will repel the electrons emitted by the hot body and no current will flow. Thus such a system has uni-directional conducting properties: hence the term "valve."

The hot emitting body is called the "cathode" as it is the electrode by which the current leaves the evacuated tube, and the non-emitting cold plate is called the "anode." A valve consisting only of an anode and a cathode is called a "diode," and this is the most elementary type of valve. Rectification of high-frequency alternating currents in radio telegraphy was the first practical use to which this valve was put.

When a positive potential is maintained on the anode then as the potential is increased the current flow increases until the anode collects all the electrons as fast as they are being shot from the cathode. Increase in the potential above this value does not result in a corresponding increase in the current, which is termed the "saturation current." Typical curves showing the relation between anode potential and current are given in Fig. 3.6 for various values of cathode temperature. These curves indicate the saturation current effect and show how the saturation current is increased by higher values of cathode temperature.

The cathode of a thermionic valve can be either *directly heated*, in which case it consists of a metallic filament which is heated by the passage of a direct or alternating current through it, or it may be *indirectly heated* by making it in the form of a cylinder embracing a heater wire through which a current passes. In the latter case the cathode is electrically insulated from the heater but is constructed in a manner which permits easy transfer of heat from the heater to the cathode. The importance of designing for good thermal conductivity tends to lead to some fragility and weakness in the insulation and so in order to reduce the risk of insulation breakdown between heater and cathode the maximum permissible voltage between them is normally limited in small valves to the order of 100 V. The indirectly-heated cathode takes longer to reach its operating temperature after first switching on the power than a directly-heated cathode, but this is no great disadvantage in most forms of equipment. Moreover, the heat stored in the heater-cathode assembly has the advantage that the cathode after warming up is maintained at a constant temperature when a.c. is used for the heater, whereas the temperature, and hence the emission, of a directly-heated filament fluctuates at twice the a.c. supply frequency. It should also be noted that as the cathode of an indirectly-heated valve is insulated from the heater, the whole of the cathode is at the same potential, and this offers greater flexibility in circuit design in the use of such valves since they may be operated from a common heater supply and their cathodes can be connected in any desired manner in their respective circuits without mutual interaction.

Cathodes in directly-heated valves were originally made from tungsten wire, either pure or containing about 1 per cent of thorium oxide. It was later found, however, that certain oxides produced a more copious supply of electrons at lower operating temperatures than tungsten and thus were more economical in heater current. As a result, most modern valves, except high-power radio transmitting valves, have oxide-coated cathodes. Directly-heated valves of this type employ a wire filament of either nickel, tungsten or nickel alloy, coated with barium, strontium or calcium oxides. Indirectly-heated valves have a cathode consisting of an oxide-coated nickel tube inside which, and insulated from it, is a tungsten wire heater in the form of a bent hairpin.

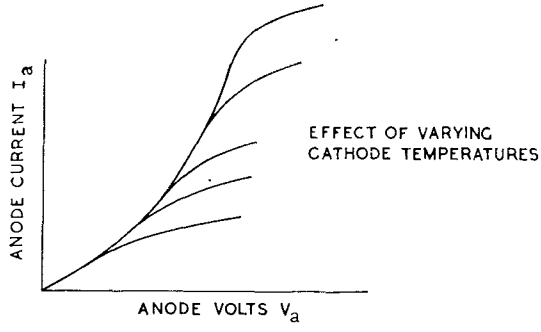


FIG. 3.6. ANODE CURRENT/ANODE VOLTAGE CHARACTERISTIC OF A DIODE VALVE

The Three-electrode Valve (Triode). The addition of a third electrode in the form of a "grid" situated between the cathode and anode, enormously increases the usefulness of the thermionic valve. By virtue of its position, the grid may be caused to exercise an electrostatic control over the stream of electrons passing from the cathode to the anode. The extent of this control is dependent upon the magnitude and polarity of the grid voltage with respect to the cathode and, since the grid is between the cathode and the anode, the change of grid potential required to produce a given change of anode current is less than the change of anode potential required to produce a similar change in anode current. Hence the valve may be used as an

amplifier. Such an amplifier is represented diagrammatically in Fig. 3.7 and comprises two circuits, the grid and anode circuits, associated and mutually dependent.

The relation between grid and anode potentials and anode currents, i.e. the characteristic of a triode, can most conveniently be shown graphically, on account of the multitude of factors affecting the emission and passage of the electrons. They can, however, be expressed approximately in mathematical terms in the same way as one characteristic

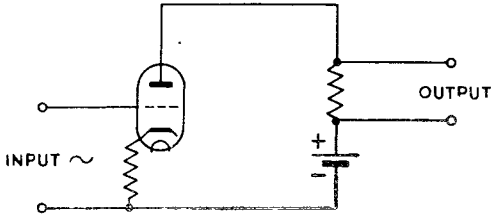


FIG. 3.7. PRINCIPLE OF A VALVE AMPLIFIER

of a resistor, namely, Ohm's Law can be expressed either as $V = IR$, or as a straight line graph (Fig. 3.8).

The characteristics of a typical triode are shown in Fig. 3.9 (*a*) showing the relation between grid potential and anode current (in mA) for various values of anode potential, and (*b*) showing the relation between anode current (in mA) and anode potential for various values of grid potential. Both sets of curves are obtained from the same data and, in fact, contain the same information in different

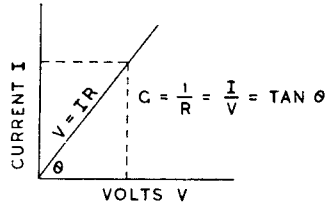


FIG. 3.8. CONDUCTANCE OF A RESISTOR

forms. The grid and anode potentials are given with reference to the negative end of the cathode as being at zero potential.

From these curves the following parameters can be deduced, namely, internal impedance, amplification factor and mutual conductance.

Internal Impedance (R_a). The conductance (G) of a resistor (Fig. 3.8) is given by the slope of the line showing the relation between I and V and is equal to the tangent of the angle θ. In a similar manner a measure of the conductance of a valve under given conditions may be deduced from Fig. 3.9 (*b*) but, unlike the conductance of a pure resistor, it will obviously be a variable quantity, its value being the rate of change of anode current with respect to the anode voltage, for a constant grid

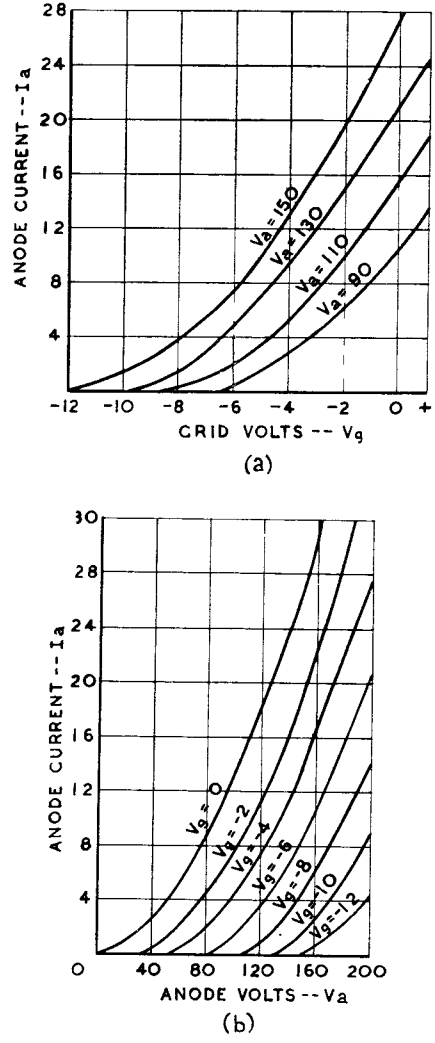


FIG. 3.9. CHARACTERISTICS OF A TRIODE VALVE
(*a*) Relationship between grid potential and anode current
(*b*) Relationship between anode current and anode potential

voltage. This ratio is reasonably constant for values where the valve characteristic is fairly straight. The reciprocal of this ratio i.e. $\frac{dV_a}{dI_a}$ is known as the internal impedance (R_a) and is expressed in ohms (Ω). It is also called the "anode characteristic impedance" or "a.c. resistance."

It is spoken of as an impedance, although for all practical purposes it is purely resistive at audio frequencies.

Amplification Factor (μ). The amplification factor is the ratio between the change of anode potential and the corresponding change of grid potential that will keep the anode current at a constant value. It can readily be deduced from Fig. 3.10, being the slope of the tangent to the curve and is approximately constant over a wide

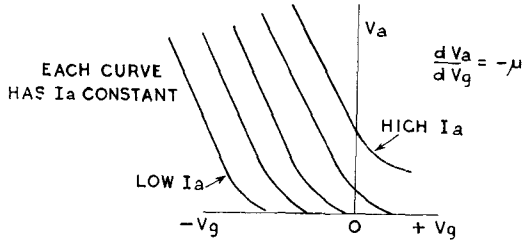


FIG. 3.10. RELATIONSHIP BETWEEN ANODE AND GRID POTENTIALS (AMPLIFICATION FACTOR)

range of conditions. It will be noticed that this slope is negative, indicating that there is a phase shift between the potential applied to the grid and the output potential.

Mutual Conductance (g). The mutual conductance is the relation between the change of anode current and the corresponding change of grid potential, whilst the anode potential is maintained at a constant value. It is expressed in mA per V.

The above three factors are connected by the following relationship—

$$\text{Mutual conductance} = \frac{\text{Amplification factor}}{\text{Internal impedance}}$$

or

$$g = \frac{\mu}{R_a}$$

Static and Dynamic Characteristics. Each of the curves given in Fig. 3.9 (a) show the relation between grid potential and anode current assuming a constant voltage to exist between the anode and the cathode. In practice, the output load is inserted in the anode circuit (see Fig. 3.7) and the anode supply voltage is assumed to be of constant value. On account of the varying anode current and, in consequence, the variable drop of potential in the load, the anode potential also varies. Where the load is purely resistive, curves showing the characteristics of the combined valve and load can readily be deduced from those already given and are shown in Fig. 3.11. It will be observed that these curves become considerably straighter when the value of the load resistance R approaches that of the internal impedance of the valve.

The curves are drawn from measurements made with steady potentials on the electrodes and are called the static characteristics. In practice, valves are for the most part used in alternating current circuits and the load, instead of being purely resistive, is also reactive. The behaviour of the valve under these conditions is given by what is called the dynamic characteristics. The static and dynamic characteristics are for all practical purposes the same so far as the valve is concerned, but they may differ widely when the valve and load are considered together.

Multi-electrode Valves. Additional electrodes can be inserted in a valve system for a variety of purposes and such valves are classified generally as "multi-electrode valves."

To avoid the effects of electrostatic capacitance between the electrodes of a triode, which may result in instability at radio frequencies, an additional grid is inserted between the control grid (i.e. the normal grid of the triode) and the anode. Having four electrodes, the valve is called a

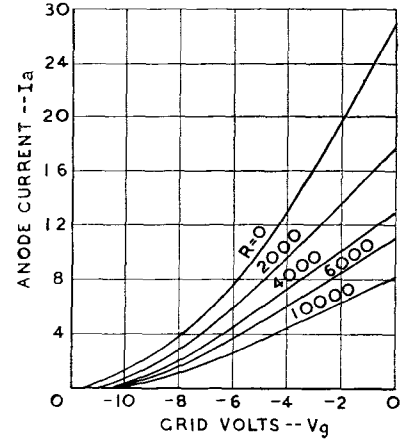


FIG. 3.11. DYNAMIC CHARACTERISTIC OF COMBINED VALVE AND LOAD

"tetrode" and the extra grid, forming a "screen" between the anode and the other two electrodes, is connected to a low impedance source of potential equal to about half the anode supply voltage. A tetrode, or a screen-grid valve, has a high amplification factor, a high internal impedance and a low anode-to-control-grid capacitance, but its power handling capacity is restricted owing to the effects of secondary electron emission from the anode.

To overcome the effects of secondary emission and the low power handling capacity of a screen-

grid valve a fifth electrode, called the "suppressor grid," is inserted between the screen grid and the anode. A valve of this type having five electrodes is called a "pentode." In respect of low anode-to-control-grid capacitance, high amplification factor and high internal impedance, the pentode has characteristics similar to those of a tetrode. Its maximum power output is higher than that of the corresponding triode.

Thermionic Valve Circuits

Amplifier. Consider the circuit shown in Fig. 3.7 with the curves shown in Fig. 3.9. The method of heating the cathode has a negligible effect on the operation of the valve and is therefore omitted. V_g and V_a are fixed voltages and, for distortionless amplification, are adjusted so that the valve is normally working on the straight portion of its characteristic. If a sinusoidal alternating voltage v is now introduced into the grid circuit, it varies the instantaneous value of the conductance of the valve. For calculation of the effect of the load impedance (Z), the conception of varying conductance is inconvenient and, for small values of v the valve can be shown to be equivalent to a generator of voltage $-\mu v$ (μ being the amplification factor of the valve), having an internal resistance equal to the internal resistance R_a of the valve. The alternating voltage E appearing across the load is therefore given by $E = \dfrac{-\mu v Z}{R_a + Z}$, the negative sign indicating the phase change between output and input voltages. The power dissipated in the load impedance is equal to $\dfrac{E^2 \cos \phi}{Z}$, which is equal to $\dfrac{\mu^2 v^2 R}{(R_a + R)^2}$ when the load impedance is purely resistive and equal to R. From the foregoing it can be shown that for maximum voltage amplification the load impedance should be as high as practicable and for the maximum power output the load impedance should be equal to the internal impedance of the valve. If the valve and load impedances are widely different, as for example in the case of a telephone line which usually has a lower impedance than an otherwise suitable amplifying valve, then a transformer of suitable ratio is inserted between them to obtain an "impedance match" and hence maximum "power transfer." The shunt impedance of the winding should generally be high compared with the load and the impedance ratio of the windings should be equal to the ratio of load impedance suitable for the valve, to that of the load to be fed.

This is the basis of all amplifier design but it must be emphasized that this consideration applies only for small voltages in the grid circuit, when the valve characteristics are practically straight for all possible resulting grid and anode voltages. Where this is not the case, due to the non-linearity of the valve characteristics, there may be considerable distortion of wave form which can, in general, be minimized by increasing the impedance of the load.

To increase the total amplification an amplifying valve may be followed by one or more further stages of amplification by the use of additional amplifying valves, and these may be coupled together in one of the three ways shown in Fig. 3.12. In multi-valve amplifiers of this type the last valve must be capable of supplying the required power without excessive distortion.

It has been shown that the voltage amplification factor, i.e. voltage gain, of an amplifier connected to a purely resistive load R is equal to

$$\alpha = \frac{E}{v} = \frac{\text{Amplifier voltage output}}{\text{Amplifier voltage input}} = \frac{-\mu v \dfrac{R}{R_a + R}}{v} = \frac{-\mu R}{R_a + R}$$

From this it will be seen that the gain increases as R increases; also the gain is independent of frequency. For a large output, however, a relatively high anode battery voltage is required and this is not always convenient in practice. To reduce the anode voltage required, choke coupling or transformer coupling may be employed. Chokes and transformers, however, have frequency characteristics, their impedance being less at low than at high frequencies. The amplification factor, therefore, rises with frequency but is liable to fall off at higher frequencies owing to self-capacitance of the windings. Where high fidelity of amplification is of prime importance the resistance-capacity coupling arrangement of Fig. 3.12 (*a*) is therefore to be preferred. Fig. 3.13 shows some typical curves of amplifier gain, at various frequencies, for each of the methods of coupling. The peaks in the curves for the choke and transformer coupling are due to circuit resonances.

In modern telegraphy extensive use is made of alternating current signalling methods and, as a result, the valve amplifier is a basic tool of present-day telegraph practice. The multi-channel voice-frequency telegraph systems employed on the majority of land-line telegraph routes in the U.K., and on short submarine cables to the Continent of Europe, operate over standard types of telephone circuit, both audio and carrier, and these are dependent for their operation upon the use of valve amplifiers. These amplifiers are required to

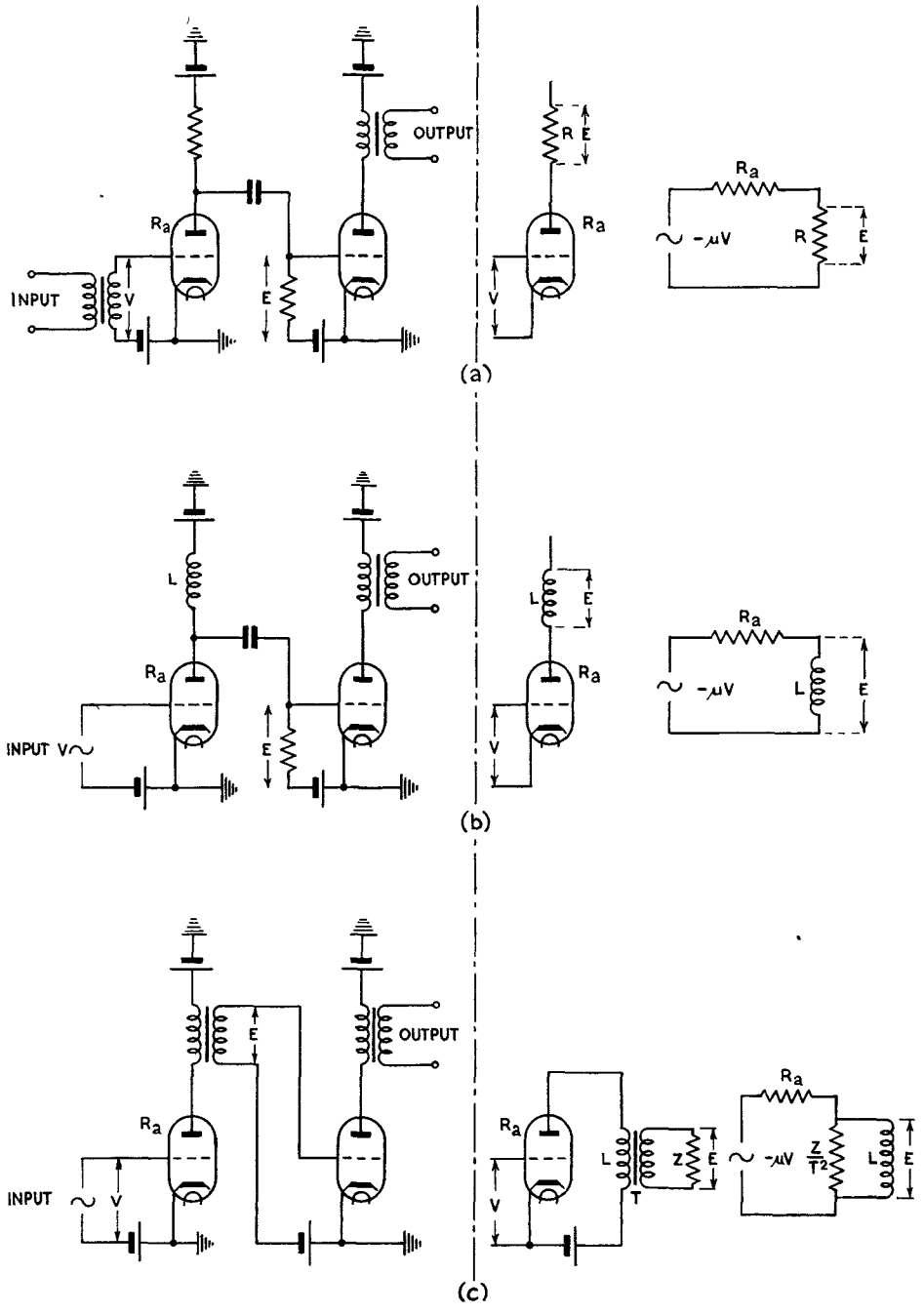


FIG. 3.12. COUPLING OF VALVES IN MULTI-STAGE AMPLIFIERS

(*a*) Resistance-capacity coupling (*b*) Choke coupling (*c*) Transformer coupling

operate with minimum distortion and to have a high degree of stability over long periods without undue maintenance attention and this is a problem on long circuits in which a large number of amplifiers is required. In this respect circuits routed in telephone carrier and co-axial systems present a greater problem as, due to the very great attenuation of the very high frequencies employed in the lines, it is necessary to increase correspondingly

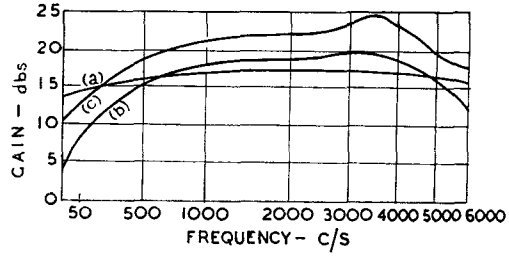


FIG. 3.13. VARIATION OF AMPLIFIER GAIN WITH FREQUENCY

(*a*) Resistance-capacity coupling
(*b*) Choke coupling
(*c*) Transformer coupling

the number of amplifiers to be inserted.* For such systems the negative feedback amplifier is commonly used.

Negative Feedback Amplifiers. If an amplifier is so arranged that a fraction of the output voltage is fed back and injected into the input circuit in phase opposition to the incoming signal voltage, then it is said to be operating with negative feedback. Clearly, with such an arrangement, the net voltage applied to the grid of the amplifying valve at any instant is the difference between the voltage of the input signal and that of the voltage fed back from the output. Fig. 3.14 indicates the basic principle employed in a negative feedback amplifier.

α represents the ratio of the output to the input voltage of the amplifier without feedback. β is the proportion of the output voltage which is fed back to the input circuit across resistor R. v is the incoming signal voltage and e is the resultant voltage applied to the grid of the amplifying valve.

Now in this case, $\alpha = \dfrac{-\mu Z}{R_a + Z} = \dfrac{E}{e}$, the negative sign indicating that a phase change of 180° has taken place within the valve itself. Thus $E = \alpha e$ and the voltage fed back is $\beta E = \beta\alpha e$.

* Typical repeater station spacings are—
(*a*) for audio type circuits, 50 miles;
(*b*) for carrier type systems, 22 miles;
(*c*) for co-axial type systems, 6 miles.

In any feedback circuit, the voltage (e) applied to the grid is the vector sum of the input signal voltage (v) and that fed back ($\beta\alpha e$), therefore

$$e = v + \beta\alpha e$$

For negative feedback, the product $\alpha\beta$ is negative, indicating phase opposition between the input signal voltage (v) and that fed back ($\beta\alpha e$). Hence we can write $e = v - (\beta\alpha)e$
so that

$$v = e + (\beta\alpha)e = e[1 + \beta\alpha]$$

Therefore the overall gain of the amplifier is given by

$$\frac{E}{v} = \frac{\alpha e}{e(1 + \beta\alpha)} = \frac{\alpha}{1 + \beta\alpha}$$

In practice $\beta\alpha$ is made much greater than unity and with this condition the overall gain of the amplifier is approximately

$$\frac{E}{v} = \frac{\alpha}{\beta\alpha} = \frac{1}{\beta}$$

From this approximate formula it will be seen that with negative feedback the overall gain of the amplifier is substantially independent of the amplifier characteristics and therefore a high stability of gain may be obtained from the use of negative feedback, despite variations in the supply voltage and ageing of the valves in service. This offers enormous operating and maintenance advantages.

The three basic methods employed for application of negative feedback are illustrated in Fig. 3.15 and comprise (*a*) parallel or voltage feedback, (*b*) series or current feedback, and (*c*) bridge feedback.

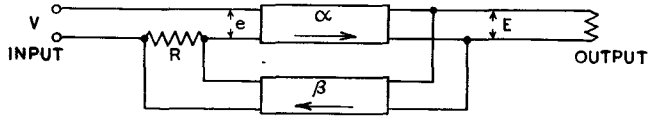


FIG. 3.14. PRINCIPLE OF NEGATIVE FEEDBACK

Since the vector relation between the voltage on the grid of a valve and that of the output are already 180° out of phase, it is possible to apply negative feedback by resistive components only, so that no phase change is necessary in the β path.

Push-pull Amplifiers. A push-pull amplifier employs two matched valves connected by means of special centre-tapped transformers as shown in Fig. 3.16.

When an incoming a.c. signal is applied to the primary of the input transformer a corresponding alternating voltage is produced between points A

and B of the secondary winding. Since the secondary winding is accurately centre-tapped, the alternating voltage produced between A and E is always equal and opposite to that produced between B and E and these are applied between the grids and cathodes of the two valves.

When no signal is being received equal and constant anode currents flow in each valve. Hence there is no resultant flux and consequently no magnetization of the transformer core occurs; this feature is advantageous in preventing distortion of the wave form during the transmission of signals.

When a signal is being received equal but opposite grid voltages are applied to the two valves and in consequence the resulting variations in the anode circuits in the two valves will be equal but opposite, provided that the valves have identical characteristics and also provided that the grid swings do not extend beyond the straight portions of the dynamic characteristics of the valves and that grid current is not allowed to flow. The varying anode currents will produce alternating potentials across the two halves of the output transformer winding from C to K and from D to K and these will be equal in magnitude but opposite

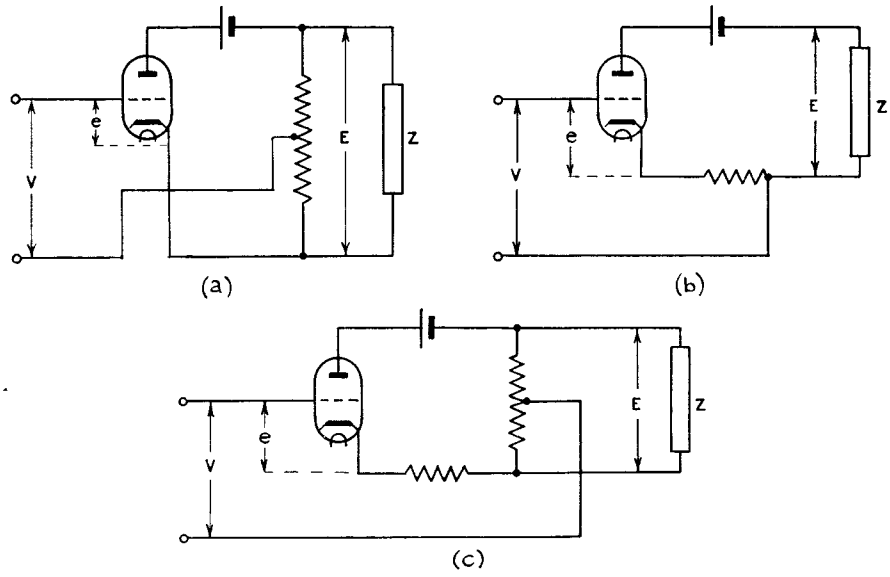


FIG. 3.15. METHODS OF APPLYING NEGATIVE FEEDBACK
(*a*) Parallel or voltage feedback (*b*) Series or current feedback (*c*) Bridge feedback

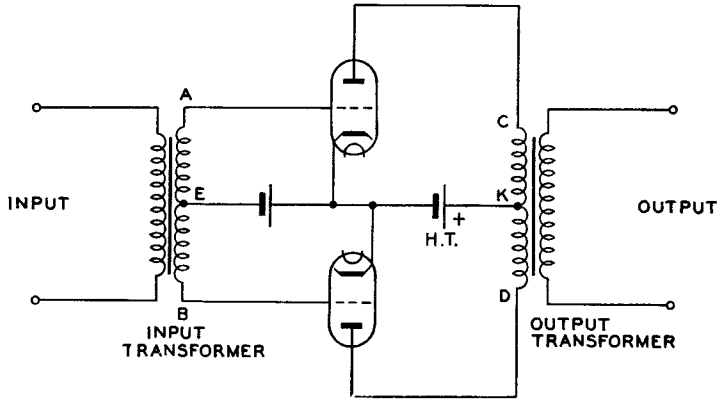


FIG. 3.16. PRINCIPLE OF PUSH-PULL AMPLIFIER

in phase, i.e. 180° out of phase. Hence the alternating potential from C to D will be the sum of the voltages between C to K and K to D. These are additive and therefore the alternating current in the two halves of the winding is equivalent to an alternating current of the same value throughout

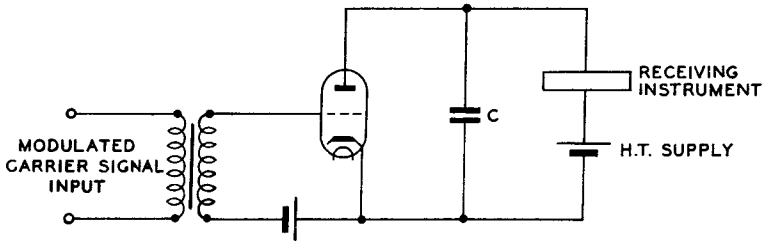


FIG. 3.17. PRINCIPLE OF ANODE-BEND DETECTOR

the transformer winding. It is important to note that, on the other hand, the alternating components of the two anode currents flowing through the H.T. battery to the transformer centre-tap are equal and opposite, so cancelling each other out; hence no resultant alternating current component flows in this lead and the possibility of back coupling to earlier stages is thereby reduced. The alternating current flowing in the primary winding CD of the output transformer will produce a corresponding voltage across the secondary output. As only half the total input voltage is applied between grid and cathode of each valve, the push-pull arrangement is capable of handling twice the input voltage that either valve could deal with singly. It therefore enables a greater output with lower distortion to be obtained than could be achieved with a single valve and is particularly useful in the final stages of audio-frequency amplifiers where the input voltage is high.

A further important advantage of the push-pull arrangement is in its reduction of the even harmonics produced by the non-linearity of the characteristics of the amplifying valves and this is of particular value in telegraphy, as the presence of even harmonics of a fundamental signal frequency produces an asymmetrical wave shape which detracts from the desired sharp build-up of the telegraph signal.

Detectors. The process of detection, i.e. demodulation, is essentially one of rectification and is the process by which the positive and negative half-waves of a modulated carrier signal are unequally attenuated or amplified to enable the modulating signal of the carrier to be detected for operation of the receiving instrument. It follows therefore that a detector must be a device having a non-linear characteristic and a valve under suitable conditions is eminently suited for this purpose.

There are two main methods of using a valve as a detector depending upon whether (*a*) the non-linearity of the anode current/grid voltage characteristic is utilized, or (*b*) the non-linearity of the grid current/grid voltage characteristic is utilized. In the former case, called anode-bend detection, the valve grid is biased to operate on either the lower or the upper bend of the curve. Lower bend detection is more commonly used and this is illustrated in Fig. 3.17.

The electrical effects which occur are indicated in Fig. 3.18.

The valve is normally biased to a point P (Fig. 3.18) in the lower bend of the characteristic. The effect of a received carrier signal is to cause the grid voltage to vary and thus in turn to vary the anode current. Due to the lower bend characteristic, however, the variations of the anode current produced by the negative half-waves of the carrier

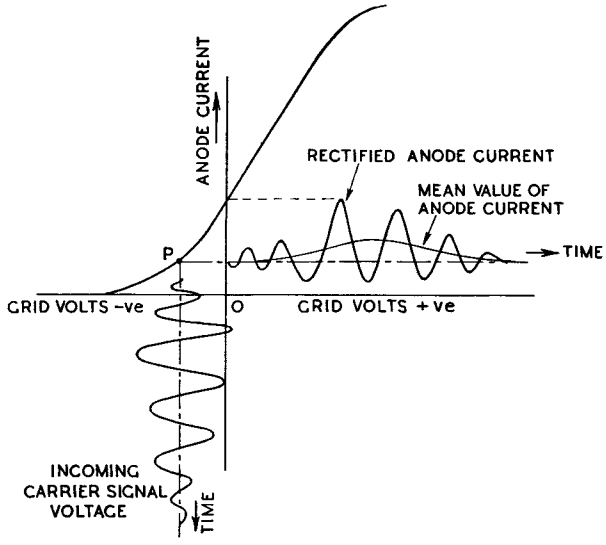


FIG. 3.18. DEMODULATION OF CARRIER SIGNAL IN LOWER-BEND ANODE DETECTOR

signal are much less than those caused by the positive half-waves. This is clearly evident in the illustration of the effect in Fig. 3.18.

Thus the *mean* anode current will vary in the manner illustrated and the anode current resulting from rectification of the incoming carrier signal may be resolved into the mean anode current and an alternating current corresponding to the

incoming carrier signal. The receiving instrument responds to the mean anode current and the capacitor C in Fig. 3.17 offers a low impedance shunt path to the receiving instrument for the carrier frequency currents. The variations in the mean anode current correspond to the modulating frequency of the carrier.

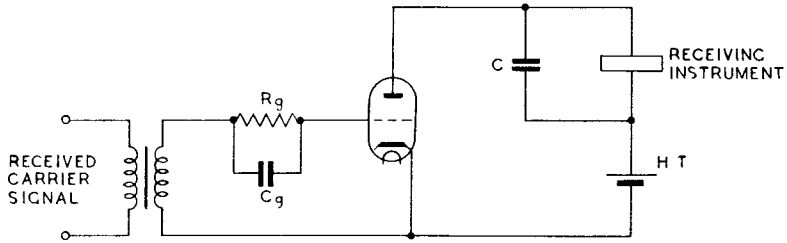


FIG. 3.19. PRINCIPLE OF LEAKY-GRID DETECTOR

For grid current detection the basic circuit arrangements employed are shown in Fig. 3.19; the grid leak resistor R_g may alternatively be connected from the grid to the cathode. The normal grid potential is zero and the arrangement may be considered as a diode detector and a triode amplifier of the rectified signal.

The electrical effects which occur in a detector of this type are illustrated in Fig. 3.20.

Fig. 3.20 (*a*) illustrates the effect of the incoming carrier signal on the flow of grid current. During each positive half-wave of carrier signal a pulse of grid current flows and the magnitude of the pulse increases as the amplitude of the signal increases. These currents cause a negative charge to be built up on the capacitor plate attached to the grid and, if no grid leak resistor R_g were present, the voltage built up across C_g would be equal to the peak value of the incoming carrier signal voltage. The presence of R_g, however, allows the charge developed across C_g to leak away partially during negative half-waves of the signal; the charge on C_g progressively increases, however, as the signal amplitude increases and then falls again as the signal amplitude is decreased. Thus the mean grid voltage varies in the manner indicated in Fig. 3.20 (*b*) and this results in a similar but amplified variation in the mean anode current. The actual anode current may be resolved into the mean anode current and an alternating component which is an amplified replica of the input signal. The receiving instrument in the detector output operates in response to the variations in the mean anode current and the capacitor C in the output circuit offers a low impedance shunt path for the carrier frequency currents. As in the anode-bend detector, the variations in the mean anode current correspond to the modulating frequency.

It is important to note that for satisfactory operation of the grid current detector it is essential that the grid capacitor should offer a low impedance to the signal carrier frequency whilst the grid leak resistor must be high, to enable the rectified voltage charge on the capacitor to be maintained during successive half-waves. The CR value of the capacitor and grid leak combination must nevertheless be chosen to ensure the requisite degree of "leak-away" during the end of the modulating cycle. These considerations limit the use of this method of detection to those cases where the carrier frequency is considerably greater than the highest modulating frequency. For this reason, anode-bend detectors are nearly always employed in voice frequency telegraph equipment. A resistor and capacitor combination is, however, often included in the grid circuit of voice frequency telegraph detectors for the purpose of providing an output which, within certain limits, is of a constant value and independent of the received signal level.

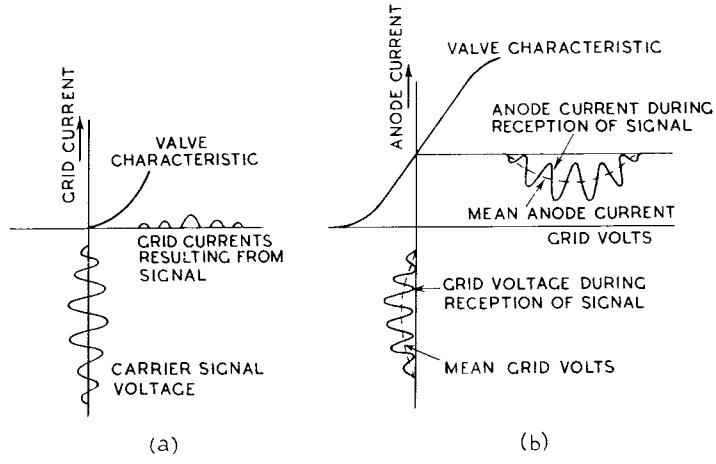


FIG. 3.20. DEMODULATION OF CARRIER SIGNAL IN LEAKY-GRID DETECTOR

(*a*) Variation of grid current
(*b*) Variation of anode current

This arrangement is frequently called a "limiter," and although in respect of constant output it is similar to automatic volume control devices, i.e. automatic gain control, the limiter causes considerable distortion of wave-form which should be absent in a true constant volume amplifier.

It operates as follows. The valve is an anode-bend detector normally biased to produce a small or negligible anode current and having a parallelled resistor and capacitor in the grid circuit. When the amplitude of the signal applied to the grid is increased from a very small value, the anode current increases in approximately the same ratio until the point is reached at which grid-cathode current flows in the grid circuit. When this occurs, the grid current charges the grid capacitor and this is equivalent to a temporary increase in the negative grid bias voltage. The valve is therefore biased back to beyond the cut-off point, i.e. the point corresponding to no anode current, and therefore part of each positive half-wave of signal is ineffective in producing anode current. Moreover, the temporary negative grid bias voltage increases as the amplitude of the signal is increased, until only the peak of the wave is producing grid current to maintain the charge on the grid capacitor. Under these conditions the anode current varies for each positive half-wave of the signal from zero to approximately that produced at zero grid potential and is therefore independent of the amplitude of the applied signal. Thus for any signal amplitude above a certain minimum, i.e. that amplitude required to produce grid current, the output of the detector is approximately constant.

This property is extremely useful in voice frequency telegraph receivers having a telegraph relay in the valve anode circuit, for it enables the relay to operate under constant conditions despite line variations and the consequent changes which occur in the level of the received signal. Practically all telegraph receivers employ limiters operating on these principles, although there may be certain differences in circuit details.

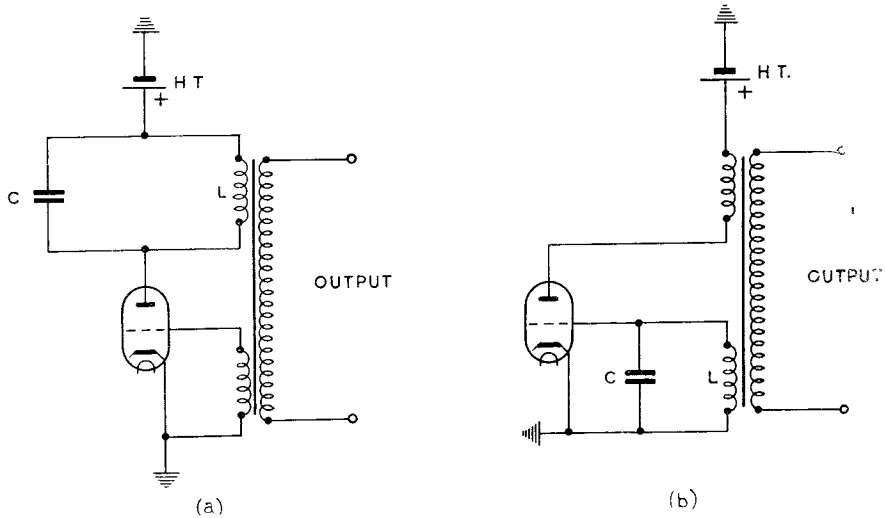


FIG. 3.21. BASIC OSCILLATOR CIRCUITS
(*a*) Tuned-anode oscillator (*b*) Tuned-grid oscillator

Valve Oscillators. A valve oscillator is a device employed for generating an alternating e.m.f. In telegraphy, oscillators are employed for several purposes as, for example, the generation of carrier frequencies for voice frequency telegraph transmission and for transmission testing and measuring devices. Usually a sinusoidal wave form is desired but, for certain special applications, other wave forms rich in harmonics are required, and the saw-toothed oscillator (so called because of the nature of its wave form) is an example of this type which is commonly employed for providing a time base on a cathode ray tube.

Fig. 3.21 (*a*) and (*b*) indicate two elementary forms of valve oscillator employing tuned-anode and tuned-grid respectively.

The grid and anode circuits are coupled together by two windings on a transformer and a third winding provides the oscillator output. The action of the circuit is due to the reaction, i.e. positive

feed-back between the anode and grid windings. The directions of the windings are so arranged that a slight increase in anode current induces an e.m.f. in the grid circuit which reinforces the increase and this continues until, owing to grid current, the increasing grid potential fails to increase the anode current. The e.m.f. in the grid circuit therefore collapses and the die-away is reinforced by the feedback circuit until the curvature of the valve characteristic prevents further reduction of anode current. The drop in grid potential is then arrested and the feed-back again begins to increase the grid potential to repeat the process. The frequency of oscillations produced is very nearly the resonance of the oscillatory circuit and is given by the formula

$$f \simeq \frac{1}{2\pi\sqrt{LC}}$$

Alternating current of almost any frequency can therefore be generated by using suitable values of inductance and capacitance and a variable oscillator may be obtained by making C variable. The circuits shown in Fig. 3.21 are basic oscillator circuits and, although most oscillators in general use are more elaborate, to ensure constancy of frequency and output, the principles of operation are the same.

Feedback from the anode to the grid circuit sometimes occurs unintentionally in amplifiers and results in either actual oscillation or, when it is less severe, instability and irregularities in amplification.

Where accuracy of the frequency of an oscillator is an important factor it is necessary to ensure that overloading does not occur and modern practice in such cases is to employ a low power oscillator followed by one or more stages of amplification. Temperature variations will affect the L and C components of an oscillator and therefore cause a change in frequency. For this reason, much research and development work has been devoted to produce components having a very small temperature coefficient. In cases where a very high degree of accuracy is essential the oscillator is enclosed in a temperature-controlled cabinet and is thus not subjected to the effects of changes in the ambient temperature.

Quartz Crystal-controlled Oscillators. There are many crystalline substances which produce an electromotive force when the crystal is subjected to mechanical stress, owing to electrical asymmetry within the atomic groups of which the crystal is built up. Crystals which exhibit this phenomenon are known as "piezo-electric" and quartz is the best known and most widely used. The piezo-electric effect is also reversible, that is to say the application of an electric field to a piezo-electric crystal will produce a mechanical strain in the crystal.

All elastic materials can be made to vibrate, and the natural frequency of vibration of a given specimen will depend upon its dimensions and its mode of vibration. Thus, if a piezo-electric element is placed in an alternating electric field it will be forced into mechanical vibration at the frequency of the applied field. If this frequency is adjusted to coincide with the natural vibration frequency of the element, a large increase in its amplitude of vibration will occur because the driving force is in phase with the natural frequency of vibration of the element. If a suitable piece of piezo-electric material be set in vibration by an impulsive force it will continue to vibrate, in the absence of further interference, at its own natural frequency but with gradually diminishing amplitude. During these periodic vibrations the displacement will give rise to electric charges on the crystal surfaces, of sign and magnitude proportional to the amplitude of the vibration. Suppose now that the element, provided with metal electrodes necessary for the application of the electric force, is connected between the grid and cathode of a thermionic valve. The alternating potential produced by the vibration will be amplified and will produce larger voltage variations of the same frequency in the anode circuit. If these are fed back to the element to reinforce the original variations of potential, they will also reinforce the vibration which will continue so long as the circuit is connected.

One method of feeding back the anode potential variations is through a small anode-grid capacitor, although in most cases a sufficient feedback path exists in the form of inter-electrode capacitance. Other circuit connexions may be used but there must be a feedback path via the piezo-electric element between an amplifier input and its output. and the voltage variations fed back must be appropriately phased with regard to the original vibration. The circuit of Fig. 3.22 is one of the simplest forms of crystal-controlled oscillator employing quartz crystal elements. The output power from such an oscillator is low and it is usual to add one or more stages of amplification.

In any type of quartz crystal-controlled oscillator, the frequency of oscillation is determined primarily by the natural vibration period of the selected quartz element, the effects of circuit and supply changes being small. Quartz is an extremely stable substance; the frictional losses in vibration are small and special types of quartz vibrator possess almost zero frequency-temperature coefficients of vibration. In consequence of these

factors, frequency stabilities are achievable with quartz control of an order (i.e. 1 part in 10^8) which cannot be approached with valve oscillators employing coil and capacitor elements alone.

Quartz crystal-controlled oscillators are available in the range 0·4 kc/s to 100 Mc/s and this range can be extended upwards or downwards by frequency multiplication or division. The principal uses of quartz crystal-controlled oscillators are for the control of radio transmitters operating in the frequency range 16 kc/s to 200 Mc/s; master oscillators for co-axial telephone cable systems; generation of the synchronizing signal at 1 kc/s for 12-channel carrier telephone systems; and the provision of a primary standard of frequency for reference and calibration of other oscillators.

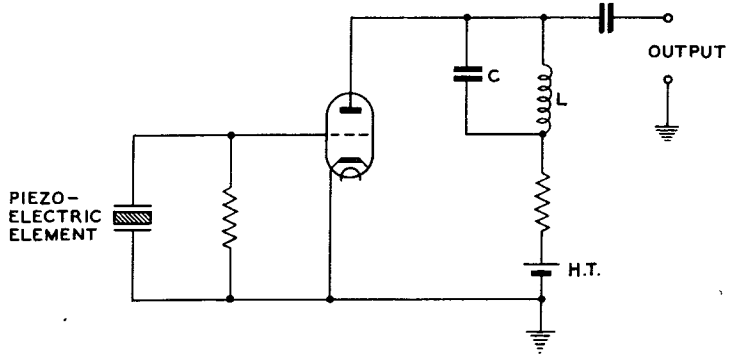


FIG. 3.22. PRINCIPLE OF CRYSTAL-CONTROLLED OSCILLATOR

Tuning-fork Controlled Oscillators. The tines of a tuning fork vibrate at a frequency determined by their physical dimensions and mass and the elasticity of the material employed. If one tine is caused to vibrate, the other will vibrate in sympathy and, providing the amplitude is small, the periodicity of vibration of the tines is the natural frequency of vibration for the fork. If such a fork is accurately made and constructed from a material having a very small temperature coefficient, e.g. Elinvar, it will have a highly stable frequency over a fair range of ambient temperature conditions. The amplitude of vibrations of a fork will normally decay due to the damping effect caused by air resistance and molecular friction in the fork. The vibrations can, however, be sustained if the fork is supported with its tines in an alternating magnetic field excited from an alternating current whose frequency is equal to that of the natural frequency of the fork.

This phenomenon is employed in a tuning fork oscillator and Fig. 3.23 indicates the principle of operation.

The tuning fork is mounted, as shown, with the tines between the poles of a polarizing permanent magnet and having a drive coil and a pick-up coil wound on the magnet poles and connected in the anode and grid circuits respectively of a valve. When the fork is caused to vibrate, an alternating e.m.f. is induced in the pick-up coil and the resulting alternating current component in the anode circuit, acting through the drive coil, sustains the fork in constant vibration at a frequency which is almost equal to the natural frequency of the fork. Hence the resulting oscillator output frequency is nearly equal to the natural frequency of vibration of the fork and is largely independent of any changes in the electrical components in the valve circuit. This type of oscillator is suitable for generating low frequencies and is extremely reliable. It is often used in telegraphy for speed control of certain types of synchronous telegraph instruments and also for testing purposes.

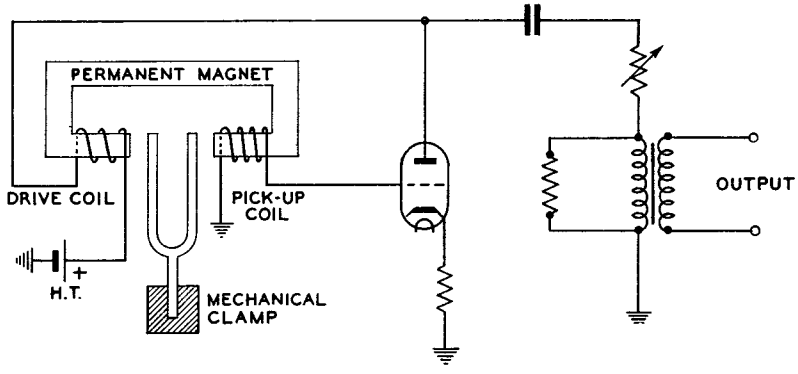


FIG. 3.23. PRINCIPLE OF TUNING-FORK OSCILLATOR

Thyratron. A thyratron is similar in construction to a triode thermionic valve but is filled with mercury vapour or an inert gas at low pressure. The grid does not control the anode current as in an ordinary triode but if its potential is more negative than a certain critical value, known as the "striking voltage," it prevents the passage of electrons from the cathode to the anode and so there is no anode

current. As the grid potential is increased it permits a small anode current to flow and eventually this is sufficient to ionize the gas or vapour. The positive ions neutralize the charge on the grid and the anode current immediately rises to a value, and in a manner, determined almost entirely by the anode supply voltage and the external circuit conditions. Apart from a constant voltage drop across the valve of about 14 V, the action is similar to that of a relay, and large amounts of power can be controlled. A thyratron rated at 0·5 A, 300 to 400 V, is about the same size as a vacuum type valve capable of delivering only 1 W.

The grid control is in one direction only: the anode current once started is no longer dependent on the grid circuit conditions and to stop the discharge it is necessary in nearly every case to interrupt the anode circuit or otherwise reduce the anode potential to zero. In certain small thyratrons the discharge, if it is of the order of a few mA only, can be stopped by applying a large negative potential to the grid. The extinguishing grid voltage is, however, uncertain and depends largely on the anode circuit conditions.

The striking voltage is fairly constant for a given anode voltage but it depends slightly on temperature, which affects the vapour pressure. More consistent results are obtained from thyratrons filled with argon or helium instead of mercury vapour.

Cold-cathode Glow-discharge Tubes

These tubes comprise two or more electrodes in an envelope filled with a gas, or mixture of gases, at low pressure (of the order of 40 mm Hg). The usual gases employed are neon, helium and argon.

In the simplest form, i.e. the two-electrode tube, the cathode is usually considerably larger in area than the anode and is sometimes coated with potassium or barium. The gas in the tube is always ionized to a slight degree by the effects of cosmic rays, photo-electric emission from the cathode (particularly if coated) and minute traces of radioactive substance in the materials. A small potential applied between the electrodes will cause a current, i.e. "the dark-current," of the order of 1 μA to flow, the free electrons passing to the anode and the positive ions, at a much lower velocity, to the cathode. If the potential difference is increased, the velocity of the ions increases, so that the electrons ionize more molecules by collision and the greater number of positive ions at higher velocity strike the cathode and release more electrons. This process goes on until ultimately, when a critical potential is attained, the current increases independently of the potential and the tube glows. In practice, the current must be limited by an external resistance to prevent the glow-discharge becoming an arc which would result in rapid destruction of the tube.

As the current is increased above the value at which the glow is just maintained, by increasing the p.d. applied to the combination of tube and resistance, or decreasing the resistance, the potential across the tube at first decreases. It then increases very slightly until the whole of the cathode is covered with glow, whereafter a substantial increase of current can be achieved only by increasing the applied p.d. at a greater rate. The increasing bombardment of the cathode by positive ions raises its temperature and eventually results in thermionic emission, leading to the establishment of an arc and destruction of the cathode. Such tubes are therefore operated only in the glow-discharge region.

The relative constancy of the potential drop across the tube in the glow-discharge region (even above the current at which the glow first covers the cathode) over a range of current provides the characteristic which makes such tubes useful as voltage stabilizers. Tubes with running potentials ranging from about 50 V to 150 V and maximum current-carrying capacity of from 8 to 200 mA are manufactured. The striking potential is usually between 15 and 50 V greater than the running value. The different characteristics are obtained by variation of electrode size and spacing and by variations in the composition and pressure of the gas filling.

Specially constructed glow-discharge tubes which enhance the effect of variation in glow intensity with variation of current have been used for facsimile recording.

The range of usefulness of glow-discharge tubes can be increased by the addition of other electrodes. The three-electrode tube is finding increasing application as a switching element. The third electrode, known as an auxiliary anode or priming electrode, is set much closer to the cathode than is the main anode so that the striking potential of the priming gap is considerably lower than that of the main gap. When the priming gap is rendered conductive by a potential pulse of suitable magnitude, the ionization is sufficient to initiate conduction in the main gap, if the p.d. of this is above the running value, and the resultant current through the external resistor produces the useful output of the device. As with nearly all gas-filled valves, the quiescent condition can be restored only by reducing the anode potential to below the running value for a period sufficient to permit the gas to de-ionize. This period for most simple cold-cathode tubes is between 1 and 10 msec and places

a restriction on their circuit applications, but these are tubes with more complex electrode systems in which the effective de-ionization time may be as low as 30 μsec.

Average performance figures for a typical tube are—

Main gap self-striking potential 150 V.
Main gap running potential 72 V.
Priming gap striking potential 72 V.

Priming gap current at which transfer of conduction to main gap occurs (the supply to main gap being between 72 and 150 V) 5 μA.

Another class of cold-cathode glow-discharge tube is the multiple-cathode counter tube. One example of this class has a central disc-shaped anode surrounded by a ring of 30 wire electrodes parallel to the axis of the anode. Every third electrode is considered as a cathode and nine of them have a common connexion, the tenth having a separate lead out. The remaining 20 electrodes are connected alternately to two common connexions to form two sets of "guide" electrodes. The anode is connected through a high resistance (of the order of 1 MΩ) to a potential of between + 350 and + 400 V. Normally the common cathode lead is earthed and the one separate cathode connected to earth through a resistor. The two sets of guide electrodes are maintained generally at a positive potential of about 40 V. When the anode potential is applied, conduction is established between the anode and one of the cathodes, a glow surrounding this cathode.

If one of the guides is reduced in potential to about — 45 V, the glow discharge will transfer and if the second guide is reduced similarly in potential whilst the first is restored to its positive potential, the glow will transfer again and, when the second guide is restored to its initial potential, the glow will transfer to the nearest cathode which is the next one round the circle. Successive cycles of operation will cause the discharge to transfer completely round the tube, the position indicating the number of operations. When the glow is established on the tenth cathode, a potential difference is produced across the resistor and this indication may be used to operate a further counting device to register the number of complete cycles. Such tubes can count at a rate of about 4,000 per sec. Other varieties in the same class, working on somewhat similar principles but with different electrode assemblies, are claimed to work at a speed of 20,000 per sec.

The multiple-cathode tube can, if all cathode connexions are led out, be used as a pulse distributor.

CHAPTER 4

ELECTROMAGNETIC RELAYS—TELEPHONE AND TELEGRAPH

ELECTROMAGNETIC relays may be divided into two main classes, namely non-polarized and polarized. Telegraph relays comprise both types whilst telephone relays are usually non-polarized.

The conditions of service imposed on telegraph relays are generally more severe than those demanded from telephone relays as the former are

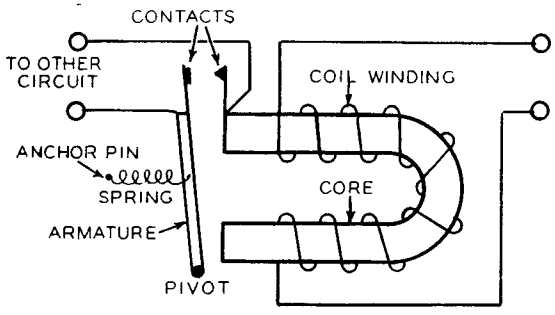


FIG. 4.1. SIMPLE ELECTROMAGNETIC RELAY

required to repeat, with negligible distortion, individual elements of the telegraph signalling code during the transmission of intelligence. Furthermore, a relay may be required to perform hundreds of thousands of operations over long periods without any readjustment being made. These exacting requirements call for a high degree of excellence in mechanical, magnetic and electrical design.

Telephone relays are required chiefly for switching purposes and for repeating single-current impulses at speeds generally much lower than those required for telegraph signalling, the conditions imposed in their operation and design are consequently less exacting than those for telegraph relays.

In modern telegraph systems both manual and automatic switching facilities are employed extensively and telephone relays form a large part of the circuit elements. Indeed it is true to say that, under switching conditions, telegraph and telephone circuits are in many respects similar in design.

The Electromagnet. A simple form of electromagnet is shown in Fig. 4.1. A coil of insulated wire is wound round a soft iron rod of horse-shoe shape called the "core." A small rectangular piece of soft iron, known as the "armature," is located near the ends of the core; the armature is pivoted and a spring normally holds it against a "stop." When an electric current is passed through the coil of wire the core becomes magnetized and attracts the armature. When the current is switched off the armature returns to its normal position under the influence of the restoring spring.

The Electromagnetic Relay. If two contacts are fitted to the electromagnet described in the last paragraph, one to the movable armature and the other in a fixed position, so that the contacts touch when the armature is attracted to the core, they can form part of another circuit (see Fig. 4.1) thus converting the electromagnet into a relay.

The foregoing explains the broad principles of the electromagnetic relay. The specific case of the telephone relay will now be considered in detail.

The Telephone Relay

If an examination is made of the various types of telephone relay, it will be found that the same principles of construction apply in practically all cases. These principles will be explained with the help of Fig. 4.2 which depicts in skeleton form a telephone relay of a popular form of construction.

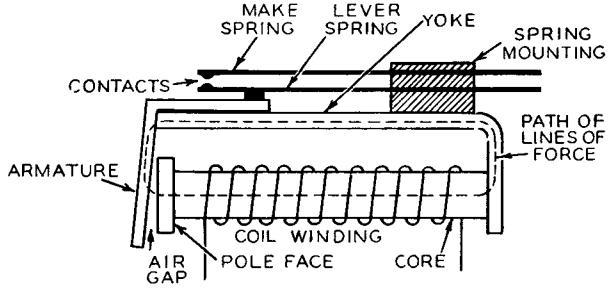


FIG. 4.2. ELEMENTS OF A TELEPHONE RELAY (B.P.O. STANDARD 3,000-TYPE)

The component parts and the generally accepted nomenclature are as follows—

(*a*) *Core*, consisting of a soft iron rod with an enlarged end; this enlarged end is called the "pole face."

(*b*) *Winding*, consisting of insulated wire wound round the core.

(*Note.* The complete assembly of core and winding is called the "coil.")

(*c*) *Yoke*, which is an L-shaped piece of soft iron attached to one end of the coil.

(*d*) *Armature*, which is an L-shaped piece of soft iron pivoted at the front end of the yoke.

(*e*) *Spring-set*, consisting of a number of flat springs carrying contacts and mounted on the yoke.

For convenience of construction and economy in space the core is made in the form of a straight bar but a magnetic circuit of horse-shoe shape is obtained by means of the yoke.

When a current flows through the winding a magnetic field is built up, most of the magnetic

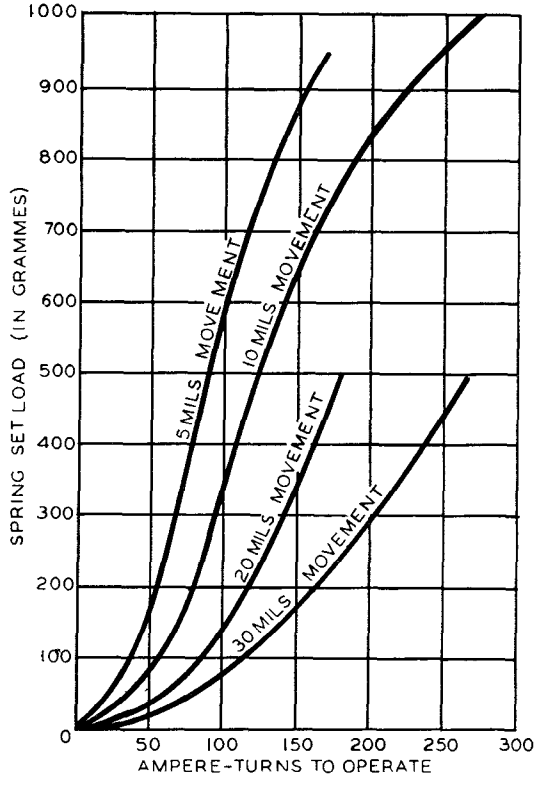


FIG. 4.3. TELEPHONE RELAY OPERATION: AMPERE-TURNS REQUIRED FOR DIFFERENT LOADS AND ARMATURE TRAVELS

lines of force (or flux) following the dotted path shown in Fig. 4.2. The armature is therefore attracted to the core, thus operating the lever spring and closing the contacts. On cessation of the current, the magnetic field collapses and the mechanical pressure of the contact springs causes the armature and contacts to resume their normal positions.

The magnetic circuit consists of the core, yoke, armature and the space, known as the "air gap," between the armature and the pole face.

To operate a relay, the current flowing in the coil must create sufficient lines of force in the magnetic circuit to produce an attraction between the armature and the pole face which is strong enough to overcome the force exerted by the contact springs. The number of lines of force produced, up to the point where the iron is becoming saturated, is proportional to

$\frac{I \cdot T}{S}$ where I is the strength of the current,
T is the number of turns of wire in the coil winding, and
S is the reluctance of the magnetic circuit, i.e. the resistance of the magnetic circuit to the creation of magnetic lines of force.

In general the product of I and T, known as the "ampere-turns," should be kept low for economic and circuit reasons; therefore S should also be kept as low as possible.

To ensure a low reluctance the following steps are taken—

(*a*) The core, yoke, and armature are made of Swedish iron and then annealed. When made in this way these components not only possess low reluctance but, under normal conditions, quickly lose practically all their flux when the magnetizing current ceases. This second point is important, as any flux that is retained when the current ceases (known as "residual flux") will retard, if not prevent, release of the armature.

(*b*) The air gap is kept short. This is important as, in the majority of relays, the air gap, however short, forms by far the greatest portion of the total reluctance of the magnetic circuit. The point is illustrated in Fig. 4.3, which shows that the number of ampere-turns required to attract the armature increases with an increase of the armature movement, which is equivalent to an increase in the air gap.

(*c*) A pole face is formed at the front end of the core. This enlarges the area of the air gap and, since reluctance is inversely proportional to the area of the gap, the reluctance is reduced.

(*d*) The anti-corrosive finish of the core, yoke and armature is thinly applied. Commercial anti-corrosive finishes all consist of materials having little or no magnetic property and the thickness of the coating on the pole face or armature is, in effect, equivalent to an increase in the air gap.

The distance through which the armature moves is known as the "stroke" or "travel" of the relay. This is always less than the air gap because if the iron armature were allowed to make metallic contact with the iron pole face a magnetic circuit of very low reluctance and comprised entirely of magnetic material would be formed. Such a circuit is termed

a "closed magnetic circuit" and has the property of retaining a considerable amount of residual magnetism after cessation of the magnetizing current. As this would prevent correct release of the armature, a "stud" or screw of non-magnetic material known as the "residual stud" or screw (shown in Figs. 4.7 (*a*) and 4.8 (*a*)) is used to keep the armature separated from the pole face when the relay is operated. The portion of the air gap which remains when the relay is operated is known as the "residual air gap."

Elementary Theory of Relay Operation

Let T = number of turns in the coil winding
A = cross sectional area of the air gap (m^2)
l = length of air gap (m) when armature is unoperated
x = residual air gap (m)
S_i = reluctance of the iron circuit
μ_0 = absolute permeability of free space $= 4\pi \cdot 10^{-7}$
μ_r = relative permeability of air = 1
F = force (newtons) exerted by the contact springs on the armature when unoperated
f = additional force (newtons) exerted by the contact springs per m of deflexion.

When a current I (amperes) flows in a relay coil it produces a magneto-motive force $(MMF) = IT$ ampere-turns.

The reluctance of the magnetic circuit

$$= S_i + \frac{l}{\mu_0 \mu_r A} = S_i + \frac{l}{\mu_0 A}$$

S_i is so small in comparison with $l/\mu_0 A$ that it may be neglected in elementary theory. Therefore the total flux generated is

$$\phi = \frac{IT}{l/\mu_0 A} = \frac{\mu_0 A}{l} \cdot IT \text{ webers}$$

Hence the flux density in the air gap is

$$B = \frac{\mu_0 IT}{l} \text{ webers/metre}^2$$

The magnetic pull on the armature therefore

$$= \frac{B^2 A}{2\mu_0} = \left(\frac{\mu_0 IT}{l}\right)^2 \cdot \frac{A}{2\mu_0}$$

$$= \frac{\mu_0 A T^2}{2l^2} \cdot I^2 = \frac{2\pi A T^2 I^2 10^{-7}}{l^2} \text{ newtons}$$

To operate the relay, the magnetic pull must overcome the mechanical force exerted by the contact springs. Hence the minimum value of current I_0 in the relay coil required to cause the armature to move is given by the expression—

$$\frac{2\pi A T^2 I_0^2 10^{-7}}{l^2} = F$$

Therefore $$I_0^2 = \frac{10^7 l^2}{2\pi A T^2} \cdot F$$

The "sensitivity of a relay" is defined as the minimum value of current required to produce operation. Thus in this case the sensitivity current is I_0. It should be noted that the magnetic operating force produced is proportional to the square of this current and inversely proportional to the square of the length of the air gap.

When the armature is operated, the air gap is x and therefore the magnetic pull is given by the expression—

$$\frac{2\pi A T^2}{x^2} \cdot I_0^2 10^{-7} \text{ newtons.}$$

The force exerted by the contact springs when operated will be given by the expression—

$$F + f(l - x) \text{ newtons}$$

For the armature to restore, therefore, the current in the relay coil must be reduced to a value I_r given by the expression—

$$\frac{2\pi A T^2}{x^2} \cdot I_r^2 10^{-7} = F + f(l - x)$$

Therefore $$I_r^2 = \frac{10^7 x^2}{2\pi A T^2} \left(F + f(l - x)\right)$$

It should be noted that the difference between the operating and the restoring currents increases as the stroke $(l - x)$ of the armature increases. In actual practice the difference will be greater than that indicated by the above expressions since the effect of magnetic fringing and leakage have been neglected in the simple theory given in the foregoing.

Coil. The wire is generally wound directly on to the core after the latter has been prepared by covering it with thin insulating material and fitting a coil cheek (illustrated in Figs. 4.11 and 4.12) at each end. The coil may consist of one or more separate windings depending on the function of the particular relay; the number of turns and the resistance of each winding are also variable according to requirements. The resistance and the code number of the coil are generally stamped on the outside wrapping of the coil or on the coil cheek at the armature end. The end of the coil which is attached to the yoke is known as the "heel end."

Contact Springs. A "lever spring" is one which is actuated directly by the armature.

A *make spring* is one which makes an electrical connexion when the armature is operated.

A *break spring* is one which breaks an electrical connexion when the armature is operated.

A *contact unit* is a combination of springs in electrical association. Fig. 4.2 shows a contact

unit of two springs, mounted so that the contacts make when the relay is operated.

Other contact units can be arranged to give "break," "change-over," and "make-before-break change-over" actions.

A *spring-set* is a set of springs mechanically clamped together to comprise one or more contact units. Fig. 4.11 shows a spring-set consisting of

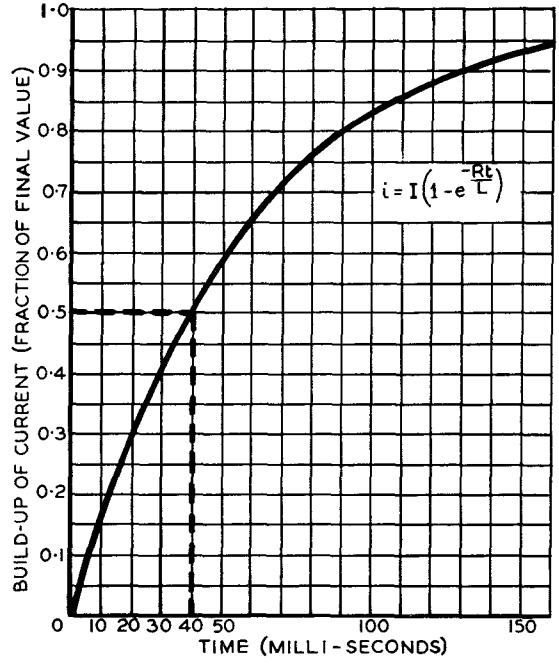


FIG. 4.4. GROWTH OF CURRENT IN AN INDUCTIVE CIRCUIT

three contact units, namely two change-over actions and one make-before-break change-over action. It will be seen in Figs. 4.7 (*a*) and 4.8 (*a*) that one relay can be made to operate more than one spring-set but there is, of course, a limit to the number of springs that may be safely lifted, varying according to the circuit conditions and the mechanical restrictions of particular types of relay.

It is sometimes required that one contact unit should operate earlier than the remainder; this unit is said to have an X action. On the other hand it may be necessary for one unit to operate later than the rest; this is known as a Y action.

To reduce the risk of failure, contacts should bear firmly against one another when closed; the contact springs are therefore usually made of nickel silver (an alloy of copper, nickel and zinc) because this metal possesses the requisite flexibility and durability.

The value of the requisite magnetizing force (which is proportional to the ampere-turns) is determined by the load which the springs place on the armature. This load will depend on the number and pressure of the contact units. The relationship between the load of the springs and the ampere-turns required to operate the armature is illustrated, for a typical relay, in Fig. 4.3. Contact pressure is measured in grammes (1 lb = 454 g), a typical pressure being 14 g, i.e. 0·5 oz (approximately).

Contacts. As a reliable electrical connexion cannot be assured between the nickel silver springs themselves, domes of a special material are fitted to form the actual points of contact. Various pure metals and alloys have been used from time to time for contacts, the aim being to find a material of high electrical conductivity which, in addition to resisting atmospheric corrosion, is not burnt by the sparking which always occurs where an electrical contact is broken. Platinum is a very good metal for contacts which are required to carry heavy currents or to operate very frequently. In other cases cheaper materials are satisfactory, and silver is used for the contacts on modern relays. A spring with platinum contacts is identified by a small notch cut in the tip of the spring.

Operate and Release Lags. The "operate lag" of a relay is the interval of time between the application of the voltage to the coil and the opening or closing of the last contact unit to operate. Similarly, the "release lag" is the interval of time between the disconnexion of the coil circuit and the opening or closing of the last contact unit to restore to normal. The operate and release lags are each made up of a *waiting* period and a *moving* period. In most relays the waiting period constitutes the greater portion of the lag and, in an elementary study of relays, the moving period may be considered negligible. Factors affecting the operate and release lags of relays are dealt with in the following paragraphs.

Self-induction in the Coil Winding. The coil of a relay possesses inductance and an interval will therefore elapse before the current (which rises gradually) attains its maximum value.

Neglecting the effect of eddy currents (which is explained later), the strength of the magnetic field (or flux) set up is proportional to the current in the winding and some time will therefore elapse before the flux is sufficient to overcome the spring pressure and operate the armature. Thus an operate lag results.

A typical curve showing the rise of current in an inductive circuit is given in Fig. 4.4. In most relays the armature operates at a current considerably less than the value finally attained, thus providing a factor of safety.

If the curve in Fig. 4.4 represents the rise of current in a particular relay and, assuming that the armature operates when the current reaches 0·5 of its final value, it will be seen that the operate lag is 40 msec.

Eddy Currents. When the circuit of a coil winding is either closed or broken, the growth or decay respectively of the magnetic field will induce e.m.f.'s in any conducting materials which are near enough to be within its influence, e.g. the core, yoke or armature; and, as the metals of which these components are made constitute closed electrical circuits, the e.m.f.'s will cause currents to circulate. These currents are called "eddy currents" and they themselves produce ampere-turns, the effects of which are to retard the growth of the main rising magnetic field or to oppose its decay when collapsing. This is in agreement with Lenz's law according to which induced currents always flow in such a direction that the magnetic effects they produce oppose the change to which they owe their origin (which in this case is the changing ampere-turns due to the main current). The magnitude of the eddy currents is proportional to the rate at which the flux increases or decreases and inversely proportional to the resistance of the closed circuit in which they flow.

The effect of eddy currents on a relay is twofold. In the first place the operating flux which, as has been seen, already builds up slowly due to the inductance of the coil, is further retarded: in other words, the operate lag is lengthened. Secondly, on cessation of the coil current, instead of collapsing almost instantly, the flux takes some time to fall to zero; a release lag is therefore introduced. The decay of flux in a typical relay is illustrated in Fig. 4.5.

It will be explained later how the eddy current effect is turned to great advantage in the design of relays which are required to be slow acting.

Air Gap. A variation of the air gap affects the operate lag. An increase in the air gap will increase the reluctance of the magnetic circuit when the armature is in the unoperated position. When the coil circuit is closed, the current will have to rise to a higher value before the flux will reach the point at which the load of the springs on the armature is overcome. An increase in the air gap, therefore, results in an increased operate lag.

Residual Air Gap. A variation of the residual air gap affects the release lag: a decreased residual air gap reduces the reluctance of the magnetic circuit when the relay is operated. In consequence, the number of ampere-turns required to maintain a flux sufficient to retain the armature is reduced and further, the larger flux produced by the current in the coil produces, on disconnexion, eddy currents of greater magnitude. Thus a longer time is taken to reach the point in the decay of the eddy current flux at which the armature is released. The release lag of a relay can therefore be increased by shortening the residual air gap. It is not advisable, however, to reduce the residual air gap too much, as subsequent wear on the relay parts may cause the gap to disappear altogether, with the consequent danger that, owing to the presence of residual flux, the relay may fail to release.

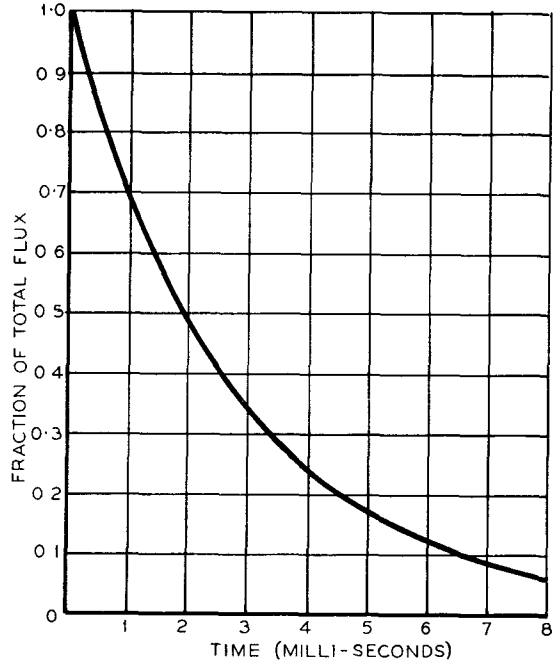


FIG. 4.5. DECAY OF FLUX AFTER DISCONNEXION OF CURRENT IN A TELEPHONE RELAY

Contact Pressure. It will be obvious that an increase in contact pressure will, by its effect on the armature, increase the operate lag and decrease the release lag.

Fast Relays. Most general purpose relays are known as fast relays but the terms "fast" or "slow" as applied to relays are purely relative. A relay in which no special features have been introduced to affect its natural speed of operation and release may be regarded as a fast relay.

The paths of flux in the magnetic circuit are shown diagrammatically in Fig. 4.6. When the circuit of the coil is completed the inductance will affect the rise of current in the manner illustrated in Fig. 4.4; a short operate lag will result. The eddy current effect is not felt to a great extent as the

currents generated in the core, yoke and armature by the slow rising main current are comparatively small and therefore the rise of flux will follow the same type of curve as that of the rise of the current in the coil. After the armature has been attracted there is a further increase in flux owing to the reduction of the air gap between the core and the armature. The path of the leakage flux, which is always present to some degree, is shown in Fig. 4.6. The amount of this flux depends on the

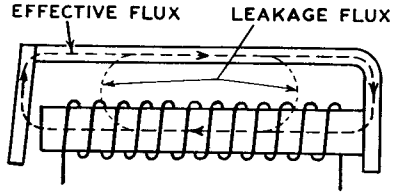


FIG. 4.6. FAST RELAY OPERATING

magnetic circuit and the better the magnetic circuit the less will be the leakage flux.

On disconnexion of the coil, the current drops to zero immediately but, as previously explained, the decay of the flux is slightly retarded by the eddy currents.

The release may be assisted considerably by the use of a large residual air gap which, by increasing the reluctance, prevents a large increase in flux when the armature is attracted to the core and increases the number of ampere-turns required to hold the armature in an operated position.

In practice the operate and release lags of ordinary fast relays lie between 10 and 30 msec.

Slow Relays. For certain functions relays slower in action than the fast relay described in the foregoing paragraphs are required.

It has already been shown that the phenomenon of eddy currents has an effect on the operate and release lags of relays and it is by deliberately making conditions favourable to the formation of eddy currents that a slow acting effect is principally obtained. The eddy current effect can be considerably increased by providing a closed path, of low electrical resistance, around the core. The device may be an additional winding (this winding being short-circuited) or a thin copper sleeve fitted over the core but, more frequently, it consists of a thick copper ring, known as a "slug," placed over one end of the core.

The magnetic effects produced by the eddy currents depend on the position of the slug on the core. These effects are discussed in detail in later paragraphs.

Operate Lag of a Slugged Relay. Consideration will now be given to relays carrying slugs at either the heel or armature ends of the core and the sleeved or short-circuited coil types will be neglected for the moment.

The first case to be considered is that of a relay fitted with a heel-end slug illustrated in Fig. 4.7 (*a*),

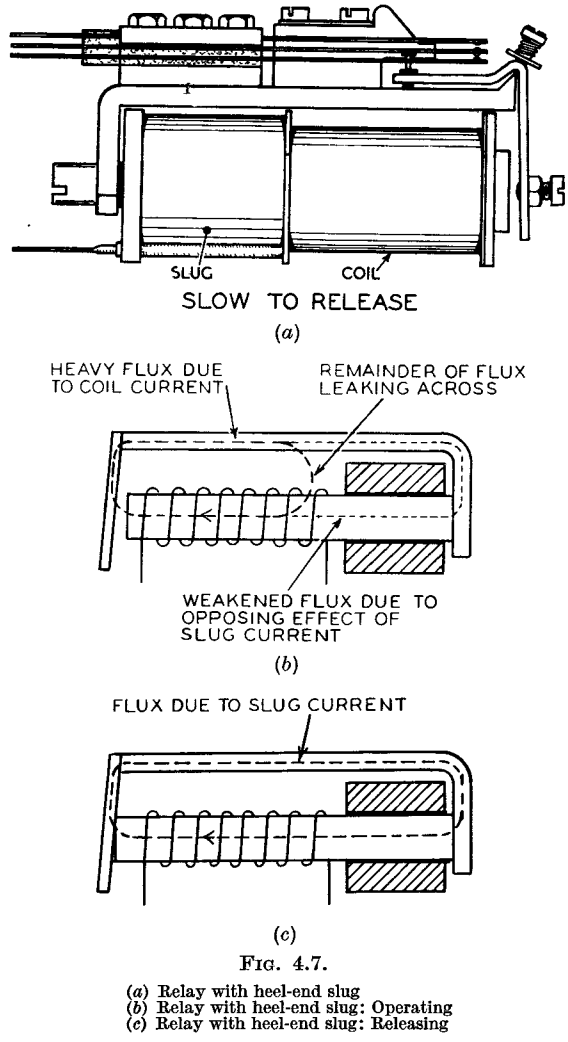


FIG. 4.7.

(*a*) Relay with heel-end slug
(*b*) Relay with heel-end slug: Operating
(*c*) Relay with heel-end slug: Releasing

schematic drawings of which appear in Figs. 4.7 (*b*) and (*c*).

When the circuit of the winding is closed, the rising flux induces a heavy eddy current in the slug which in turn sets up a magnetizing force in opposition to that of the main current. The tendency will be for the lines of force of the winding to avoid entering the slug in any appreciable quantity until the current in the latter has subsided. The winding flux will therefore leak across to the yoke and complete a magnetic circuit as shown in Fig. 4.7 (*b*).

By means of this leakage action the flux through the air gap is enabled to rise fairly rapidly. A heel-end slug has little effect therefore on the operate lag of a relay.

As the current in the winding reaches a steady value. the eddy current in the slug dies away and so allows the winding flux to extend gradually throughout the whole of the magnetic circuit.

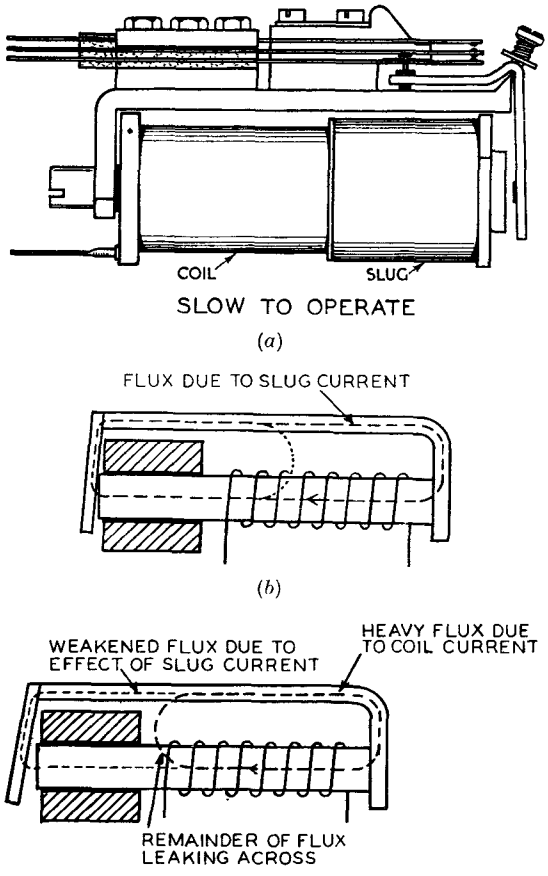


FIG. 4.8.

(*a*) Relay with armature-end slug
(*b*) Relay with armature-end slug: Releasing
(*c*) Relay with armature-end slug: Operating

Consider now the relay with an armature-end slug illustrated in Fig. 4.8 (*a*), schematic drawings of which appear in Figs. 4.8 (*b*) and (*c*).

When the winding circuit is closed, flux will commence to build up through the core but, owing to the rising flux in the portion of the core enclosed by the slug, eddy currents will flow round the slug. The effect of this is to cause a large proportion of the winding flux to leak from the core to the yoke without traversing the armature gap. As the rate of change of the flux in the slugged portion of the core diminishes, the eddy currents in the slug subside and a greater proportion of the winding flux can then pass through the slug and armature circuit. When this flux reaches a sufficiently high value the armature will operate, and it will be clear that the time required to reach this point depends upon the tension of the relay springs. If this tension is small the operating value of flux in the armature air gap is reached fairly quickly, a longer time being taken to overcome a greater tension. Fig. 4.9 illustrates the variation of currents and flux in a relay during the operating period.

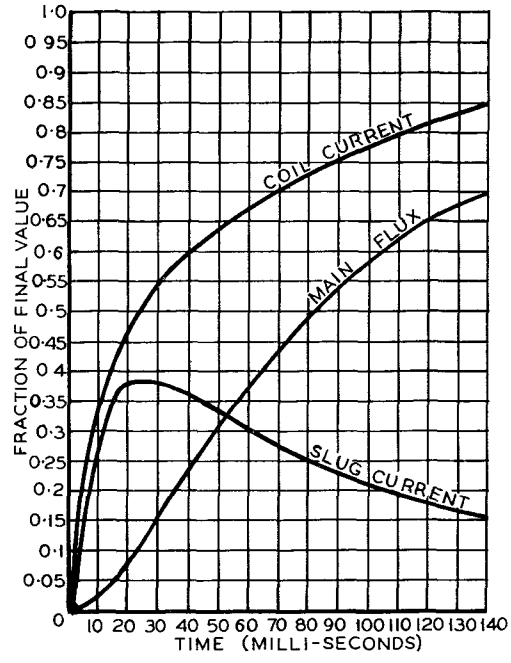


FIG. 4.9. GROWTH OF CURRENT AND FLUX IN A SLOW-OPERATING RELAY

Thus it will be seen that, whilst a heel-end slug has little effect on operation, the operate lag of a relay provided with an armature-end slug is greater than that of a relay without a slug and that the greater the spring tension on the relay the greater will be the operate lag.

Release Lag of a Slugged Relay. When the circuit of the winding is disconnected, the previously steady current drops to zero immediately but the rate of decay of the flux is determined by the eddy currents produced in the slug by the flux change and the armature is held operated so long as the

flux produces an attractive force sufficient to withstand the pressure of the springs.

Owing to the flux leakage between the core and the yoke, the flux caused by the eddy currents in the slug will tend to be confined to the portion of core near the slug. In the case of the armature-end slug this portion contains the armature hence the flux in the armature air gap will be maintained for the maximum amount of time.

On the other hand, in a relay equipped with a heel-end slug the flux will tend to circulate round the heel-end of the relay, and the leakage path is in effect acting as a shunt on the armature circuit and, in consequence, the flux value at which the relay releases will be reached slightly more rapidly.

In relays which have been designed for slow release this shunting effect is very small, owing to the low reluctance of the short residual air gap. The release lag of these relays is therefore very little less than that of similar relays which are equipped with armature-end slugs.

The actual release lag of a slugged relay depends also on the spring tension, and it will be appreciated that the lighter the spring tension on the relay the smaller will be the flux required to retain the armature in the operated position and the greater will be the time required for the flux to die down to that value.

With light, but reasonably safe spring pressures, a safe residual air gap and a large copper slug, release lags up to 350 msec can be obtained.

Relays with Copper Sleeves. Although the present practice is to fit a slug when slow operation is required some relays have in the past been provided with a thin copper sleeve. The sleeve extends over the whole length of the core and the coil is wound over it. When being operated, the effect of the eddy current in the sleeve opposes that of the winding current and the flux due to the combined effects therefore rises slowly; similarly, on release, the decay of the flux is retarded.

The required condition as regards slow operation or release can however be obtained by the use of a slug in the appropriate position and, to keep the number of different relay parts to a minimum, sleeves are not now fitted to new relays.

Relays with Separate Closed Windings. A relay can be provided with the equivalent of a copper sleeve in the form of a second winding, this extra winding being short-circuited. A winding is less efficient than a slug, as the amount of copper per cubic inch of winding space is less and the resistance is greater. The separate closed winding, however, affords flexibility, as it enables the relay to be made either fast or slow as circumstances demand. This is achieved by connecting the ends of the extra coil to control contacts which may be opened or closed at will. A variety of conditions can then be set up and the relay can be made—

(*a*) Slow to operate and release.
(*b*) Fast to operate and release.
(*c*) Slow to operate but quick to release, or
(*d*) Quick to operate and slow to release.

An example of this facility is described later in connexion with relays which are insensitive to alternating currents.

Relays with Shunted Windings. Sometimes a slow releasing effect is obtained on single-coil relays by shunting the coil with a non-inductive resistance or the winding of another relay. When the main circuit is opened the flux in the relay commences to die away, thereby inducing an e.m.f. across the relay coil. Owing to the presence of a closed circuit the induced e.m.f. causes current to circulate through the relay coil and this retards the rate of decay of the flux.

Summary of Conditions Governing Slow Operation and Release. Owing to the number of variable factors, e.g. spring load and armature air gap, it is difficult to give definite data for slow relay design, but the following general rules apply in practice—

(*a*) Relays which are required to be slow releasing and quick operating are usually equipped with heel-end slugs, lightly loaded spring sets and small residual air gaps. When, however, the speed of operation is not important but the maximum amount of release lag is required, an armature-end slug may be used.

(*b*) Relays which are required to be slow operating are equipped with armature-end slugs and heavy spring loads are used.

Effect of Slugs, etc., on the Impedance of Relays. The presence of a slug, sleeve or separate closed winding, by slowing down the rate of change of flux, reduces the inductance and therefore the impedance of the relay. Such a relay may be regarded as a transformer with one of its windings short-circuited.

It has been shown how in the fast relay the inductance of the coil causes the current to rise slowly and therefore introduces an operate lag. Since the presence of a slug, or its equivalent, reduces the inductance of a relay, the current will rise to its maximum value in a shorter interval of time than in the case of a fast, i.e. unslugged, relay. It follows therefore that the inductance of the winding does not play a large part in creating the operate lag of a slugged relay. In effect, one slowing factor is reduced but another is introduced.

Impulsing Relays. In automatic switching systems the operation of selector electromagnets is controlled by the subscriber by means of a dial

which is connected at the subscriber's end of the line. When the dial is operated, the continuity of the line is rapidly broken and remade a number of times in succession, the number of "breaks" being the same as the digit dialled. At the exchange a relay coil is joined across the line and the contacts of this relay are employed to repeat the dialled impulses to the selector electromagnet. Such a relay is called an impulsing relay.

To secure correct functioning of the selector electromagnet it is important that the interval of time for which the line circuit is opened by the dial shall be repeated without distortion by the relay contact, and this necessitates a relay with equal operate and release lags. When a relay is connected to a line, however, the operate and release lags are both influenced by line conditions but not necessarily to an equal extent. Lines differ widely in characteristics and the problem is to design an impulsing relay which will have equal operate and release lags when joined to any line. This ideal cannot be achieved in practice as, in general, a variation in line conditions which gives an increase in operate lag will reduce the release lag, and vice versa; therefore a relay with short operate and release lags is the best compromise.

An impulsing relay need not differ greatly from an ordinary fast relay except in the matter of adjustments. Thus for quick operation the armature load is kept to a minimum, while to ensure quick release a large residual air gap is provided.

One method of ensuring the early release of a relay is to limit the maximum flux in the air gap so that on cessation of the main current the point at which the flux permits release will be reached at an earlier stage. This can be done by fitting an armature shaped as shown in Fig. 4.10 so that the flux passes through a narrow neck, or isthmus. Magnetic saturation of this restricted portion of the armature is reached with a comparatively low magnetizing force and further increase in the relay current does not materially increase the flux in the air gap. In this way the release lag is reduced and to some extent stabilized. An isthmus armature is also lighter and therefore more suitable for quick action.

Differential Relays. This relay is provided with two windings on a single core, which are arranged so that when both are energized the magnetic effect of one winding is neutralized by that of the other, with the result that effective flux is not produced. Any disturbance of this condition of balance resulting from an increase, decrease or reversal of current in either winding will, if the unbalance is sufficient, cause the relay to operate. This unbalanced condition can be produced in various ways, e.g. by shunting one winding or placing resistance in series with it.

Post Office Standard Telephone Relays. It has been mentioned previously that there is a great variety of relays in existence. Some years ago the British Post Office decided to standardize relay construction and, based on a study of all the different types, a relay was designed in collaboration with British manufacturers which embodied principles which had been proved to be sound by

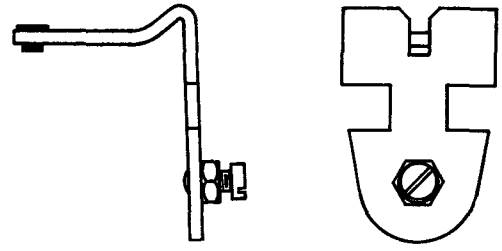


FIG. 4.10. ISTHMUS ARMATURE

years of experience and possessed certain novel features making for ease of maintenance. Two sizes of this standard relay are made, the 3,000-type for heavy duty and rigorous operating requirements and the 600-type for light duty. A 3,000-type relay is shown in Fig. 4.11 (*a*) and (*b*). The features of the standard relay are described in the following paragraphs.

Magnetic Circuit. The magnetic circuit is of very low reluctance. The armature end of the yoke is enlarged and machined to a knife edge and the bend of the armature is V-shaped and fits snugly over the knife edge. With this arrangement a good magnetic continuity is ensured at the pivot. The coupling of the yoke to the core is such as to minimize the reluctance at this point, but at the same time to permit the withdrawal of the core and winding without removing the relay from the mounting plate. Corrosion of the components is prevented by nickel plating and, as this material is slightly magnetic, the effect of the plating on the reluctance of the magnetic circuit is kept to a minimum.

For slow operating or slow releasing relays three lengths of slug are employed, namely $\frac{1}{2}$ in., 1 in., and $1\frac{1}{2}$ in., according to the spring-set load and the required lag.

To minimize the number of contact faults due to dust, the standard relay is mounted with the springs at the side, i.e. on edge, so that dust will tend to fall clear of the contacts. This necessitates the fitting of an armature retaining screw to hold the armature in position when the relay is not energized (see Fig. 4.11).

Contact Springs. The nickel-silver contact springs are 14 mils thick for normal use, but 12 mil springs are used if it is necessary to reduce the armature load. Exceptionally, springs exceeding 14 mils in thickness are employed.

A block, moulded from synthetic material, is mounted on the yoke of the relay (see Figs. 4.11 and 4.12). This is known as the "buffer block" and is grooved so that it engages with lugs formed on the sides of the make or break springs to limit their "follow" when the associated moving spring moves out of contact with them. Thus a make spring rests on the buffer block when the relay is normal and is lifted off by the moving spring when the relay operates. A break spring, with the relay normal, is held away from the buffer block by the pressure of the moving spring but when this pressure is removed by the operation of the relay the break spring is checked by the buffer block after a limited amount of follow.

The make and break springs can be readily adjusted to bear against the block with any desired pressure, break springs being adjusted with the armature operated. The subsequent adjustment of the moving springs to ensure that the make and break springs are lifted clear of the block, when the armature is operated or unoperated respectively, will then guarantee that the contact pressures are slightly above the block pressures to which the make and break springs have been adjusted. To lift a break spring it is, of course, necessary to tension the moving spring sufficiently to overcome the pressure of the break spring against the block, and it should also be given sufficient additional tension to enable it to exert a slight pressure against the armature in its unoperated position.

This method of adjustment ensures a definite standard of contact pressure, a point of considerable importance as it has been proved that where low pressures are used fault liability is greatly increased.

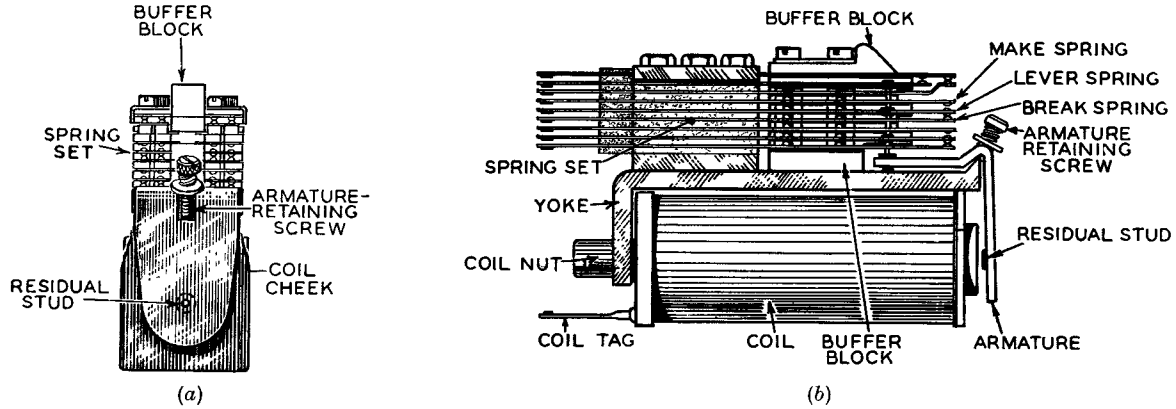


FIG. 4.11. B.P.O. 3,000-TYPE TELEPHONE RELAY
(*a*) Front view (*b*) Side view

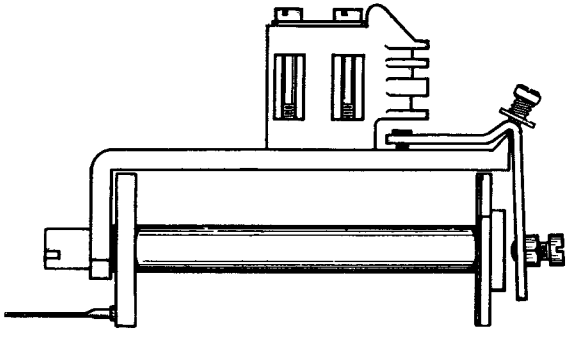


FIG. 4.12. SKELETON OF TELEPHONE RELAY

Contacts. Twin contacts are employed, the end of each spring being centrally slotted for about half an inch and a dome-shaped contact fitted to the tip of each prong so formed. The prongs permit of a slight amount of independent flexing so that a double contacting action normally occurs. The liability to contact failure due to dust, etc., is thus considerably reduced because one contact can maintain the circuit if its twin be rendered temporarily ineffective by a particle of dust.

High-speed Relays. If a relay is required to operate in less than about 5 msec ordinary telephone relays are not suitable. At one time such requirements were met by means of telegraph relays or electronic relays, which were extravagant in

both cost and mounting space. This led to the development of a relay by Messrs. Siemens having small response times, which are achieved by the use of an efficient magnetic circuit, low inductance windings and a moving system of small mass, whilst

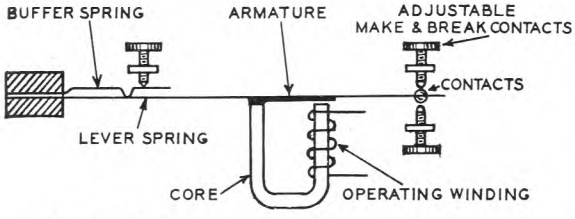


FIG. 4.13. PRINCIPLE OF SIEMENS HIGH-SPEED RELAY

still retaining good contact pressures and low current values.

There are at present two important Siemens types of standard B.P.O. high-speed relay, one with a single coil and another with two coils. Each has one change-over contact unit with single platinum contacts and is designed to mount on a 3,000-type

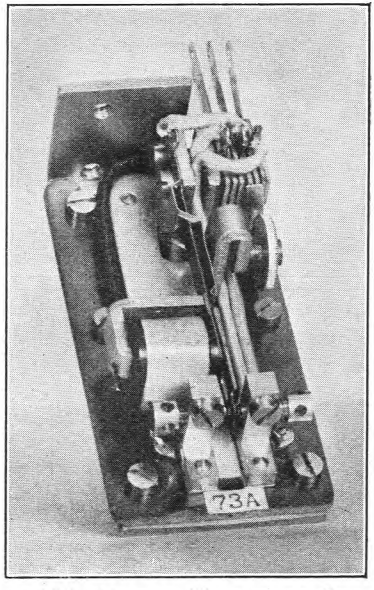


FIG. 4.14. SIEMENS HIGH-SPEED RELAY

relay drilling. When suitably energized the relay operates and takes approximately 0·5 msec to break the break contact and 2 msec to operate fully. Similar timing figures are obtained on release of the relay. Both the residual air gap and the contact opening are set between 4 and 5 mils.

The mechanical arrangements of the relay are shown in principle in Fig. 4.13. The windings are carried on moulded bobbins which are fitted over one or both legs of the U-shaped soft iron core. The lever spring is of nickel silver to which is welded the soft iron armature. Movement of the buffer spring under the action of its adjusting screw applies tension to the lever spring and causes the armature to hinge on the inner leg of the core. The fixed contacts have screw adjustments.

This relay which is illustrated in Fig. 4.14 is very robust and reliable in operation and is finding increasing use in both telephone and telegraph switching circuits.

Telegraph Relays

Electromagnetic telegraph relays may be divided into two main classes, (*a*) non-polarized and (*b*) polarized relays. Non-polarized telegraph relays are essentially similar in principle to telephone-type relays in that a spring-loaded armature is caused to operate by a flow of current through an electromagnet. The actuation of the armature when a current flows through the relay coil occurs independently of the direction of the current flowing and this is the principal difference from a polarized telegraph relay. In polarized relays the operation of the armature depends not only upon the magnitude of the current flowing but also upon its direction of flow through the windings of the coil.

Non-polarized Telegraph Relays. Fig. 4.15 shows the essential details of construction of a typical non-polarized relay.

Two soft iron armatures *A* are mounted on a pivoted brass spindle *B*. Each armature is split in

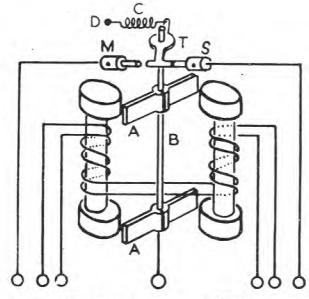


FIG. 4.15. PRINCIPLE OF NON-POLARIZED TELEGRAPH RELAY

halves at the spindle by a non-magnetic separator to prevent the possible formation of a closed magnetic circuit with the electromagnets. The spindle at its upper end carries a light contact tongue *T* which plays between two adjustable contact screws *M* and *S*. The tongue is connected by means of a very light electrical connexion to the relay base and is normally held over to the *S*

contact screw by the action of the spring C the tension of which is adjustable by the screw D.

The armatures play between the poles of two electromagnets and the magnetic circuit so formed is round the iron cores and across the four air gaps and armature in series.

When current flows through the relay windings in series the extremities of the armatures are each attracted to the adjacent electromagnet poles, thus

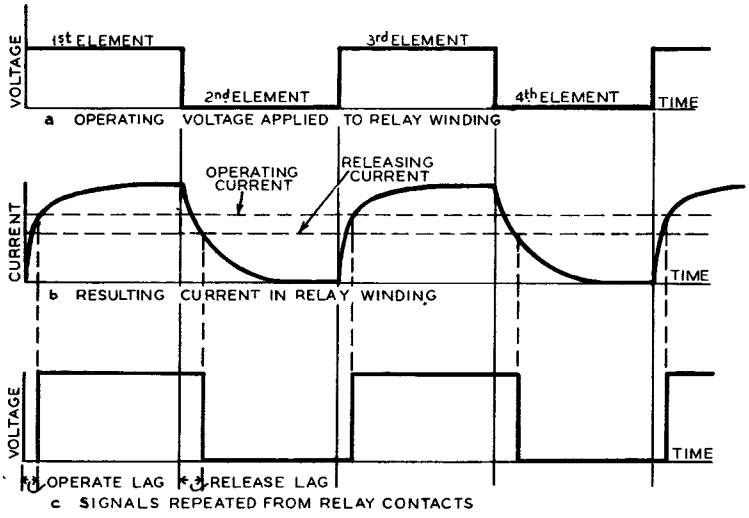


FIG. 4.16. INPUT AND OUTPUT SIGNALS OF A NON-POLARIZED TELEGRAPH RELAY

(*a*) Operating voltage applied to relay winding
(*b*) Current in relay winding resulting from (*a*)
(*c*) Signals repeated from relay contacts

producing a torque on the relay spindle in opposition to that exerted by the restraining spring C. When a current of sufficient strength passes through the coils the relay operates and the tongue moves over and makes contact with the M contact screw. Contacts M and S are connected to local battery supply whilst the tongue is connected to whatever circuit into which it is required to repeat the signal.

The relay is normally provided, as shown by the dotted lines in Fig. 4.15, with two coils wound differentially and having half of each on the two soft iron cores of the electromagnets. The coils are identical in electrical and magnetic characteristics and thus the windings may be employed either in opposition for differential working (as will be described in Chapter 7) or in series- or parallel-aiding.

The theory of the operation of a non-polarized telegraph relay is similar to that already described for the telephone relay. The magnetic pull on the armature is proportional to the square of the current and the sensitivity is inversely proportional to the sum of the lengths of the air gaps. Thus for optimum adjustment, contacts S and M are made as close together as possible consistent with the tongue making and breaking contact and the armatures, when operated, are made to approach the poles as closely as possible without touching.

Signal Distortion Due to Relays. It has been explained earlier how the values of the operate and the release lags differ in the case of the telephone-type relay. The non-polarized telegraph relay possesses similar characteristics in this respect. Hence if the operate and release lags are not equal the signals repeated by such a relay will be distorted. This will be clear from examination of Fig. 4.16 which indicates a case in which the release lag is greater than the operate lag.

It will be seen from the figure that the time durations of the first, third and the fifth elements of signal transmitted from the relay have been lengthened and elements 2 and 4 have been shortened as compared with the duration of the signals applied to the relay.

For distortionless transmission the duration of the operate and release lags must be equal and this is difficult to attain in a non-polarized relay and involves meticulous adjustment of the relay and restraining spring.

In modern telegraph circuit design non-polarized telegraph relays have been superseded for many years past by polarized relays as these are more sensitive and stable in operation.

Polarized Telegraph Relays. In polarized relays the operation of the armature depends on both the *magnitude and the sense* of the current in the operating windings. This polarized characteristic is achieved by the use of a polarizing magnetic flux derived from a permanent magnet or magnets. Operation of the armature is produced as a result of the redistribution of magnetic flux which results when current flows in the operating windings. The magnitude and nature of the flux redistribution is controlled by the magnitude and sense of the operating current. Such a relay may readily be made equally sensitive to operation in either direction, that is to say it is symmetrical and is highly stable in operation.

Magnetic Circuits. There is a number of alternative arrangements employed in the design of the

magnetic circuits of polarized telegraph relays and Fig. 4.17 shows the basic types most commonly used. In each case, the permanent magnet is shown in bold lines, the permanent flux by dotted lines and the flux generated by the current through the coils by thin full lines.

In Fig. 4.17 (*a*) is shown the simplest form of galvanometer and the permanent magnet the place of the battery. With the armature in the mid-pole (or neutral) position it connects points of equal magnetic potential and no longitudinal flux passes through it. The operating windings of the relay are placed over the armature which is free to move within the coil.

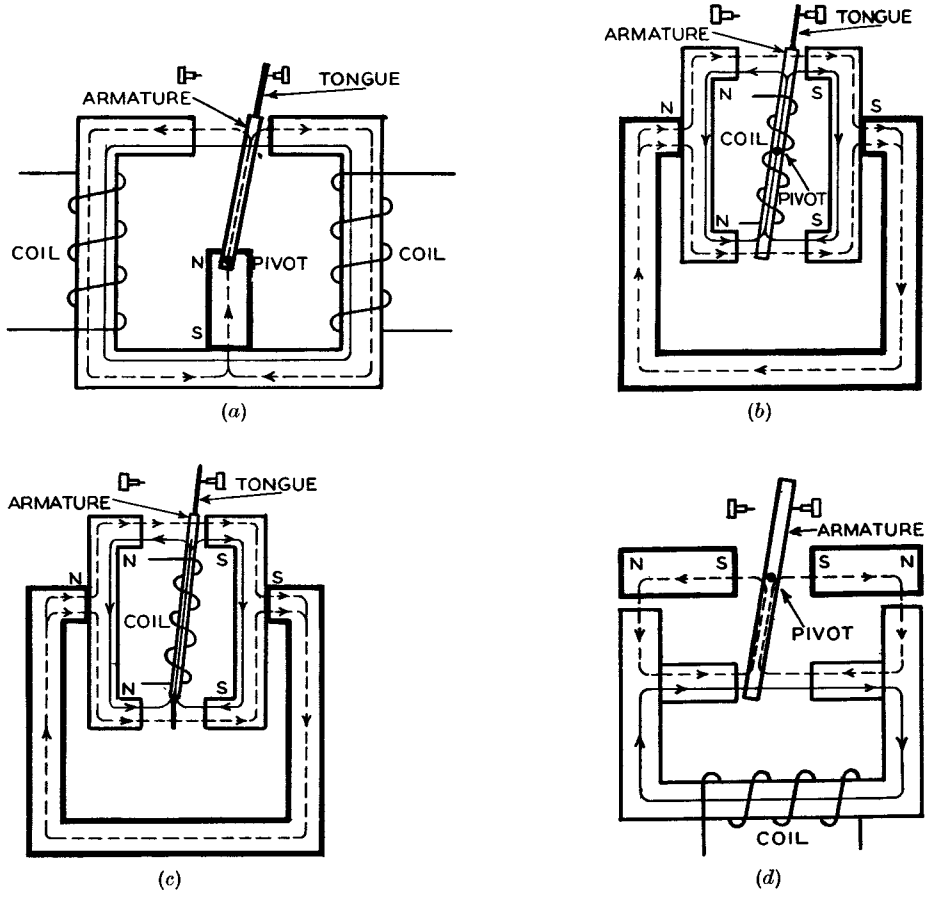


FIG. 4.17. BASIC MAGNETIC CIRCUITS OF POLARIZED TELEGRAPH RELAYS

magnetic circuit from which the B.P.O. Standard "B" Relay is developed. The armature carries the whole of the permanent flux which, after passing through the armature, splits into two paths through the pole pieces and the yokes, the windings being placed on the yokes. In Fig. 4.17 (*b*) and (*c*) are shown later designs of magnetic circuits where the armature does not carry the whole of the permanent flux but only an "out of balance" flux. The configuration of the magnetic reluctances is analogous to that of the resistances in a Wheatstone bridge, the armature taking the place of the

A novel development from the basic magnetic circuit illustrated in (*a*) is the type shown in (*d*). In this case two identical permanent magnets of modern magnetic material of high coercivity are employed in such a manner that their fluxes unite in the armature and pass through it longitudinally. The armature is pivoted at its centre of gravity midway between the poles of the permanent magnets and is therefore mechanically balanced. The operating winding is wound on the lower portion of the soft iron magnetic circuit and since this core carries only the flux generated by the

current in the windings together with the "out of balance" flux it is therefore of very small cross-section. The soft iron magnetic circuit is completed by a yoke made up of two limbs which have a greater cross-section, enough to carry the combined fluxes from the permanent magnets and the winding. An air gap (the working air gap) is formed between the two limbs of the yoke and one end of the armature operates within this air gap. From the figure it will be seen that the longitudinal

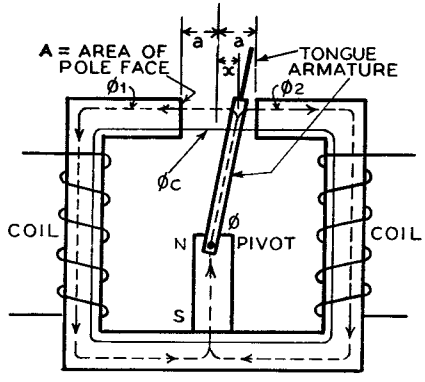


FIG. 4.18. ELEMENTS OF MAGNETIC CIRCUIT OF POLARIZED TELEGRAPH RELAY: TYPE 1

reluctance of the armature is in circuit only with the permanent magnets and the direction of the flux in the upper part of the armature is constant; the m.m.f. generated by the current in the windings has to overcome only the transverse reluctance in the lower part of the structure.

In all these designs arrangements are made to ensure that the changes in flux generated by the current in the windings find a path of low reluctance and do not pass through the permanent magnet. Although it is difficult to bring this point out clearly in the sketches of the basic magnetic circuits it will become clearer later on in the more detailed sketches illustrating the construction of the several different relays. The circuit shown in Fig. 4.17 (*b*) is used in the Creed relay and in polarized electromagnets such as are used in teleprinters; that shown in Fig. 4.17 (*c*) forms the basis of the design of B.P.O. Relays 299, 320, 324 and 328 while that shown in Fig. 4.17 (*d*) is used in the Carpenter Relay.

Theory of the Polarized Relay. *Type* 1. The magnetic circuit of the simplest form of polarized relay represented in Fig. 4.17 (*a*) is reproduced in greater detail in Fig. 4.18. Considering the distribution of flux in this circuit when no current is flowing in the windings of the operating coils it will be seen that the permanent magnet produces a total flux ϕ (known as the polarizing flux) which divides at the upper extremity of the armature into two parts ϕ_1 and ϕ_2 in the left hand and right hand air gaps respectively.

$$\phi_1 + \phi_2 = \phi \text{ webers}$$

The values of ϕ_1 and ϕ_2 are inversely proportional to the reluctances of their respective paths. The reluctance of the iron circuit is negligible in each case by comparison with that of the air gap and the reluctance may therefore be assumed to be proportional to

$$\frac{\text{the length of the air gap}}{\text{the cross-sectional area of the gap}}$$

The flux in each case is inversely proportional to the reluctance. Therefore

$$\phi_1 \text{ is proportional to } \frac{A}{a+x}$$

and

$$\phi_2 \text{ is proportional to } \frac{A}{a-x}$$

where A = the cross-sectional area of the air gap;
a = the distance from the face of the pole piece to the armature face when the armature is central between the poles;
and x = the displacement of the armature from its central position.

The forces of attraction acting on the upper extremity of the armature may be deduced from the magnitude of the flux present in the air gaps by means of the well-known formula—

$$\text{Force } F = \frac{\phi_A^2}{2\mu_0 A} = \frac{\phi_A^2}{8\pi 10^{-7} A} \text{ newtons}$$

where ϕ_A is the flux in the air gap and A is measured in metre^2. Putting C for $\frac{1}{8\pi 10^{-7}}$ the force F can be expressed in the form

$$F = C\phi_A^2$$

Thus the force F_1 exerted on the armature tending to pull it to the left is

$$F_1 = C\phi_1^2$$

Similarly the force F_2 exerted on the armature tending to pull it to the right is

$$F_2 = C\phi_2^2$$

Therefore the resultant force acting to the right is

$$F_R = F_2 - F_1 = C(\phi_2^2 - \phi_1^2)$$

Clearly when ϕ_2 is greater than ϕ_1 the resultant force is positive and therefore acting to the right. When, however, ϕ_1 is greater than ϕ_2 then the

resultant force is negative and acting in a direction tending to move the armature to the left. Obviously when $\phi_1 = \phi_2$ then the resultant force is zero.

It will be clear that the only position in which $\phi_1 = \phi_2$ is when the armature is placed symmetrically between the poles, i.e. in the mid-position. This is often called the neutral position since in this position the total flux ϕ divides equally between the air gaps and the poles therefore exert equal and opposite forces on the armature thus producing a state of equilibrium. The slightest displacement of the armature from this position will clearly result in the magnetic forces becoming out of balance. Thus if the armature is displaced a distance x from the neutral position, then the resultant force

$$F_R = C(\phi_2^2 - \phi_1^2) \quad . \quad . \quad (1)$$

is proportional to

$$C\left(\frac{A}{a-x}\right)^2 - C\left(\frac{A}{a+x}\right)^2 = CA^2\left(\frac{1}{(a-x)^2} - \frac{1}{(a+x)^2}\right) \quad (2)$$

The greater the displacement x of the armature, the greater will be the unbalanced magnetic force and this force acts in a direction which tends to increase the displacement of the armature still further. Thus if the armature is displaced from the neutral position very slightly to the right then it will continue to move with increasing acceleration to the right until it reaches the fully operated position on the right-hand contact stop.

Conversely, if the armature is displaced from the neutral position to the left, then it will continue to move to the left with increasing acceleration until it reaches its fully operated position on the left-hand contact stop.

Now consider the effect of a current I flowing in the operating windings of the relay. This will produce a flux ϕ_c passing up one limb of the yoke and down the other and through the gaps and armature extremity. For one direction of current ϕ_c will be in a direction to assist ϕ_2 and oppose ϕ_1. In the reverse direction of the current, ϕ_c will oppose ϕ_2 and assist ϕ_1.

Considering the case in which ϕ_c assists ϕ_1 and opposes ϕ_2 then the resultant flux in the right and left hand air gaps will be $(\phi_2 - \phi_c)$ and $(\phi_1 + \phi_c)$ respectively. Hence the resultant force acting to the right upon the armature as a result of these fluxes will be given by the expression—

$$\begin{aligned} F_R &= C(\phi_2 - \phi_c)^2 - C(\phi_1 + \phi_c)^2 \\ &= C(\phi_2^2 - 2\phi_2\phi_c + \phi_c^2 - \phi_1^2 - 2\phi_1\phi_c - \phi_c^2) \\ &= C(\phi_2^2 - \phi_1^2 - 2\phi_2\phi_c - 2\phi_1\phi_c) \\ &= C(\phi_2^2 - \phi_1^2) - 2C\phi_c(\phi_2 + \phi_1), \end{aligned}$$

Therefore

$$F_R = C(\phi_2^2 - \phi_1^2) - 2C\phi_c\phi \quad . \quad . \quad . \quad (3)$$

$$= F_p - F_c \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where F_p = the resultant polarizing force,

and F_c = the resultant force developed by the operating current.

It will be clear from this expression that when F_p is greater than F_c the resultant force acting on the armature is to the right and the armature therefore remains on its right hand stop.

When $F_p = F_c$ there is no resultant force to move the armature.

When F_p is less than F_c then the resultant force is negative, i.e. operating to the left and the armature will therefore be moved over to its left hand stop.

Furthermore, as acceleration is proportional to the force applied and inversely proportional to the mass to be moved, it will be clear that the transit time of the armature from one operated position to the other will be reduced as $F_c - F_p$ is increased and also as the mass of the armature is reduced. Thus to obtain a small transit time $F_c - F_p$ should be as large as possible and the armature as light as possible. For the same reason the armature travel should be as small as practicable.

The sensitivity of the relay is measured by the minimum value of current required to operate the armature. The critical point is reached when $F_p = F_c$ because the slightest increase in F_c thereafter will cause the armature to move. Thus when $F_p = F_c$,

$$C(\phi_2^2 - \phi_1^2) = 2C\phi\phi_c$$

Therefore $(\phi_2 + \phi_1)(\phi_2 - \phi_1) = 2\phi\phi_c$

that is $\phi_2 - \phi_1 = 2\phi_c$ since $\phi_2 + \phi_1 = \phi$

$$\therefore \phi_c = \tfrac{1}{2}(\phi_2 - \phi_1) \quad . \quad . \quad . \quad (5)$$

This expression shows that the more nearly ϕ_2 and ϕ_1 are made equal, the less is the value of ϕ_c required to operate the relay armature and hence the greater the sensitivity of the relay, since ϕ_c is proportional to the operating current in the relay windings. It should be noted from the previous demonstration that ϕ_1 and ϕ_2 will be most nearly equal when the reluctance of their respective flux paths are nearly equal and this occurs when $(a + x)$ is nearly equal to $(a - x)$. Thus x must be as small as possible for maximum sensitivity.

Another very important characteristic of a polarized relay to be observed is the magnitude of the effect which the polarizing flux plays in the

operation of the relay. Thus from the previous equation (3)

$$F_R = C(\phi_2^2 - \phi_1^2) - 2C\phi\phi_c$$
$$= C(\phi_2 + \phi_1)(\phi_2 - \phi_1) - 2C\phi\phi_c$$

Therefore $$F_R = C\phi[(\phi_2 - \phi_1) - 2\phi_c] \quad . \quad (6)$$

Thus when ϕ_2 is nearly equal to ϕ_1 and $2\phi_c$ is large compared with $(\phi_2 - \phi_1)$, the value of F_R is nearly equal to $-2C\phi\phi_c$; that is to say the operating force acting on the armature is approximately

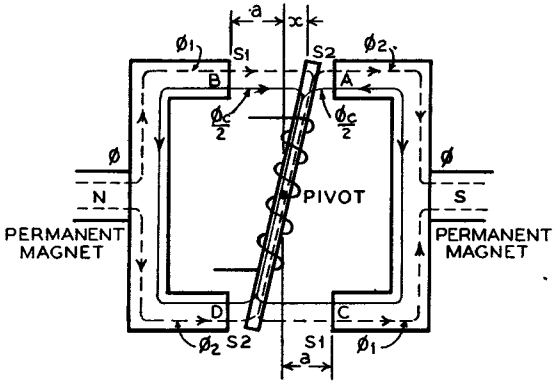


FIG. 4.19. ELEMENTS OF MAGNETIC CIRCUIT OF POLARIZED TELEGRAPH RELAY: TYPE 2

proportional to the product of the total polarizing flux (ϕ) and the current flux (ϕ_c).

If ϕ is made large compared with ϕ_c then clearly it will considerably assist the operation of the relay which in consequence can be made much more sensitive to small operating currents than is possible in the case of non-polarized relays.

It has been demonstrated how the polarizing flux makes the operation of the relay dependent upon the direction of flow (i.e. the polarity) of current through its operating windings. Notice also that when the relay is operated to either position the polarizing flux acts in a direction which assists in maintaining the armature in its operated position. In the case illustrated in Fig. 4.18 the armature will remain operated in either position even in the absence of operating current. Such a polarized relay is often called a "side-stable" relay since it will remain operated to either side until actuated to the other side by current of opposite polarity.

For satisfactory operation of a relay over long periods and with minimum maintenance it is essential that, when the armature tongue operates and makes contact with either side contact it should do so if possible without bounce. If bounce occurs it gives rise to sparking and consequent wear of the contact material and effectively increases transit time, so producing signal distortion. To ensure good electrical contact the tongue must bear upon the side contacts with a good pressure; also the impact force at the moment that the contacts close requires to be as high as practicable so as to break down any surface oxide film or pips formed due to sparking. Practical designs are a compromise between the requirements for high contact pressure and minimum bounce. The force available to produce contact pressure may be derived from equation (6).

Type 2. Let us now consider the second basic type of polarized relay as illustrated in Fig. 4.17 (*b*) and shown in greater detail in Fig. 4.19.

The theory of operation of this relay is essentially similar to that already described for Type 1. The principal difference is that in this case the configuration of the magnetic circuit is in the form of a magnetic bridge and is analogous to the electrical Wheatstone bridge circuit. The relay armature is connected in the magnetic bridge circuit in a position corresponding to the galvonometer in the case of the Wheatstone bridge and the permanent magnet similarly corresponds to the electrical battery. The permanent magnet produces flux in the magnetic bridge arms and the flux produced through the armature depends upon the difference in magnetic potential which exists between the points it connects in the bridge. Thus when the armature is symmetrically positioned in the mid-position between the pole shoes, the reluctance of each of the four bridge arms is equal and the armature therefore connects points of equal magnetic potential in the bridge. Thus in this condition no flux passes through the armature. In other positions of the armature it only carries the difference flux in the bridge arms and this is an important difference from the first type of relay considered in which the armature carried the *whole* of the polarizing flux.

In the type of relay illustrated, the armature is mounted on a central pivot and each end of the armature is therefore equally effective in producing operating forces to actuate the relay, whereas in the first type of relay only one end of the armature is effective. It should be pointed out, however, that for a given angular movement of the armature the change in the differential reluctance of the air gaps is twice that produced when only one end of the armature is active: that is, there is twice as much out-of-balance flux to be annulled by the signals coil before a flux can be built up to move the armature. The bridge principle of operation results in the direction of the longitudinal flux in the armature being reversed for each operation of

the relay whereas in the first type of relay the direction of the longitudinal flux is constant.

Another important difference to be noted in this type of relay is that the operating coils embrace the armature which therefore carries the whole of the current flux produced and this flux is reversed in the armature when the current is reversed, and interacts with the polarizing flux to cause the operation of the relay as follows.

Referring to Fig. 4.19 it will be seen that the flux ϕ produced by the permanent magnet divides into two main paths ϕ_1 and ϕ_2 via the pole shoes. The flux from pole A may pass through two paths, namely from A to B and from A via the armature to D. Similarly the flux from pole C may pass from C to D and from C via the armature to B. The distribution of the flux is inversely proportional to the reluctances of the respective paths. Since the armature is symmetrical about its pivot and the pole gaps A to B equal the pole gaps C to D, the reluctance from A to B will equal the reluctance from C to D and the air gaps between the armature and A and D will be equal. Similarly the air gaps between the armature and C and B will be equal. The flux at air gaps C and B will therefore each equal ϕ_1 and the flux at air gaps A and D will each equal ϕ_2. The longitudinal flux through the armature will therefore equal $\phi_2 - \phi_1$.

The resulting force due to the polarizing flux acting at each end of the armature will therefore be

$$F_p = C(\phi_2^2 - \phi_1^2) \text{ where } C \text{ is a constant} \quad . \quad (7)$$

In the position of the armature shown in Fig. 4.19 the resultant force acts to the right in the case of the upper end of the armature and to the left at the lower end of the armature. Thus a clockwise torque on the armature is exerted by the two forces which maintains the armature in the operated position shown.

When a current flows in the operating windings, it produces a flux ϕ_c in the armature in a direction determined by the polarity of the current. This flux divides equally at the pole gaps since the reluctance of the path via the armature and pole shoes A and C is equal to that via B and D. Consider the case in which the direction of ϕ_c is in opposition to the polarizing flux ϕ_2 at the pole gap A; the resulting flux in this pole gap will be $\left(\phi_2 - \frac{\phi_c}{2}\right)$. The same resultant flux will exist at pole gap D. In the case of pole gaps C and B, however, the current flux will assist the polarizing flux and the resultant flux will in each case be equal to $\left(\phi_1 + \frac{\phi_c}{2}\right)$. The resultant force acting at *each end of the armature* will therefore be as follows—

$$\begin{aligned}\text{Resultant Force } F_R &= C(\phi_2 - \tfrac{1}{2}\phi_c)^2 - C(\phi_1 + \tfrac{1}{2}\phi_c)^2 \\ &= C((\phi_2^2 - \phi_1^2) - \phi_c(\phi_2 + \phi_1))\end{aligned}$$

therefore since $(\phi_1 + \phi_2) = \phi$,

$$F_R = C((\phi_2^2 - \phi_1^2) - \phi\phi_c) \quad . \quad (8)$$

that is

$$F_R = F_p - F_c \quad . \quad . \quad (9)$$

The direction of the resultant force acting at the upper and lower ends of the armature are mutually assistive in producing the total operating torque about the armature pivot.

Notice the general similarity of equation (8) with that of equation (3) derived from the first type of relay.

The various other arguments and conclusions derived in the first type of relay may be similarly derived in this case.

Type 3. The third basic type of relay shown in Fig. 4.17 (*c*) is similar to the second type already described in so far as its magnetic circuit operates on the bridge principle. There is, however, an important difference in the method of mounting the armature. In this case the armature is firmly and symmetrically clamped between the lower pole gaps between non-magnetic spacers. The armature is designed so that it is sufficiently flexible to enable it to be flexed as a cantilever between the pole shoes of the upper air gap. Thus considering for a moment the effect of this method of clamping the armature, it will be clear that, in the absence of magnetic forces, the armature will assume a position of rest such that it lies symmetrically between the upper pole gaps. If the upper extremity of the armature is then pulled to either left or right a bending moment will be produced causing it to deflect as a cantilever and the deflexion of the extremity of the armature will be proportional to the deflecting force applied. The armature and clamp develop a moment of resistance, i.e. a restoring force, acting in opposition to the deflecting force. Hence immediately the latter force is removed the armature will spring back and, after a period of damped oscillation about the neutral position, will finally come to rest in the neutral position between the upper poles.

In the design of polarized relays of this type it is a matter of choice, depending upon the relay characteristics required, as to what relationship is employed between the magnetic forces due to the polarizing flux and the mechanical force of restoration exerted by the armature when deflected. For example, if the resultant polarizing force on the

armature when operated is greater than the mechanical force of restoration, then the armature will remain in either operated position, even in the absence of current in the operating windings. Such a relay is then said to be "side stable." On the other hand, if the mechanical restoring force is greater than the polarizing force in the operating positions of the armature, then in the absence of operating current in the relay windings, the armature will

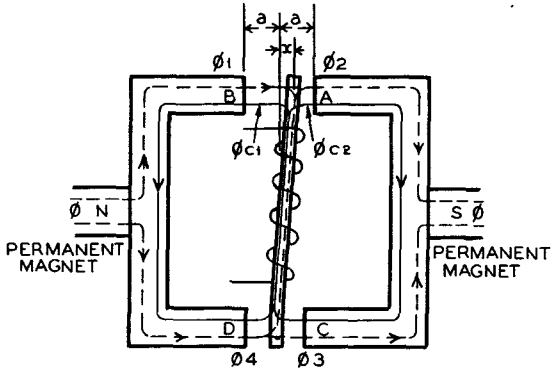


FIG. 4.20. ELEMENTS OF MAGNETIC CIRCUIT OF POLARIZED TELEGRAPH RELAY: TYPE 3

revert to its neutral, i.e. central, position. Such a relay is said to be "centre stable."

It will also be noted from consideration of Fig. 4.20 that this relay differs from relays of Type 2 in that only the upper extremity of the armature is effective in the production of operating forces since the lower end is clamped. Also, unlike the previous type of relay, the reluctances of the two parallel paths for the current flux are not constant but vary, depending upon the deflexion x of the armature.

Considering the operation of the relay, then, as the magnetic circuit is of the bridge type, the distribution of flux due to the permanent magnet will be similar to that in the case of the previous type of relay. In the position shown in Fig. 4.20, i.e. the armature deflected to the right, the flux due to the permanent magnet in the top right hand air gap is ϕ_2 and is greater than ϕ_1 in the top left hand air gap. In consequence the flux ϕ_4 in the lower left hand gap will be greater than ϕ_3, i.e. that in the lower right hand air gap. Since the armature is firmly clamped however in the lower gap the forces operating at this end of the armature do not play any active part in the operation of the armature. The resultant force due to the polarizing flux acting on the upper extremity of the armature is—

$$F_p = C(\phi_2^2 - \phi_1^2) \text{ where } C \text{ is a constant.}$$

This force is, however, opposed by the mechanical force of restoration due to the flexure of the armature and if we call this force F_r, then the resultant force on the armature to maintain it in its operated postition is $(F_p - F_r)$.

As already explained, the armature will remain operated when F_p is greater than F_r but will restore to its neutral position when F_p is less than F_r.

Now consider the effect of an operating current in the relay windings. This will produce a flux ϕ_{c2} in the right hand air gap and ϕ_{c1} in the left hand air gap. Suppose the direction of the current is such that ϕ_{c2} is in opposition to the polarizing flux ϕ_2, then conversely ϕ_{c1} will assist the polarizing flux ϕ_1. Hence the resultant magnetic force acting on the upper extremity of the armature will be—

$$= C(\phi_1 + \phi_{c1})^2 - C(\phi_2 - \phi_{c2})^2$$

and will be operating in the left hand direction. The mechanical force of restoration F_r will assist the resultant magnetic force so that the total resultant force F_R acting on the armature and operating to the left will be—

$$F_R = C(\phi_1 + \phi_{c1})^2 - C(\phi_2 - \phi_{c2})^2 + F_r \quad (10)$$

It should be noted that, as the value of F_r is proportional to the deflexion x and its sense is always such that it acts in a direction tending to restore the armature to its neutral position, that in the above equation the value of F_r is a maximum in the fully operated position of the armature; it falls to zero at the point where the armature reaches the neutral position and then increases in value and in opposition to the magnetic force actuating the armature to the left hand stop. Thus when the operating current has completed the operation of the armature to its left hand stop, the resultant force maintaining the armature in this position becomes—

$$F_R = C(\phi_1 + \phi_{c1})^2 - C(\phi_2 - \phi_{c2})^2 - F_r \quad (11)$$

These effects may be illustrated graphically as shown in Fig. 4.21 which indicates the manner in which the resultant polarizing force and force due to the operating current vary depending upon the position of the armature between the poles and the consequential changes produced in the flux paths during transit of the armature from one contact to the other.

Two curves are shown for the force produced by the operating current, namely C_1 C_3 C_2, which corresponds to, say, positive operating current and produces a force which tends to operate the relay armature to the right hand stop; and D_1 D_3 D_2 which corresponds to negative operating current

and tends to operate the relay armature to the left hand stop.

In the case illustrated in Fig. 4.21 the relay is side stable since the polarizing force is greater than the mechanical force of restoration. Thus in the right hand operated position the polarizing force $= B_2P_2$ and the force of restoration $= B_2R_2$. Now $B_2P_2 - B_2R_2 = B_2F_2$ and in the absence of current the armature is maintained by this force in the operated position. Similarly the resultant

If the armature is designed so that the force of restoration is approximately equal to the polarizing force in all positions of the armature then the work to be done in operating the relay is reduced and the sensitivity of the relay is greatly increased. (Note that the work to be done in moving the armature from the right to the neutral position is represented by the area OB_2F_2.)

In practice the movement of the armature is restricted by the contacts within the limits as

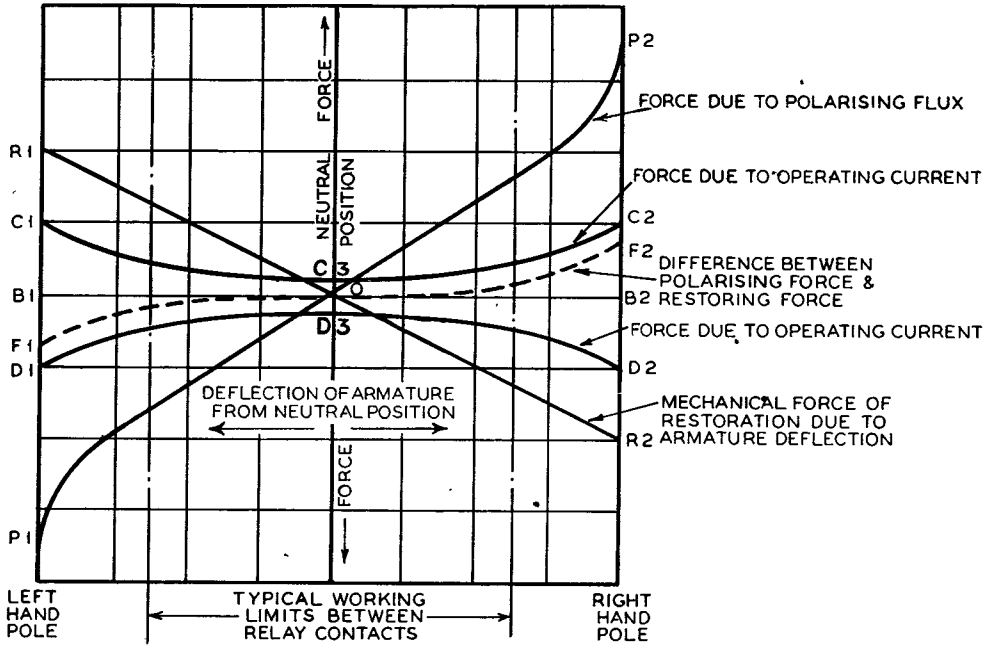


FIG. 4.21. GRAPHS SHOWING HOW POLARIZING, OPERATING AND RESTORING FORCES VARY WITH THE POSITION OF THE POLARIZED RELAY ARMATURE: TYPE 3

force when the armature is in the left hand position $= B_1F_1$.

To operate the relay, the force produced by the current must be greater than B_2F_2 and B_1F_1 respectively. Thus when operating the relay armature from right to left the current force B_2D_2 must be greater than B_2F_2. Since $B_2D_2 = B_2C_2$, $B_2D_2 - B_2F_2$ is equal in magnitude to C_2F_2 but acting to the left and this is the resultant force which accelerates the armature initially to the left. The resultant force during transit will be seen from the graphs to vary. Thus in the neutral position of the armature the resultant force $= OD_3$ and, when fully operated to the left by an energizing current, the resultant force maintaining it in this position

$$= B_1F_1 + B_1D_1.$$

indicated by the chain dotted lines in Fig. 4.21 and thus a close balance is maintained between the force of restoration and the polarizing force since only a small force is required from the operating current to produce operation of the relay.

It must be realized, however, that the increased sensitivity obtained by the use of a mechanical restoring force opposing the magnetic forces results in reduced contact pressures, particularly in the absence of a holding current.

Type 4. The fourth type of magnetic circuit employed in telegraph relays is of comparatively recent design and is that shown in Fig. 4.17 (*d*) and reproduced in Fig. 4.22.

It will be seen that the two permanent magnets are mounted with like poles toward the armature which is pivoted at a point approximately on the

centre line of these magnets. The flux paths from these magnets include the upper and lower air gaps, the pole pieces and the longitudinal reluctance of the armature. The reluctance of this path is substantially greater than that of the operating coil flux path which includes only the transverse

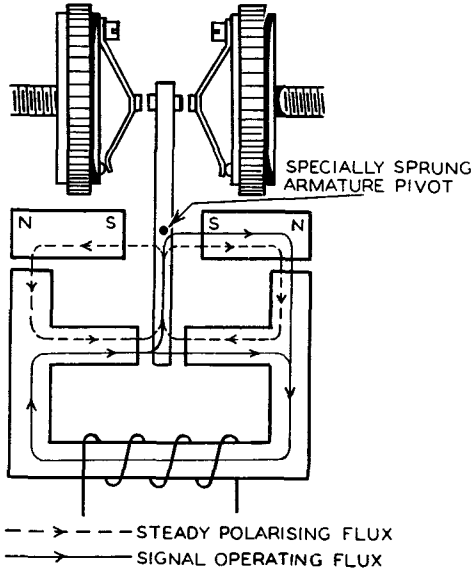


FIG. 4.22. ELEMENTS OF MAGNETIC CIRCUIT OF POLARIZED TELEGRAPH RELAY: TYPE 4

reluctance of the armature and the lower air gaps. The lower or operating gap is approximately one half that of the upper air gap and the total reluctance of the signal flux path is only slightly greater than that of the operating gap. The core of the operating coil is connected to points in the magnetic structure which are at the same magnetic potential when the armature is central. Further, the armature is pivoted approximately on the centre line of the magnets and its movements at this point are relatively small and produce very little change in the distribution of the permanent magnetic flux. When the armature is in the central position, permanent flux does not traverse the core of the operating coil and it is possible to use a core of small cross-section and hence a small operating coil. Since the pole pieces carry both the polarizing and the operating fluxes they are made of comparatively large cross-section to maintain a high value of incremental permeability. The design of the magnetic circuit as a whole ensures that the hysteresis and eddy current losses are reduced to a minimum and the operating coil produces a maximum effect on the armature.

It will be clear from a consideration of the magnetic circuit that, if the two permanent magnets are identical, the theory of operation of this type of relay is generally similar to that described for the first type and the various relationships derived in that case will also apply to the Type 4 relay.

The British Post Office Standard BN Relay. This is a polarized relay which employs the type of magnetic circuit illustrated in Figs. 4.17 (*a*) and 4.18. Details of the assembly are shown schematically in Fig. 4.23, and Fig. 4.24 gives side and top views of an actual relay of this type with its cover removed.

Two soft iron cores having arch-shaped pole shoes are placed side by side with the ends of two soft iron armatures playing between each pair of pole shoes; both the armatures and the cores are rendered magnetic by induction from a horse shoe magnet, the poles of which are placed behind the armatures. The magnet is placed with its south pole uppermost and is bent round the cores in the manner shown in Fig. 4.24 so as to make the relay as compact as possible. The whole assembly is mounted on a rectangular metal base and fitted with a cover. So that the relay may be easily removed from its circuit for maintenance purposes the internal connexions of the relay are terminated on springs of a jack fixed to the underside of the base. The external circuit connexions to the relay are wired to a plug fixed to a baseboard and mechanical arrangements are provided to enable the relay to be jacked in and out of circuit. Fig. 4.24 indicates how this is done.

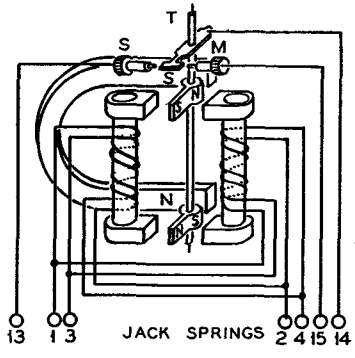


FIG. 4.23. SCHEMATIC DIAGRAM OF B.P.O. STANDARD BN RELAY

Two coils are wound on each core, each coil having a resistance of 200 Ω. Two of the coils (one on each core) are connected in parallel to jack-springs 1 and 2 and the other two coils are connected in parallel to jack-springs 3 and 4. The magnetic effect of the coils is well balanced, that is

the magnetic effect produced by a current flowing from jack-springs 1 to 2 is equal and opposite to the magnetic effect produced by an equal current flowing from jack-springs 4 to 3. The relay may therefore be operated differentially if desired.

The two armatures are manufactured from best quality Swedish iron carefully annealed after tooling and are securely fixed to a vertical spindle pivoted at the top and bottom which allows them to move freely between the pole shoes. Above the armatures the spindle carries a light contact tongue the end of which plays between two adjustable contact screws. These contact screws are mounted on an insulating block and are fixed to a carriage which may be caused to move through a small angle with respect to the armature spindle by turning a knurled knob situated in the base of the relay as shown in Fig. 4.24. This enables the relay to be readily adjusted for bias.

The permanent magnet is manufactured from tungsten steel and is fitted with its north-seeking pole downwards and its south-seeking pole upward. The flux from the north pole of the magnet passes through the lower armature whence it divides right and left through the pole shoes to pass up through the two cores; the flux then re-unites at the top to pass through the upper armature to the south pole of the magnet, thus inducing poles as shown in Fig. 4.23. It will be clear that this magnetic circuit is similar to the basic Type 1 described on page 90 except that in the case of the BN relay there are two armatures causing operation. The theory of operation is, however, the same for each.

The movement of the contact tongue and therefore the armatures is limited by the position of the contact screws but, as the carriage to which these are fixed can be rotated through a small angle about the spindle by means of a regulating screw, it will be seen that the position of the tongue and armatures in their operated positions can be varied with respect to the pole shoes, although the play of the tongue remains the same. When the contact carriage is central and the tongue is midway between the contacts, then the armatures will also be central with respect to the pole shoes and the relay will therefore be neutral. With this adjustment the armatures will remain on either contact when so operated and equal and opposite currents will be required to cause the relay tongue to be operated to "mark" and "space" respectively. If the contact carriage is moved from this adjustment then the operation of the relay will become biased, i.e. the value of operating current required through the windings to cause operation to either "mark" or "space" will no longer be equal. Thus if the carriage is moved so that when the tongue is on the

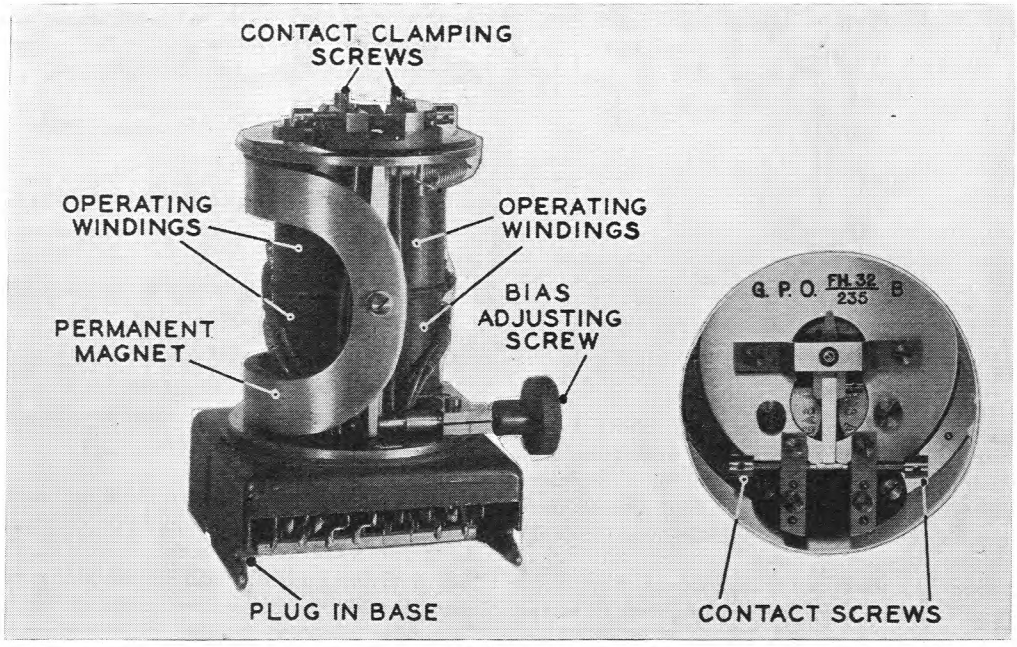


FIG. 4.24. SIDE AND TOP VIEWS OF B.P.O. STANDARD BN RELAY (COVER REMOVED)
(By courtesy of H.M. Postmaster-General)

"marking" contact the armatures are in a central position in the pole gaps then, in the absence of operating current, the armatures will be theoretically in a balanced magnetic position and the tongue will remain operated to "mark." The slightest further advancement of the carriage will, however, immediately cause the armatures to operate and the tongue will move over and make contact with the "space" contact. When a "marking" current is passed through the operating windings the relay

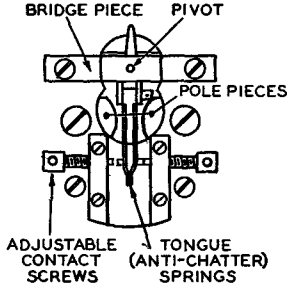


FIG. 4.25. RELAY TONGUE ANTI-CHATTER SPRINGS

tongue will operate to the "marking" contact but, immediately the current ceases, the armatures and tongue will restore to "space." The relay therefore has a "spacing bias." Conversely, if the contact carriage is moved in the reverse direction, the relay can be given a "marking bias."

In the earlier models of BN relays, the relay tongue consisted of a stiff piece of German silver carrying platinum contacts. The adjustable contact screws were also tipped with platinum. Experience showed that this arrangement was not entirely satisfactory owing to contact bounce, which is a common defect with relays having stiff tongues. When the armature and tongue move they possess kinetic energy which must be dissipated when impact occurs between the tongue and contact screws. If this energy is not completely dissipated during impact then the tongue will rebound and may bounce several times on the contact before finally coming to rest. This is disadvantageous since not only does it increase sparking and wear of the contacts but in addition effectively increases the transit time of the tongue from one contact to the other and this produces distortion of the signals repeated from the relay. To overcome contact bounce modern BN relays, in common with many other types, are fitted with a very light and flexible form of armature extension or tongue. Fig. 4.25 shows the device, called anti-chatter springs, as fitted to the BN relay.

The armature contacts are carried by two light nickel silver springs which are bent at their free ends and tensioned so that they exert a fixed pressure upon each other. By this construction the mass of the armature and contact assembly is kept as small as possible and this reduction in mass keeps the kinetic energy low. In addition, since the tongue springs are flexible, they bend when impact occurs with the contact screws and one spring is displaced with respect to the other causing the ends of the springs to slide one upon the other. The sliding friction assists in dissipating the energy of the moving armature and tongue and therefore tends to damp out any rebound due to impact.

The characteristics of Relay Standard BN are—

Two windings of 100 Ω and 4,000 turns each.

Sensitivity, i.e. minimum operating current $= \pm 0{\cdot}5$ mA.

Normal operating current $= \pm 15$ to 20 mA.

Contact gap $= 0{\cdot}002$ in.

Contact material: platinum.

Transit time $= 0{\cdot}25$ to 2 msec.

Contact pressure $= 4$ g with zero current, and 28 g with 15 mA current.

The Creed Relay. Fig. 4.26 shows a view of a Creed relay with cover removed. This relay employs the type of magnetic circuit illustrated in Fig. 4.17 (*b*) and Fig. 4.19 and the principle of operation is therefore as described on page 92. This relay may be wound with two line coils or with two line coils and two auxiliary coils as desired. Several types of line and auxiliary windings are available to suit various operating conditions. The principal components of the relay and the assembly arrangements will be self-evident from an examination of Fig. 4.26.

The armature is built up from laminations of Stalloy to reduce hysteresis losses. It is centrally pivoted and is embraced by two relay coils within which it is free to oscillate during operation. The relay coils are fixed and are firmly held in position within the pole pieces by means of a spring clamp attached to the top bearing plates for the armature pivot. The pole pieces are also constructed from laminations of Stalloy and are mounted within and embraced by a special bakelite moulding which carries the whole electromagnet unit. The electromagnet unit is pivoted at the top into the relay mounting frame in order that it may be rotated slightly with respect to the contact screws for biasing purposes. The bias adjusting screw bears

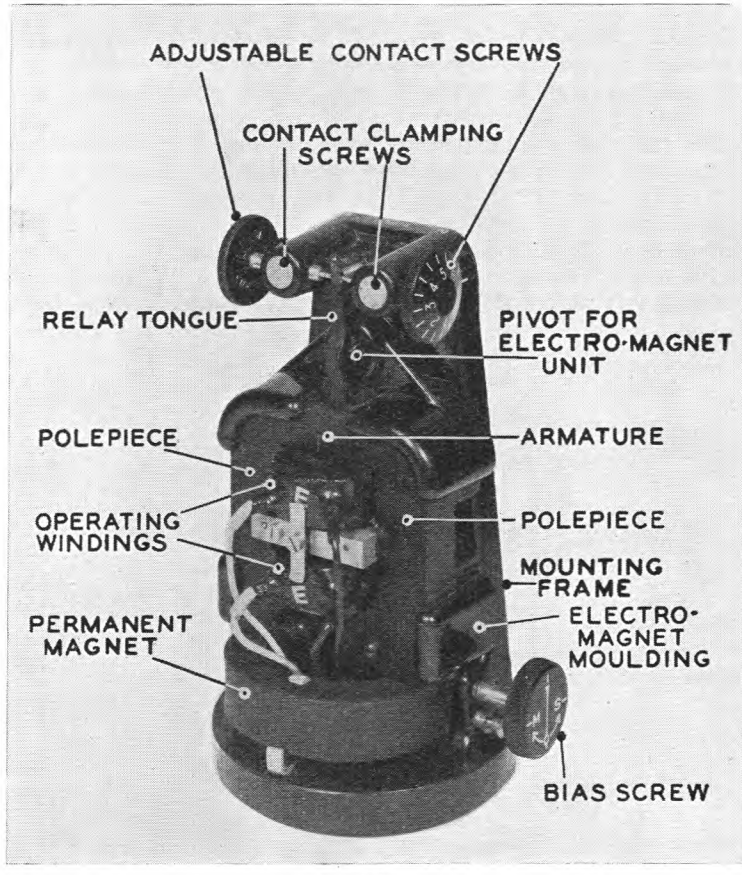
upon a lower projection of the electromagnet moulding and holds the lower end of the electromagnet unit to the left against a spring loaded stop. When the bias screw is retracted the spring stop forces the unit to the right. Thus "marking" or "spacing" bias can be given to the relay by rotation of the bias screw either clockwise or anti-clockwise. The bias screw is marked to indicate the direction of movement for "marking" or "spacing" bias and also has a zero arrowhead to indicate the central position.

The armature carries a lightweight extension which is fitted with platinum contacts at its extremity and these play between adjustable contact screws tipped with platinum contacts. Electrical connexion to the relay tongue is made by a very light low resistance helix, terminating in a hollow split plug which is connected to an electrical pin connexion on the relay supporting frame. The contact screws are fitted with graduated knurled knobs and each graduation corresponds to 1 mil movement of the contact screw, thus facilitating adjustment. A clamping screw is provided for each contact screw.

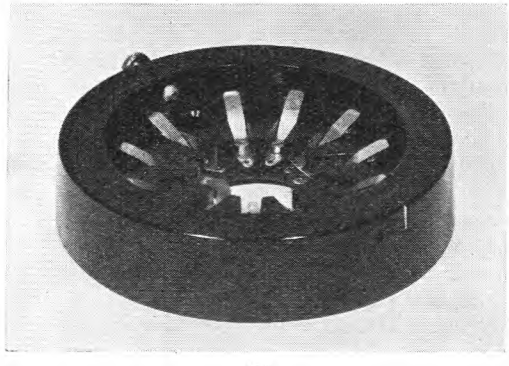
All electrical connexions of the relay are brought down to a plug-type base which may be inserted into a circular jack fitted with electrical connecting springs and the relay is mechanically locked into position when jacked-in by means of a spring loaded plunger on the jack base. When in service the relay has a circular cover with a hinged lid which a small lens is provided for viewing the tongue and contacts while the relay is in operation.

The operating characteristics of a typical Creed relay are—

Type C. Two windings each of 25 Ω and 1,200 turns.
Inductance = 3 to 4 H
Minimum operating current (both windings in series) = 2·5 mA.
Normal operating current=5 mA.



(*a*)



(*b*)

FIG. 4.26. CREED POLARIZED RELAY
(*a*) Relay (cover removed) (*b*) Relay Jack
(*By courtesy of Messrs. Creed & Co., Ltd.*)

Normal operating contact gap = 2 mils.
Transit time = 1 msec.
Current carrying capacity of contacts = 250 mA.
Contact pressure = 20 g with zero current and 90 g with 5 mA current.

For radio-telegraphy, type-G windings are recommended which comprise two windings each of 1,600 Ω and 6,280 turns. In this case the sensitivity is 0·5 mA and using a normal current of 1 mA the relay will operate at speeds up to 160 bauds without mechanical resonance.

The B.P.O. Relay No. 299. Fig. 4.27 (*a*) shows the details of the construction and assembly, while the arrangement of the relay elements and magnetic circuit are depicted in Fig. 4.27 (*b*). From this figure it will be seen that the form of the magnetic circuit conforms to that already shown in Figs. 4.17 (*c*) and 4.20 and the theory of operation is therefore the same. The operating windings are placed over the armature in the form of a single stationary spool, clearance being provided to allow the armature to move freely within the spool.

The operating windings comprise four equal windings which are normally employed for line connexions and two equal auxiliary windings which are usually employed either as vibrating windings (see Gulstad Relay, page 106) or as bias windings. Each line winding has 1,900 turns and a resistance of 185 Ω whilst each auxiliary winding has 800 turns and a resistance of 125 Ω. Fig. 4.28 shows the connexions of the relay windings; the numbers quoted refer to the tag connexions on the jack-in base. To ensure that the line windings are identical in characteristics, four similar insulated conductors are first twisted and then wound as a quad on the relay spool. The two vibrating windings are then wound on top of the line windings.

The armature is firmly clamped at its lower end between non-magnetic spacing pieces and the yokes. The non-magnetic spacers prevent the permanent magnet being short-circuited. This method of supporting the armature simplifies the relay design; the operating windings can all be wound on a single spool and the elimination of armature pivots removes a possible source of maintenance trouble.

Early models of this relay were fitted with a horse-shoe tungsten steel permanent magnet and such a magnet is shown in Fig. 4.27; the flux produced by this magnet is about 30×10^{-6} webers. Later models are fitted with a smaller magnet made of alnico producing a flux of about 67×10^{-6} webers. (Alnico is a modern magnetic alloy manufactured from aluminium, nickel and cobalt and possesses high coercivity and also permits smaller magnets with high retentivity.) The yoke and pole

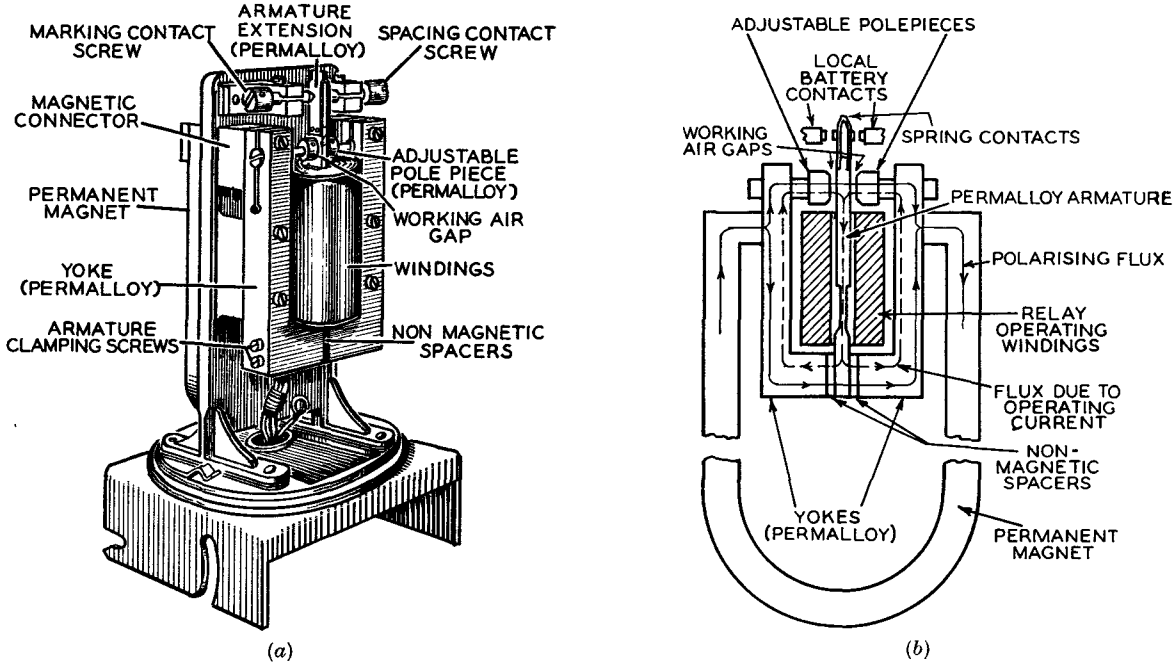


FIG. 4.27. DETAILS OF B.P.O. TELEGRAPH RELAY 299AN

pieces are manufactured of permalloy which is a nickel iron alloy of very low coercivity and high permeability. The pole pieces which are located one on each side of the top end of the armature are adjustable by means of their screw extensions, and clamping screws are provided for fixing the pole pieces after adjustment. The use of permalloy for these parts reduces the reluctance and considerably reduces the hysteresis losses.

For the same reasons permalloy is used in the construction of the armature. When a relay operates under the influence of reversals of current through the windings both operating and polarizing fluxes reverse in direction through the armature; the magnetic properties of the armature therefore play a very important part in the performance of the relay. Since permalloy has a very low coercive force, the flux collapses almost completely as soon as the magnetizing force is reversed; hence the relay is little affected by the previous state of magnetization to which it may have been subjected by a preceding signal and so the distortion of the signals repeated from the relay is reduced.

It will be observed from Fig. 4.27 (*b*) that the armature is waisted at its lower end. This is done to give the armature the necessary flexibility for movement but care is taken in the design to ensure that any mechanical resonances of the armature occur at frequencies which are well above the limits of the working range of signalling speeds: otherwise serious distortion will be produced in mixed signals of unequal length. This relay is suitable for use at speeds up to about 80 bauds and this is adequate for the majority of telegraph circuits. (Teleprinter working speed is usually 50 bauds.)

The armature extends beyond the end of the relay coil just enough to operate between the two pole pieces but its travel is limited by the contacts and not by the pole pieces. Two nickel silver anti-chatter springs are riveted at this end of the armature (one on each side) and are bent and tensioned so as to touch each other with a pressure of 20 to 60 g. The armature contacts are fixed to these springs and play between two adjustable contacts which are fixed to the rigid support carrying the permanent magnet. The material used for the contacts is copper-palladium, i.e. an alloy composed of 60 per cent palladium and 40 per cent copper.

Fig. 4.29 shows a front and rear view of a relay 299AN with the cover removed; the electrical plug connectors can be seen under the jack-in base.

The operating characteristics of Relay 299AN are as follows—

Four line windings each of 185 Ω and 1,900 turns.

Two vibrating windings each of 125 Ω and 800 turns

Effective turns ratio $\frac{\text{one line}}{\text{one vibrating}} = \frac{5}{2}$.

Minimum operating current (two line windings in series, i.e. 3,800 turns) = 0·3 mA.

Normal operating current (two line windings in series, i.e. 3,800 turns) = 5 to 6 mA.

Transit time = 0·5 to 2 msec.

Contact gap = 4 mils.

Contact material: copper-palladium.

Contact pressure = 4 g with zero current, and 30 g with 22·8 ampere-turns.

The B.P.O. Relay No. 320AN. This relay is generally similar in design to the 299AN relay but is less sensitive and is provided with only two balanced line windings each of 2,700 turns and a resistance of 110 Ω. It is cheap and very robust and, being a useful general purpose relay, it is extensively employed. Fig. 4.30 shows details of the connexions.

The armature is not waisted at the bottom as in the case of the relay No. 299AN and the permanent magnet provides a flux of only 22×10^{-6} webers; consequently this relay is centre-stable. The armature shows no tendency to mechanical resonance so that the relay can be worked at higher speeds than the 299AN and is satisfactory for speeds up to 150 bauds. A general view of the relay with cover removed is shown in Fig. 4.31.

The operating characteristics of the relay 320AN are as follows—

Two windings each of 2,700 turns and 110 Ω.

Minimum operating current (one line winding) = 4 mA.

Normal operating current = 15 mA.

Contact gap = 2 mils.

Transit time = 1·5 msec.

Contact pressure = centre stable with zero current, and 5·5 g with 82 ampere-turns.

Contact material: copper-palladium.

The B.P.O. Relay No. 324. This relay has exactly the same design characteristics as relay 320 except that, as the relay may be employed for modulating low voltage carrier tones, the contact material is platinum-iridium since this has a lower contact resistance to low voltage A.C. than copper-palladium. At one time this relay was extensively employed as a transmitting relay in multi-channel voice-frequency telegraph systems for modulating the voice-frequency carrier tones. It has, however, been superseded for this purpose by a static rectifier modulator.

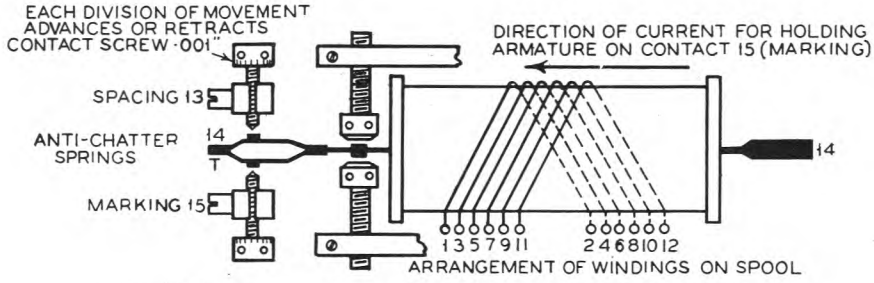


FIG. 4.28. CONNEXIONS OF B.P.O. TELEGRAPH RELAY 299AN

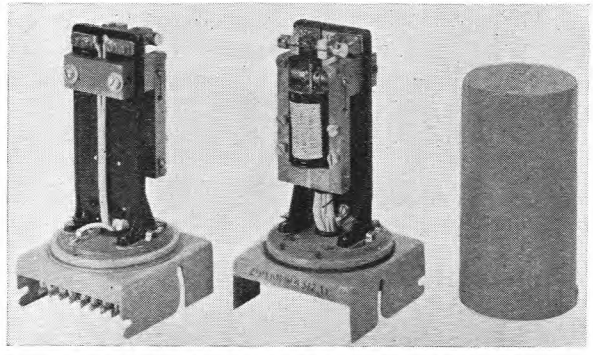


FIG. 4.29. B.P.O. TELEGRAPH RELAY 299AN

(By courtesy of Standard Telephones & Cables, Ltd.)

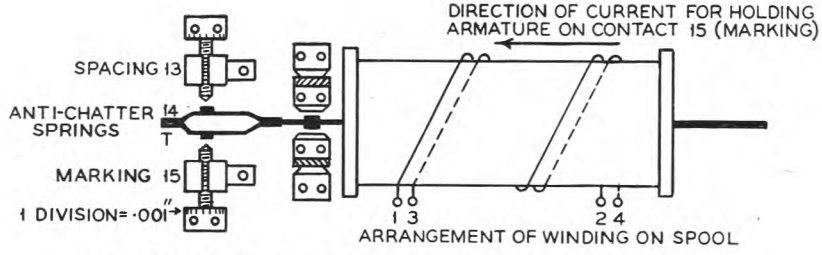


FIG. 4.30. CONNEXIONS OF B.P.O. TELEGRAPH RELAY 320AN

The B.P.O. Relay No. 328. This relay is similar to the relay 320 AN and has identical operating characteristics. It is not, however, provided with jack-in arrangements but is designed to fit on a 3000-type mounting plate to form a relay-set along

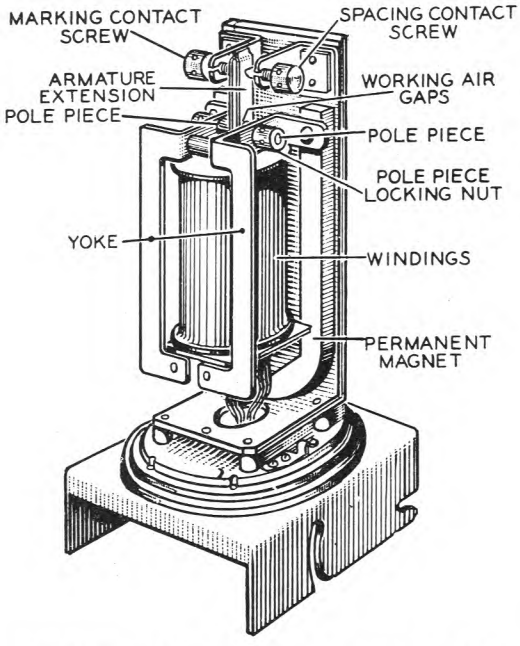


FIG. 4.31. B.P.O. TELEGRAPH RELAY 320AN
(COVER REMOVED)

with other relays of the 3000-type. External connexions to the relay are made on soldering tags. Fig. 4.32 shows a general view of this relay which is arranged so that adjustments to the pole pieces and the contact screws can be effected without removing the relay from its mounting on the plate.

This relay is particularly useful for incorporation in switching equipment where a few telegraph relays are required in association with a large number of telephone relays. The use of common mounting arrangements is, in these circumstances, of considerable help in the assembly design.

The operating characteristics are as follows—

One line winding of 15,000 turns and 1,600 Ω.
One auxiliary winding of 3,000 turns and 108 Ω.
Minimum operating current = 0·8 mA.
Normal operating current through the line winding = 8 mA.
Contact gap = 4 mils.
Transit time = 1·5 msec.
Contact pressure = centre stable with zero current, and 18 g with 75 ampere-turns.

The Carpenter Relay (Type 3). This is a high speed telegraph relay which employs the magnetic circuit illustrated in Fig. 4.22 and described in principle on page 95. It embodies a novel form of damped compliant mountings for the side contacts and the armature is hinged at its centre of gravity on springs, thus eliminating pivots. Fine adjustment of bias is provided by a movable magnetic member. The relay has a rigid compact construction and is of very modern design. The Type 3 relay is available in a number of forms and may be either side or centre-stable depending upon the operating characteristics desired. Fig. 4.22 gives a diagrammatic drawing of the magnetic circuit and shows the adjustable and damped compliant side contact mountings. The method of hinging the armature is by means of two flat springs, one on either side. Fig. 4.33 is an actual view of the upper part of the relay and is self-explanatory.

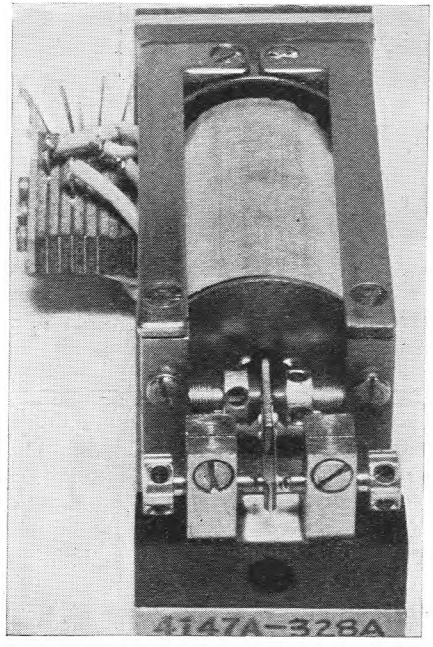


FIG. 4.32. B.P.O. TELEGRAPH RELAY 328
(By courtesy of H.M. Postmaster-General)

As already explained on page 96 the longitudinal reluctance of the armature is in circuit only with the permanent magnets and the operating winding has only to overcome the lower transverse reluctance of the air gaps and armature. The core carrying the operating winding connects points in the structure which are at the same mean magnetic potential. Hence the cross-section of this core need

only be large enough to carry the signals flux so that the diameter of the coil can be kept small and the resistance of the windings considerably reduced. Those portions of the iron circuit traversed by both the polarizing flux and the signals flux are made of ample cross-section so that their reluctance is negligible. The reluctance of the upper pair of air gaps between the inner poles of the magnets has to be overcome only by those magnets, hence their air gaps can be made wide and only the lower (i.e. working) gaps need be kept small as these carry the signals flux.

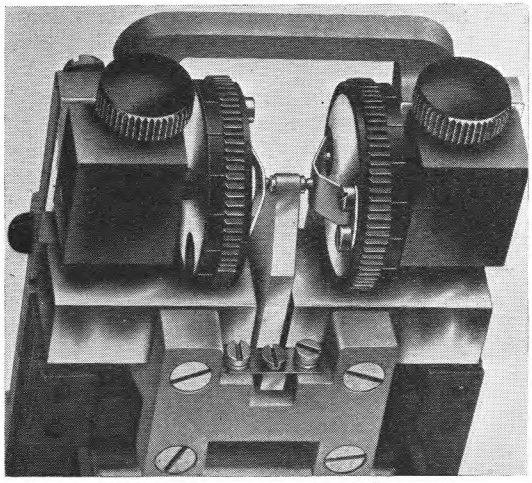


FIG. 4.33. TYPE 3 CARPENTER RELAY SHOWING ARMATURE AND CONTACT ASSEMBLY
(By courtesy of Telephone Manufacturing Co., Ltd.)

The permanent magnets are made from alnico; the pole faces are of laminated Mumetal and the armature is of radiometal. The use of modern magnetic materials and the novel design of the magnetic circuit enable the relay to be made with comparatively small dimensions.

Contact chatter is eliminated by the use of damped compliant mountings (see Fig. 4.33). Each side contact of copper-palladium is mounted on a bowed spring, one end of which is fixed and the other arranged to slide on a friction screw. The pressure between the spring and the friction screw is so adjusted that the armature is brought to rest as quickly as possible after the closure of the contacts. The damping is, however, deliberately made slightly less than critical in order to avoid the danger of introducing mechanical hysteresis. Apart from the question of accuracy of signal repetition by the relay, the rapid damping of the armature is of importance to enable the relay to work at high speeds and to prevent contact bounce. The compliance of the contact mounting is so chosen in relation to the moment of inertia of the armature as to make the frequency of oscillation high as well as heavily damped, and the armature is brought substantially to rest in approximately 2 msec.

A further advantage of the compliant mountings employed is that the working contact gap and hence the transit time can be made short whilst still maintaining adequate opening of the contacts. This follows from the fact that, after the free travel of the armature between break and make, the armature continues to move forward as a result of its momentum and operating force. Thus additional separation between the opening contacts is provided.

The contacts are adjustable by means of large insulated knurled screws with divisions corresponding approximately to $\frac{1}{1000}$ in. contact movement. The adjustment is locked by insulated knurled screws through fibre pads.

Coarse adjustment of the bias of the relay for neutrality is obtained by the setting of the contact screws. For fine adjustment a movable bias adjusting magnet is provided at the rear of the relay (see Fig. 4.34). The magnet is pivoted and may be swung to the right or left so modifying the flux in the right or left hand air gaps of the armature, thus controlling bias. The bias magnet is carried on a friction controlled screw, the head of which is accessible through a dust-trapped screwdriver hole in the back of the relay cover. Any slight bias introduced by the cover can thus be corrected *in situ*.

The operating coil is carried on a moulded bakelite bobbin and a large number of standardized windings is available up to a maximum of 20,000 turns.

For general purposes the Type 3E relay is usually provided having a winding of 48 + 48 Ω resistance and 1,800 + 1,800 turns, the inductance of each coil being 1 H at 50 c/s. If Gulstad working is required a six winding relay is employed comprising four windings each of 1,800 turns, 250 Ω and 1 H, and two windings of 900 turns and 200 Ω. Fig. 4.34 shows a rear view of the Type 3 relay with its cover removed.

In the Type 3 relay the wiring is terminated on a plug fitted to the base of the relay assembly. Fig. 4.35 shows a relay with cover jacked into a typical relay panel-jack. A special spring clip arrangement, as shown in the figure, can be fitted if required for retaining the relay and cover firmly in position when the relay is not mounted vertically or is likely to be subjected to vibration which may otherwise tend to dislodge it from its socket.

The operating characteristics of Type 3E are as follows—

The relay operates at all speeds up to approximately 400 bauds. Mechanical resonance occurs at about 440 to 480 bauds causing a slight bias of some 5 or 6 per cent but above this speed operation is again satisfactory up to about 700 bauds.

The optimum contact gap to be used depends upon the speed of signalling employed and in the case of speeds in excess of 300 bauds the gap should be reduced to the minimum which will handle the currents and voltages to be controlled.

The general purpose relay (3E2) has two coils and the normal operating current used in circuit design is 4 mA with the two coils in series aiding.

For Gulstad working the 3E1 has six coils (four line coils and two auxiliary) and requires an operating current of 2 mA through two of the line coils in series aiding.

Both the 3E types are side-stable.

If a centre-stable relay is required, Type 3.J.10 is available, having two line coils of 2,500 turns and 230 Ω each, and two auxiliary coils of 1,400 + 1,000 turns and resistance 200 + 130 Ω respectively.

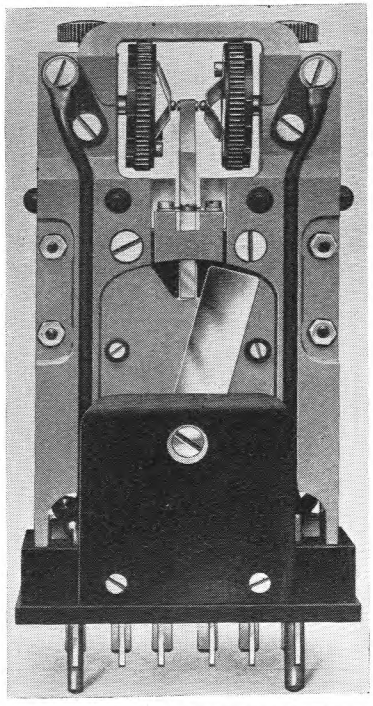


FIG. 4.34. TYPE 3 CARPENTER RELAY. REAR VIEW (COVER REMOVED)
(By courtesy of Telephone Manufacturing Co., Ltd.)

The Carpenter Relay (Type 4). In its essential features the Type 4 relay is identical with the Type 3 but is smaller and can be supplied to fit directly on to the drillings normally provided for the 3,000-type telephone relay. The wiring is taken out to soldering tags as in the 3,000-type. A plug-in type also adaptable to the 3,000-type drilling is available in addition.

A magnetic screening cover is supplied with the relay; it has a transparent removable top to facilitate contact adjustment. The relay is particularly useful as an impulsing relay in automatic switching systems. The operating characteristics of a typical Type 4 relay are as follows—

Type 4A4. One line winding and one auxiliary winding of 10,000 + 200 turns and 645 + 200 Ω respectively.
Minimum operating current through the line winding = 0·4 mA.
Normal operating current through the line winding = 4 mA.
Contact travel = 4 mils.
Transit time = 1 msec.
This relay is side-stable.

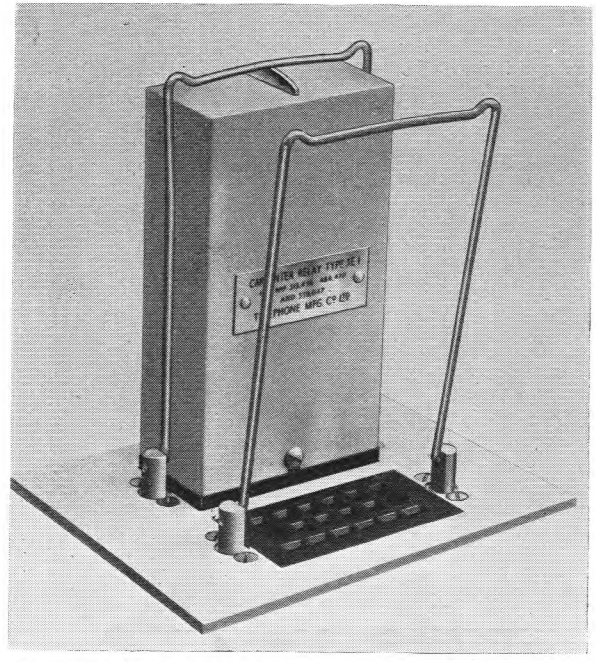


FIG. 4.35. TYPE 3 CARPENTER RELAY WITH COVER AND MOUNTED IN JACK WITH RETAINING CLIP
(By courtesy of Telephone Manufacturing Co., Ltd.)

A general view of a Type 4 relay is shown in Fig. 4.36.

The Carpenter Relay (Type 5). The Carpenter Type 5 relay is identical in principle with the

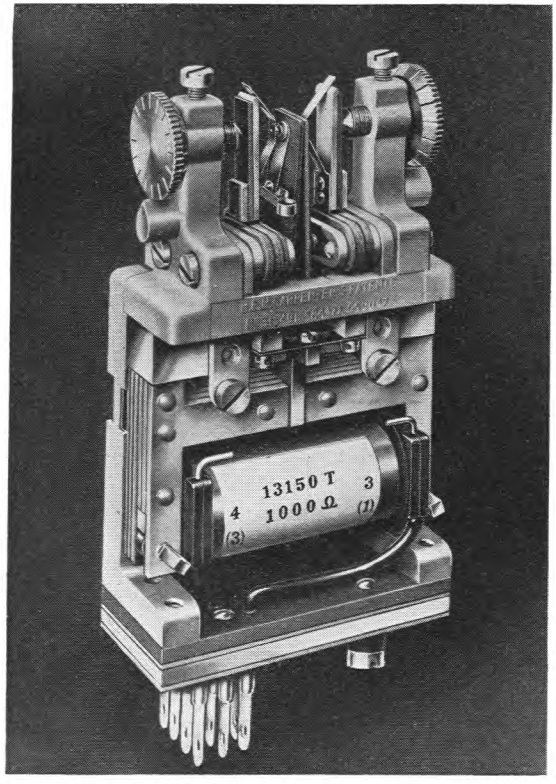


FIG. 4.36. TYPE 4 CARPENTER RELAY
(By courtesy of Telephone Manufacturing Co., Ltd.)

Types 3 and 4 described previously but is of much smaller size, the cover being the size of a match-box and the weight with socket 4·8 oz. At the same time the performance is not greatly inferior to that of the Type 4, similar input powers being needed for a 2 mil contact travel on the Type 5 as for a 4 mil travel on the Type 4.

The reduction in size has been brought about by the use of a design in which the magnetic pole-pieces form the main frame of the relay and carry all the other components. Thus no space is wasted on a separate frame structure and good mechanical strength and thermal stability are secured. A further space saving feature consists in making the main plane of the armature parallel with those of the flat pole-pieces.

Fig. 4.37 illustrates the constructional features of this relay.

No mechanical resonance capable of producing appreciable bias (i.e. $2\frac{1}{2}$ per cent or more) is experienced at speeds below 160 bauds. With most samples the first serious resonance occurs at about 240 bauds but the relay has, for some special purposes, been operated at much higher speeds.

Three models are available as follows—

(*a*) A lightly side-stable, highly sensitive model which, with a 0·002 in. static contact gap works robustly at 4 ampere-turns (r.m.s) at 100 bauds.

(*b*) A centre-stable model of slightly lower sensitivity.

(*c*) A heavy side-stable model which when adjusted to 0·003 in. static contact gap gives a contact pressure without signal of about 30 g, and requires 8 to 10 ampere-turns excitation.

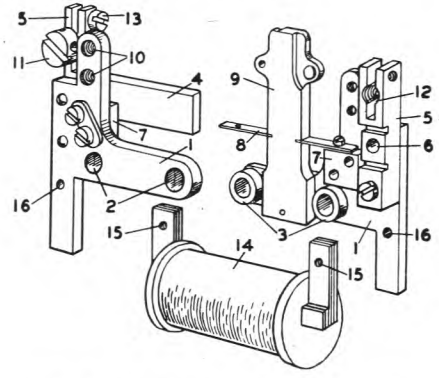


FIG. 4.37. CONSTRUCTIONAL DETAILS OF TYPE 5 CARPENTER RELAY

1. Pole-piece frame members.
2. Holes for main assembly bolts.
3. Spacers.
4. Magnet. The other magnet is not shown but bolts to
5. Spacing piece, by means of screw (not shown) inserted in
6. Hole.
7. Armature support blocks, to which are attached
8. Armature suspension springs.
9. Armature.
10. Bolt-holes in pole-pieces frame members which carry the contact support strips (not shown).
11. One of contact adjusting screws. The other, not shown, is screwed into slotted hole 12 in top of spacing piece 5.
13. Contact adjustment clamp screw.
14. Signal coil and laminated core, which is fixed to pole-piece members by screws passing through holes 15,15 and 16,16.

(By courtesy of Telephone Manufacturing Co., Ltd.)

The Gulstad or Vibrating Relay. The Gulstad relay was invented in 1898 by the Danish engineer Kay Oscar Gulstad who was Engineer-in-Chief of the Great Northern Telegraph Company.

This relay, although being a polarized type, was radically different in its principle of operation from previous types of telegraph relay. In other types of polarized relay the operation of the armature

was caused entirely by the electromagnetic forces produced by the signalling currents received in the line windings. In the Gulstad relay two special auxiliary windings are provided which are connected to a local battery supply through resistance and capacity components. The values of these components are chosen so that, in the absence of current in the line windings, the relay armature will vibrate continuously between its contacts under the control of the auxiliary, i.e. vibrating windings. The speed of vibration of the armature is arranged to correspond with the signalling speed at which it is desired to operate the circuit; thus theoretically, if the signalling speed is "X" bauds, the characteristics of the vibrating circuit are arranged to produce $\frac{X}{2}$ vibrations per second. (In practice the speed of vibration is arranged to be just slightly less than the signalling speed.)

The use of the vibrating principle in the action of the Gulstad relay results in the energy necessary to move the armature from contact to contact being supplied from the local battery acting through the vibrating windings, and the function of the signals received in the line windings of the relay is purely that of controlling the action of the vibrating circuit. The received signals will perform this function quite satisfactorily even when they are very weak.

The Gulstad relay therefore enables very much longer lines to be operated or alternatively allows circuits to be operated at a much higher speed, e.g. as much as 50 to 100 per cent greater than was possible when using normal polarized relays on physical circuits.

The principle of action of the Gulstad relay will now be examined in detail with reference to Fig. 4.38 which indicates the schematic circuit arrangements. The line is connected to the line windings L of the relay and the received signals pass through these windings and thence to earth. Two other windings, namely, the vibrating windings, are provided on the relay, namely, G1 and G2, and these are connected in the local tongue circuit of the relay with associated resistance and capacity components indicated as R, $R1$ and C.

Disregarding the action of the line coils for the present, and considering only the effects at the instant the relay tongue first makes contact with the spacing contact S, it will be seen that a current will flow in the two vibrating coils $G1$ and $G2$ as indicated by the dotted and full line arrows shown in Fig. 4.38. In the capacitor branch there is a surge of current whose maximum value is limited by the battery voltage and the resistance $R1$, neglecting the effect of the winding resistance which is small. Resistance $R1$ controls the rate at which the capacitor C charges and thus provides a means of controlling this time to any desired value. The current in the capacitor branch rises almost immediately to its maximum value and then dies away as the capacitor becomes fully charged. The current through the vibrating winding $G1$ is thus a transient one and flows in a direction whose effect is to maintain the tongue on the spacing contact.

Simultaneously with the effect just described,

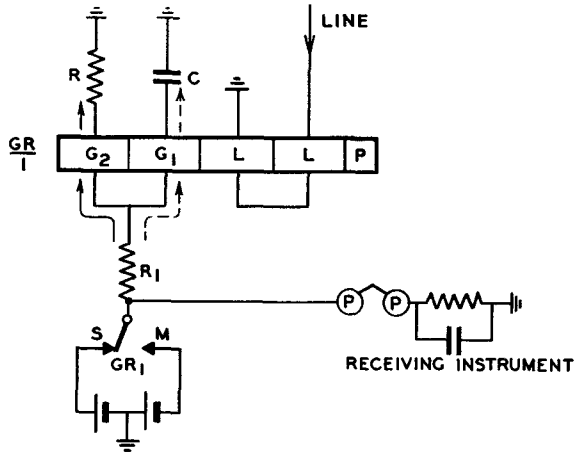


FIG. 4.38. PRINCIPLE OF THE GULSTAD RELAY

the current in the other branch via winding $G2$ is rising to a maximum value which is limited by the battery voltage and R and $R1$. This current flows through $G2$ in a direction which tends to operate the armature from the spacing to the marking contact; this action does occur in fact when the current in the capacitor branch falls sufficiently to allow its effect on $G1$ to be overcome by the opposing current in $G2$.

At the moment that the tongue moves off contact S to operate to M, current from the battery through $R1$ ceases; capacitor C, which is charged, immediately commences to discharge through windings $G1$ and $G2$ in series. The direction of this current assists the transit of the tongue over to the M contact.

The capacitor thus fulfils two important functions: it accelerates the transit of the tongue from one contact to the other and also holds the tongue firmly on the contact to which it has been operated at the moment it makes contact. This action reduces contact chatter and, by enhancing the impact and pressure upon the contact at "make," it assists in breaking down any oxide film present on the contact surfaces thus ensuring better electrical contact.

It will be clear that the flow of currents in the vibrating windings from the instant at which contact is made by the tongue with the marking contact, will be similar to those already described for the S contact except that the direction of the currents will be reversed. Thus the armature, after operation to M, will be reoperated to S, and so on. Hence if the relay is left entirely under the control of its vibrating windings it will vibrate continuously. The windings $G1$ and $G2$ are often referred to as the "accelerating" and the "opposition" windings respectively, because of the nature of their actions in the operation of the relay armature. The rate of vibration is fixed by the electrical constants of the circuit; it is increased by reducing the value of C and $R1$ and is adjusted to synchronize with the speed of transmission of the line signals.

In the absence of line signals the vibrations of the relay armature will cause signal reversals to be transmitted continuously to the receiving instrument.

It is now necessary to consider the action of the line signals in the line windings. The function of these signals is purely to control the action of the vibrating circuit and for this purpose it must suppress the vibrating action during those signals which are of longer duration than a unit signal element, i.e. dash, letter space and word space in the case of Morse. To do this, the current in the line windings must reach a value which is greater than, and in opposition to, the effect of the "opposition" windings at the instant at which the latter would otherwise reverse the armature. The resistance R in Fig. 4.38 determines the maximum current through the opposition windings and this is adjusted so that the line current takes control when dashes and letters and word spaces are being received. At the end of any of these signals the current in the line windings begins to fall and reverse and immediately its value becomes less than that in the opposition windings, the latter takes charge and causes the armature to operate to the other contact stop, so transmitting a spacing or marking signal depending on whether the preceding signal was (*a*) a dash or (*b*) a letter or word space respectively.

If in case (*a*) the line signal following a dash is a space, then the opposition winding will reverse the armature to the marking stop at the end of space. If, however, the line signal is a letter or word space, then the line current will override the action of the opposition winding until the end of the line signal, thus maintaining the armature tongue on the spacing contact. Similarly, if in case (*b*) the line signal following a letter or word space is a dot, then the opposition winding will reverse the armature to spacing at the end of the dot. If, however, the line signal is a dash, then this will override the action of the opposition winding and maintain the tongue on the marking contact until the end of the line signal for a dash.

It will be noted from the foregoing that it is unnecessary for the line current to fall to zero and reverse in sign before the relay tongue is reversed. As soon as the line current falls sufficiently below that in the opposition coil, the relay reverses under the action of the current in the opposition coil. This anticipatory action has a regenerative effect on the retransmitted signals with consequent reduction in the signal distortion and is a contributory reason for the increase in speed on long and difficult circuits which is possible with the use of Gulstad relays.

Many modern telegraph relays are designed to incorporate auxiliary "G" windings which may be employed for operating the relay on the Gulstad principle on long submarine or land-line metallic circuits. A typical application employed in B.P.O. practice has been the use of the 299AN relay with a "G" circuit as a receiving relay and repeater in private wire circuits in those cases where the circuits are routed over phantom or double phantom lines (see Chapter 7).

Testing of Telegraph Relays

The standard of performance of any telegraph system depends upon the soundness of design and construction of its components and the correctness of mechanical and electrical adjustments. Telegraph relays are very important items in most telegraph systems and it is necessary that means should be provided to ensure that their operating characteristics are satisfactory before putting them into service. For this purpose a "Relay Test Set" is normally provided at all telegraph stations having a number of relays in operation, e.g. M.C.V.F. terminals, Telegraph Switching Centres and large instrument rooms. Where only a few relays are in use then for economic reasons the working relays are normally replaced at regular intervals by spare relays which have been tested and adjusted at the nearest relay testing office.

In all cases, to ensure long periods of trouble free service, relays should be checked and adjusted in conjunction with a relay test set both before being put into service and subsequently as a routine operation. The periodicity of these routine checks will depend upon the use made of the relay and the electrical load carried by its contacts, e.g. broadcast relays usually require attention monthly, whereas the receiving relay of a channel in a M.C.V.F. system is normally only routined once in three months in B.P.O. practice.

There are various forms of relay tester in use, some are panel mounted on a wall or rack and others table mounted.

The main operating characteristics of telegraph relays which require to be checked are however similar and all telegraph relay testers are designed to check these characteristics despite the individual differences in the physical form of the testers and the electrical test circuits used.

Fig. 4.39 shows a view of a typical relay test panel used by the B.P.O. which is suitable for testing a number of relays, namely, Relays Standard BN, GN and HN and Relays 320AN and 299AN. The relay to be tested is plugged into the test jack provided on the tester and the test conditions are applied by the operation of various keys. The milliameter is provided to observe the behaviour of the relay under test. (In some designs of relay testers a cathode ray tube is incorporated to observe the behaviour of the relay.)

The facilities provided in the tester illustrated are as follows—

(*a*) Continuity of the windings.
(*b*) Sensitivity of the windings.
(*c*) Neutrality of the windings.
(*d*) Contact time or transit time.
(*e*) Continuity and neutrality of the vibrating coils.

Power Supplies. The tester requires the following power supplies—

(*a*) $\pm$ 40 V or + 80 V and earth, and
(*b*) An alternating current supply which is usually obtained from a 17 c/s telephone ringing supply or 50 c/s mains. In both cases the supply is connected to the relay under test by means of a transformer which reduces the voltage applied to the relay to 4 V.

Where the battery supply is $\pm$ 40 V the testing circuit is connected across both sections of the battery and to eliminate the possibility of false readings, due to inequalities in the two halves of the battery, the power supply for the tongue circuit is fed from a potentiometer which is connected across the battery supply. The return circuit is brought back to the centre point of the potentiometer which consists of two 2,000 Ω resistors. A resistor is also connected in the tongue circuit of the relay under test to limit the current to 20 mA.

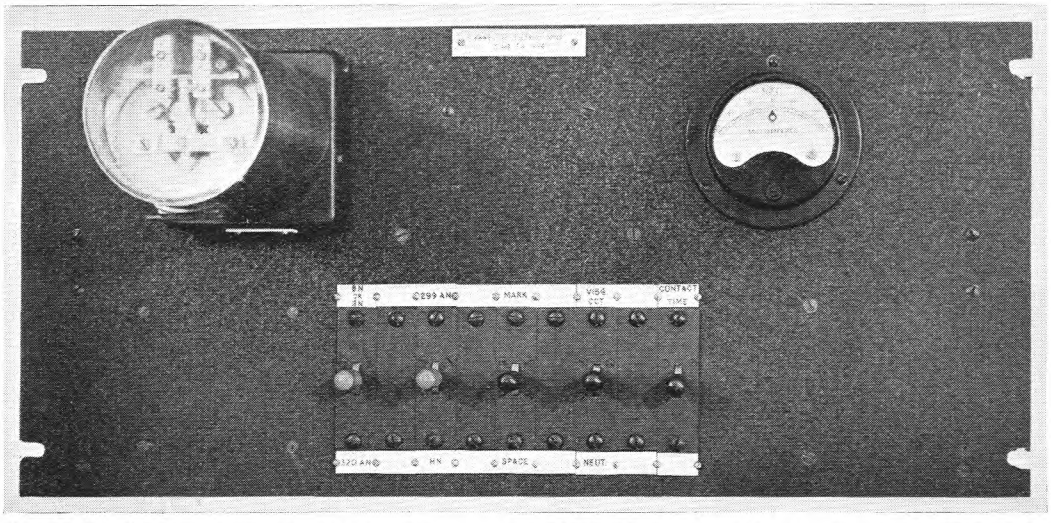


FIG. 4.39. A TELEGRAPH RELAY TEST PANEL FOR B.P.O. TELEGRAPH RELAYS STANDARD BN, GN, HN AND 320AN AND 299AN

(*By courtesy of H.M. Postmaster-General*)

Test for Continuity and Sensitivity (Fig. 4.40). These tests are both carried out at the same time. The relay is plugged into the test jack and the key appropriate to the type of relay under test is operated. This inserts a resistor in series with the line coils which limits the current to the minimum operating value for the relay. Key 3 is then operated and the battery is thereby connected to both the line coils and the tongue circuit. Key 3 is a two-position key and when operated in opposite directions reverses the connexions of the battery applied to the line coils. If the relay is correctly adjusted and has neither marking nor spacing bias the deflexion of the milliammeter will be reversed when the key is reversed, thus proving the sensitivity and continuity of the line coils. The resistors in each case are non-inductive.

Neutrality Test (Fig. 4.41). The key appropriate to the type of relay under test is again operated. The neutrality test key is then operated which causes alternating current (either 17 c/s ringing or 50 c/s supply) to be connected to the line coils. The resistance used for the sensitivity test is disconnected, the battery being again connected to the tongue circuit. Neutrality or bias of the adjustment will be indicated by the needle of the milliammeter. If the relay is neutral the needle will indicate zero although the tongue of the needle is vibrating.

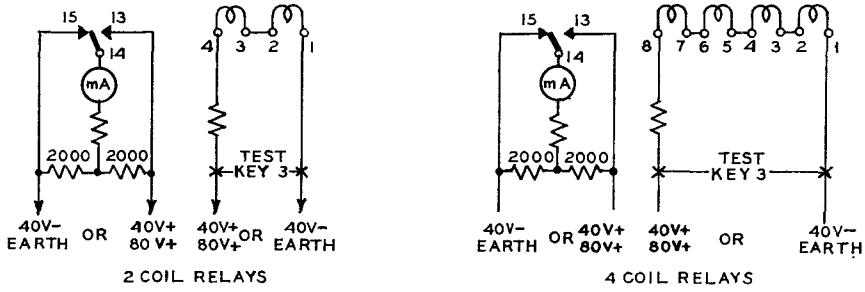


FIG. 4.40. CONTINUITY AND SENSITIVITY TEST OF A TELEGRAPH RELAY

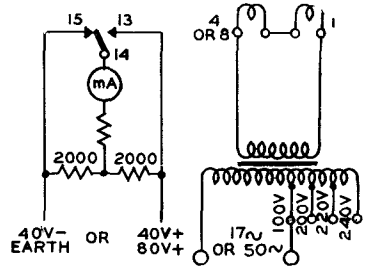


FIG. 4.41. NEUTRALITY TEST OF A TELEGRAPH RELAY

Contact-time Test. The conditions set up by the key for this test are shown in Fig. 4.42 from which it will be seen that the same pole of the battery is connected to both contacts of the relay under test and alternating current is applied to the line coils. The needle of the milliammeter is therefore deflected in the same direction irrespective of whether the tongue rests upon the marking or spacing contact. When the tongue is in transit between the contacts the battery is disconnected from the milliammeter and the needle therefore tends to return to zero. The longer the transit time the closer the needle approaches zero, hence the deflexion registered when the tongue is vibrating may be regarded as indicating the relative contact time. For example, assuming the transit time between the contacts is nil, the deflexion would be the same as when the tongue is resting upon either contact. As, however, in practice there must be a finite transit time the deflexion will always be less than the steady deflexion which would occur when the tongue is resting upon one or the other contact.

The resistor in the tongue circuit is adjusted to give a steady deflexion of 20 mA with the tongue at rest. This will permit of the deflexion on the milliammeter when the tongue is vibrating being read as a percentage of the total contact time by multiplying the actual reading by five.

For example, suppose the contact time test is indicated by a deflexion of 18 mA.

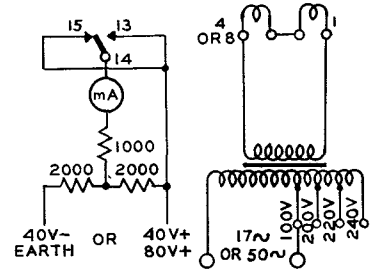


FIG. 4.42. CONTACT-TIME TEST OF A TELEGRAPH RELAY

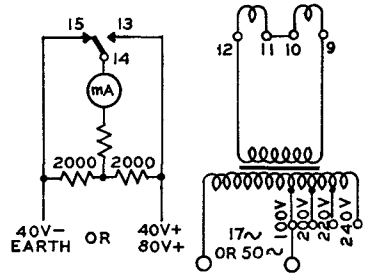


FIG. 4.43. NEUTRALITY AND CONTINUITY TESTS OF VIBRATING COILS

Then since the steady deflexion is 20 mA, the percentage contact time is

$$= \frac{18}{20} \times \frac{100}{1} = 18 \times 5 = 90 \text{ per cent.}$$

The transit time T can also be calculated from—

$$T = \frac{1}{2f} \times \frac{(D - d)}{D} \times 1{,}000 \text{ msec}$$

where f is the a.c. supply frequency and d is the measured deflexion during vibration and D the steady deflexion when on one contact.

Thus in the example quoted and using a 50 c/s a.c. supply

$$T = \frac{1}{2 \times 50} \times \frac{(20 - 18)}{20} \times 1{,}000 = 1 \text{ msec.}$$

By means of this test a very close setting of the contacts and consequently a short transit time may be obtained.

Neutrality and Continuity Tests of Vibrating Coils (Fig. 4.43). This test is similar to that employed for testing the sensitivity and continuity of the line coils. Operation of the appropriate key connects battery to the tongue circuit and alternating current to the vibrating coils. If the relay is correctly adjusted the tongue will vibrate between the contacts and the needle will therefore take up a zero position.

Differential Test. When a relay is to be employed differentially it is essential to check this characteristic of the relay and some testers apply this test condition. The basic method is to apply a.c. differentially through the windings. If the coils are electrically equal, the magnetic effects will be equal and opposite. The relay tongue should not therefore operate and this can be observed on a milliammeter connected in the tongue circuit.

CHAPTER 5

TELEGRAPH TRANSMISSION THEORY

ORDINARY telegraph systems are designed to permit the electrical communication of intelligence with the minimum possible requirements in regard to the electrical characteristics of the transmission link. This is achieved by making use of a simple arbitrary signal code to represent letters, figures, and signs, which avoids the need for transmitting the complex wave-forms required for telephony or facsimile reproduction. By this means, at the expense of some complication of the transmitting and receiving apparatus compared with that required for telephony, substantial economies in line plant are secured.

The telegraph signals are formed at the sending end of the telegraph channel by making simple

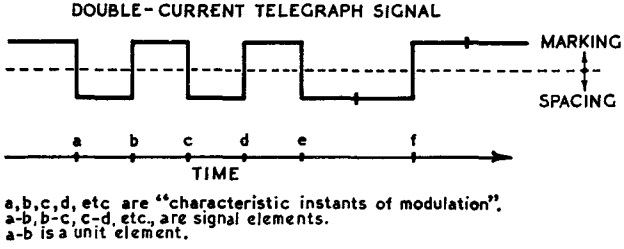


FIG. 5.1. DOUBLE-CURRENT TELEGRAPH SIGNAL

changes in the electrical conditions such as, for example, switching on and off or reversing, a steady potential, or switching on and off a voice-frequency tone, the important fact being that the significance of the signals so formed is fixed by the time intervals between successive switchings or reversals. At the receiving end the transmission is completed by the recognition of these time intervals by the receiver, thereby enabling the required characters to be recorded.

It is important that the "time-interval" characteristic of telegraph signals should be appreciated, because this feature is the basis of telegraph transmission technique and the various factors of signalling speed, distortion, and reception margin are all defined in relation to the basic time intervals on which the signals are built up.

Definitions of Terms Relating to Telegraph Transmission. To discuss both practical and theoretical telegraph transmission problems and to provide a basis for the determination of the transmission qualities of telegraph transmission channels, it has been necessary to introduce certain terms, which are defined as follows.

Telegraph Signal. A combination of signal elements characterized by their variety, duration, spacing and law of succession, or by some of those characteristics only, which together perform one function, e.g. the transmission of a character.

Telegraph Modulation. Operations performed at the sending end of a telegraph transmission channel causing a device in the transmitting apparatus to assume abruptly successive discrete conditions, which have the effect of varying in time one of several defined characteristics of an electric current, with the object of causing at the receiving end a series of discrete conditions in the appropriate device in the receiving apparatus.

Restitution (of a telegraph modulation). Operations performed by the appropriate device in the receiving apparatus in assuming a series of discrete conditions as a result of a telegraph modulation.

Characteristic Instants (of a modulation or of a restitution). Instants at which the discrete conditions of a modulation (or of a restitution) begin.

Restitution Delay. The delay between a characteristic instant of modulation and the corresponding instant of restitution.

Signal Element. That part of a modulation (or of a restitution) occurring between two successive characteristic instants.

In most telegraph systems the signal elements have a duration equal to, or a multiple of, the duration of the unit element. In start-stop systems, however, the duration of the stop element may not conform to this relationship.

Unit Element. The shortest signal element in a standardized telegraph system.

Code Elements. The unit elements in an equal length multi-unit telegraph code from permutations of which the code is formed.

Isochronous Modulation (or Restitution). Modulation (or restitution) in which the time interval separating any two characteristic instants is theoretically equal to the unit element or a multiple of this.

Start-stop Modulation (or Restitution). Modulation (or restitution) characteristic of start-stop systems.

Some of the foregoing terms are illustrated diagrammatically in Fig. 5.1.

The essential characteristic of the transmitted

electrical wave lies in the changes in character produced by the characteristic modulations and, although the changes may be effectively instantaneous at the sending end, they lose their sudden character during their propagation through the line and terminal equipments. This delay in the building up of the received signal to its final state is mainly due to the transient effects which in general accompany the changes in the transmitted wave. On account of the distortion of the transmitted wave the recognition, at the receiving end, of the time intervals between the original changes or modulations may be a matter of some difficulty. To complete the transmission, therefore, it is usual to restore the abrupt nature of the changes by some form of relay. The latter should have the property of producing locally instantaneous electrical or mechanical changes at instants corresponding to those at which the amplitude of the operating current is equal to some predetermined value.

The foregoing effects are illustrated in Fig. 5.2, which refers to the transmission of double-current telegraph signals on a simple telegraph circuit terminating on a polarized relay. The first graph shows the modulations produced by the transmitter, which consist of voltage reversals. The short periods of zero voltage, shown in the voltage graphs, occur when the tongue is moving from one fixed contact to the other. The second graph indicates the current flowing into the line. It will be seen that the peak value of the surge current is far in excess of the steady current, the current scale being one-fifth of that used for the received current. Two cases of received current have been given. In the first case the duration of the transient conditions—that is, the build-up time—is slightly less than the duration of the shortest signal element, i.e. the unit element, whereas in the second case, which gives the received current for a line of greater length, the build-up time is approximately twice the duration of the shortest element. If the duration of the transient, or build-up time, is shorter than that of the shortest element of modulation, the shape of the received signals will be unaffected by previous signals under all conditions, as the received current will always reach the steady state before the commencement of the next element. Assuming this to be so, then in the absence of external disturbing influences the response of the system to a modulation will always be the same, and the instantaneous changes produced by a perfect receiving relay will always occur with a constant delay after the corresponding operation at the origin of transmission. Under these circumstances the received signals will be in exact accordance with the operation of the transmitter, and the system will be telegraphically distortionless. For example, in the first case of Fig. 5.2, the received current always reaches the steady condition within the length of the signal elements, and therefore no distortion occurs, but in the second case this is not

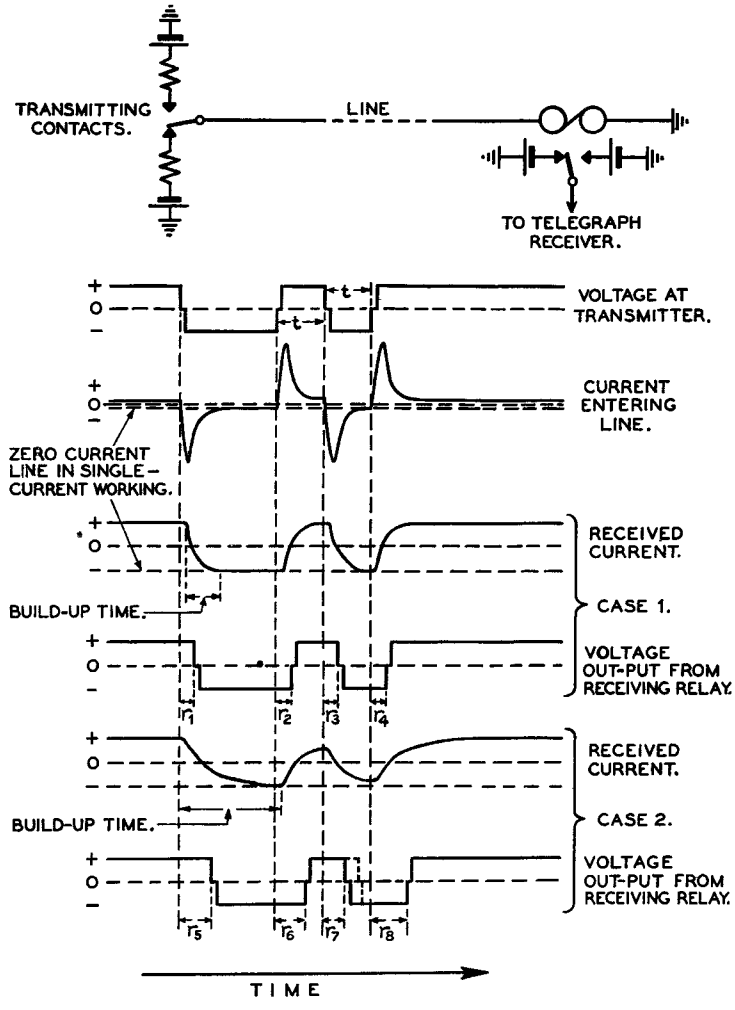


FIG. 5.2. GRAPHS OF SENT AND RECEIVED SIGNALS SHOWING BUILD-UP TIMES AND RESTITUTION DELAYS

so and as a result the second signal element is shortened and the third element lengthened. The way in which this distortion is measured and expressed is dealt with later.*

Telegraph Speed: The Baud. The degree of imperfection of the received signals is to a large extent dependent upon the relation between the duration of the transient effects and the duration of the unit element of modulation. These two factors are therefore of primary importance in telegraph transmission, since the maximum rate at which information may be passed over a channel is inversely proportional to the duration of the unit element of modulation. These facts have led to the use of the unit element of modulation as the basis for the numerical expression of modulation rate, i.e. telegraph speed, which is defined as the inverse of the duration (expressed in seconds) of the unit element of modulation. The unit of modulation rate, i.e. telegraph speed, therefore corresponds to one unit element of modulation per second and is called the *baud*. In Fig. 5.2 the duration of the unit element of modulation is shown as t sec, and the modulation rate in bauds is therefore $\frac{1}{t}$.

The following examples show the application of this definition to some well-known telegraph systems.

Teleprinter. $7\frac{1}{2}$-unit code, operating at 400 letters per min (i.e. speed of transmitting shaft is 400 r.p.m.).

$$\text{Duration of one letter} = \frac{60}{400} = 0{\cdot}15 \text{ sec.}$$

$$\text{,, of the unit element} = \frac{0{\cdot}15}{7{\cdot}5} = 0{\cdot}02 \text{ sec.}$$

$$\text{Telegraph modulation rate} = \frac{1}{0{\cdot}02} = 50 \text{ bauds.}$$

(*Note.* Assuming an average word of 5 letters and 1 space signal, 400 letters per min = 66·6 words per min.)

* Actually, distortionless transmission is still obtainable when the duration of the transients exceeds the unit element, it only being necessary that transients due to one modulation shall have died away before the receiving relay operates in response to the next following modulation. This requirement sets a theoretical maximum transient time equal to twice the duration of the unit element. To secure this limiting condition in double-current working, the requirements are that the receiving relay shall always change over when the current passes through zero, and the time taken for the current to pass from steady positive to zero is equal to the time taken from zero to steady negative. In practice such perfection is neither obtainable nor essential, but in all systems there is some limit to the permissible departure of the received signals from perfect agreement with those at the origin.

Wheatstone automatic. Assume that the transmitter is operating at a speed of 20 ft of perforated tape per min. As there are 10 centre holes per in., this is equivalent to 40 centre holes per sec, or 40 dots per sec. As each dot is followed by a spacing period equal to the duration of the dot, the length of a dot signal, which is the shortest element in the code, is $\frac{1}{80}$ sec, and the telegraph speed is therefore 80 bauds. To convert this to words per minute it is necessary, because Morse is an unequal length code, to know the average number of unit elements which are equivalent to a word of five letters with one word space. For Continental Morse and plain English this is 51·6, but for telegraph traffic it is usually taken as 48. Thus a telegraph modulation rate of 80 bauds is equivalent to $\frac{80}{48} \times 60 = 100$ words per min.

Baudot Multiplex. Quadruple system with two correcting segments, distributor running at 180 r.p.m. Number of segments on transmitting ring $= 4 \times 5 + 2 = 22$.

$$\text{Duration of unit element} = \frac{60}{180} \times \frac{1}{22} = \frac{1}{66} \text{ sec.}$$

Telegraph modulation rate = 66 bauds.

Cable Code. Automatic transmitter operating at 1,200 centre holes per min. In this case there is one element (dot, dash, or space) per centre hole so that the telegraph modulation rate is 20 bauds. For cable traffic the average number of unit elements per character is taken as 3·7, or 22·2 per word of five letters and one space. In this case therefore 20 bauds is equivalent to $\frac{20}{22{\cdot}2} \times 60$ = 54 words per min.

In cable transmission, to improve the signal shape it is often arranged for the battery only to be applied to the line for from 75 to 85 per cent of the duration of the signal elements. This does not however affect the baud speed as the number of unit elements per second is still equal to the number of centre holes per second.

Telegraph Distortion. The process of reproducing the characteristic instants of modulation at the receiving end by means of some form of relay has been given the name *restitution of modulation*, while the time interval between a characteristic instant of modulation and the corresponding characteristic instant of restitution is called the *restitution delay*. In the cases illustrated in Fig. 5.2, graphs have been drawn giving the output from the receiving relay tongue, assuming that the tongue of the relay always changes over when the current has reached a value equal to half the steady current. The time delay of the resulting signals with respect to the

original signals is indicated by r_1, r_2, r_3, r_4 in the first case, and r_5, r_6, r_7, r_8 in the second case. These time intervals are the restitution delays. In the first case these delays are all equal, for the reasons already explained; the timing of the received signals is therefore in exact accordance with that of the sent signals, and the system is telegraphically distortionless. In the second case, r_7 is considerably shorter than r_5, r_6 and r_8, and distortion results to the corresponding signal elements. In practice, the restitution delays may vary appreciably from one instant to another, and with excessive deviation from constancy the correct interpretation of the received signals is either impossible or involves unduly meticulous adjustments. The accuracy and stability of operation of a telegraph circuit is dependent on the extent of these deviations, and their value is therefore used to express the quality of transmission. The method adopted will be described by reference to Fig. 5.3.

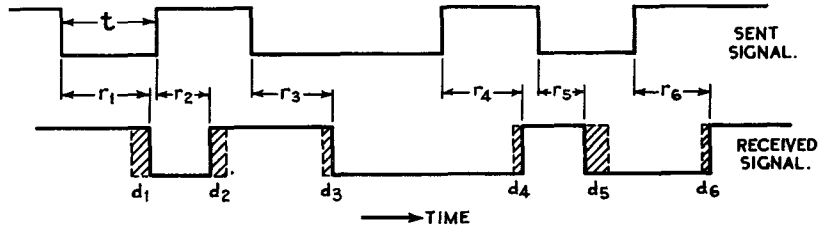


FIG. 5.3. DISTORTED TELEGRAPH SIGNAL ILLUSTRATING DEFINITION OF DISTORTION

The sent signal has been superimposed in an arbitary position on the received signal, to show up more clearly the relative displacements of the instants of modulation, the displacements being indicated by the shaded portions. The distortion is always expressed as a fraction or percentage of the duration of the unit element of modulation, indicated in the figure by t. Thus the distortion of the first significant element, that is, the total relative replacement of the two corresponding modulation instants, is given by the difference of the restitution delays, *viz.* $r_1 - r_2 = d_1 + d_2$ or $\frac{r_1 - r_2}{t} \times 100$ per cent. The value of distortion usually quoted is that given by the maximum relative displacement of any two instants of modulation in the signals concerned. In the case illustrated this is therefore $\frac{r_1 - r_5}{t} \times 100$ per cent, because r_1 is the greatest and r_5 the smallest restitution delay. In practice, when measuring the distortion on a telegraph channel at a given baud speed it is usual to use a train of signals composed of those which will suffer the greatest distortion, so that the result will give the maximum distortion likely to be experienced with any practical combination of signals at the same baud speed. For this reason the C.C.I.T. (Comité Consultatif International Télégraphique) recommends the use of 6 : 1, 1 : 6, and Q9S signals for distortion measurements on telegraph channels.

Telegraph distortion is therefore defined as follows—

The distortion of received telegraph signals is given by the maximum difference in the restitution delays of the characteristic instants of modulation, and is expressed numerically as the ratio of this difference to the duration of the unit element of modulation. (In practice this ratio is usually written as a percentage.)

In start-stop telegraph systems it is often of more practical value to measure the distortion of signals in relation to their start signal. This is known as the "distortion of a start-stop modulation" and is the ratio to the unit element of the maximum difference, irrespective of sign, between the actual and theoretical intervals separating any characteristic instant of modulation, or restitution, from the characteristic instant of the start element immediately preceding it.

It should be noted that these definitions relate to a telegraphic link comprising a transmitting device and a receiving relay, and bear no direct relation to the actual shape of the signal currents in the line. In practice the link would also include any signal shaping networks or devices normally used, as without these the values would have no practical significance.

It has been found convenient to classify telegraph distortion as follows—

(*a*) *Characteristic Distortion.* The distortion caused by transients which, as the result of the modulation, are present in the transmission channel and depend on its transmission qualities.

(*b*) *Fortuitous Distortion.* The distortion due to irregularities in any part of the circuit or apparatus, or interference from external sources.

(*c*) *Bias Distortion.* This is due to either the marking or spacing elements of the signals being consistently lengthened in duration due to asymmetry in the transmitting or receiving apparatus.

Transmitted telegraph signals may be imperfect at their origin due to transmitter distortion. This can be measured and given a numerical value as a ratio, in the same way as is done for telegraph distortion generally, by comparing the actual instants of modulation with those which would occur with perfect signals. Teleprinter transmitters are usually adjusted so that the distortion does not exceed 5 per cent.

Margin of Receiving Apparatus. All telegraph receivers are adapted to permit a certain amount of distortion in the received signals. This is necessary so as to allow for transmitter and channel distortion and possible slight difference of speed between the sending and receiving machines. The degree of distortion that a receiver will permit is termed its *margin*, and is defined as follows—

The margin of a telegraph receiver is measured as the maximum degree of distortion which may occur on any or all the signals which may be applied to it, compatible with perfect registration of all the symbols and functions for which it is designed.

In the Creed Teleprinter the necessary margin is secured by the fact that the finger setting blade, which oscillates in response to the incoming signals, only needs to remain in contact with the finger setting pin for a very short time (about 2 msec) in order to set a selecting finger. There is therefore only a short period during each signal element when the electromagnet armature and finger setting blade must be in the correct position to ensure the setting up of the proper selection, and considerable variation in the timing of the signal elements can occur before errors result.

Line Transmission Theory: Direct Current

It will have been realized from the previous section that the function of a direct current telegraph line is to transmit the impulses resulting from the sudden changes in voltage at the sending end. If the transient time, that is, the time required for the current to build up to the steady value at the receiving end, is less than the duration of the shortest signal element, there will be no telegraph distortion due to the line, and the problem is merely one of providing sufficient current to secure reliable operation of the receiving relay. If, however, the build-up time is longer than this there may be some distortion. The stage at which distortion arises is mainly dependent upon the ratio of the operating current of the relay to the steady current, but it would usually be reached when the build-up time approaches 1·5 times the duration of the shortest signal element. Thus in those cases where the line conditions become of importance in determining the quality of transmission, the signals are almost wholly composed of *transients*.

Transients arise in a transmission line when, mainly because of capacitance effects, all frequencies do not suffer the same attenuation (i.e. reduction in amplitude) in transmission nor the same change in phase, and under these conditions the line does not immediately respond to any change in the electrical conditions at the sending end but undergoes a transitory condition when passing from one steady state to another. In telephony it is usual to design the line and repeater equipment so that attenuation distortion and phase distortion are negligible, and in general therefore transient conditions are not of importance. In the telegraph case this is neither necessary nor economically practicable; in fact one of the features of telegraphy is that perfect reproduction of the transmitted intelligence is possible on lines which, due to the electrical distortion, would be wholly incapable of any other form of transmission.

Direct current telegraph transmission problems are almost entirely concerned with transient conditions, and because the mathematical solution of transient phenomena is very complex no easily applicable formulae are available for practical use. The transmission technique is, therefore, largely based on practical experience supplemented by a knowledge of the electrical phenomena, derived from mathematical and experimental studies.

Certain telegraph transmission problems can be solved, and considerable help is given in studying most problems, by what is known as the "steady-state" solution of electrical transmission. This mathematical treatment is concerned with the response of the system to a sinusoidal alternating e.m.f. after all transient conditions have subsided and provides the well-known formulae used in telephone transmission. Some account of steady-state transmission theory in relation to telegraph transmission will be given later.

Before passing to the more formal discussion of direct current telegraph transmission some account will be given of certain simple transient conditions.

Charge and Discharge of a Capacitor. When a battery is connected to a non-inductive resistor the current immediately assumes a value $\frac{E}{R}$ where E is the voltage across the resistor and R the value of the resistance. In other words there is no transient effect. If a capacitor is joined in series with the resistor as shown in Fig. 5.4, the current at first

assumes the value of $\frac{E}{R}$ but then gradually dies away as shown in the graph. This is because there is no charge and hence no voltage on the capacitor initially, and therefore the whole of the voltage E

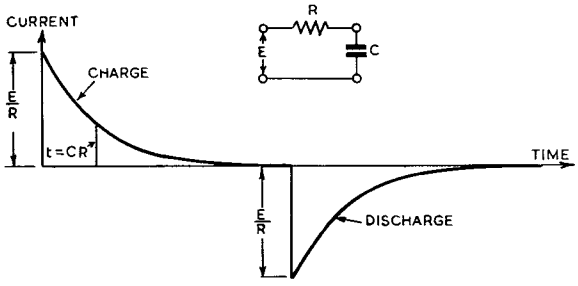


FIG. 5.4. CURVES OF CHARGING AND DISCHARGING CURRENT FOR CAPACITOR AND RESISTOR

appears across the resistor. As the capacitor becomes charged, the voltage across the resistor is reduced, and the current is also correspondingly reduced until finally it is sensibly equal to zero. By this time the voltage across the resistor is zero and the whole of the voltage E appears across the capacitor.

The equation for the current at any instant can be obtained by a simple application of the Differential Calculus and is given by

$$I = \frac{E}{R} e^{-\frac{t}{CR}} *$$

where I = the current in amperes
E = the applied voltage
R = the resistance in ohms
C = the capacitance in farads
t = the time from switching on in seconds
and e = the base of Napierian Logarithms and is equal to 2·7183 approximately

When $t = 0$, that is, at the instant of switching on, $I = \frac{E}{R}$, and when t is great, I is very small. The product CR is called the *time constant* of the circuit, and when $t = CR$ the current has a value $\frac{1}{2{\cdot}7183}$ times the initial value.

If, when the capacitor is charged, the battery is replaced by a short-circuit, the capacitor discharges through the resistor and the equation for the current is the same as that given for the charging current. The direction of current flow is of course reversed.

Single Section Artificial Line. The Tee-network shown in Fig. 5.5 is a single section artificial line representing a real line of negligible inductance and leakance, having a resistance of R ohms and a total capacitance to earth of C farads. For the artificial line the capacitance is assumed to be lumped at the centre, and this is quite legitimate providing the length of line represented is not too long. Such a network could be used to represent lengths of normal underground telegraph line of up to about 20 miles at the important frequencies present in direct current telegraph signals.

Assume that a voltage E is applied at one end of the line and the other end is earthed. It is easy to see that the initial current in the first resistor is given by $I_s = \frac{2E}{R}$, there being initially no potential across the capacitor. Similarly the initial received current will be zero. As the capacitor charges, the value of I_s will diminish while I_r will increase until finally, when the capacitor is charged, the currents in each resistor will be steady and equal to $\frac{E}{R}$, while the capacitor will be charged to a voltage $\frac{E}{2}$.

The equations for the currents are

$$I_s = \frac{E}{R}(1 + e^{-\frac{4}{RC}t})$$

$$I_r = \frac{E}{R}(1 - e^{-\frac{4}{RC}t}).$$

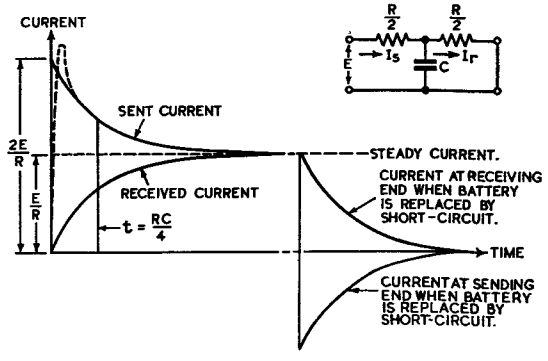


FIG. 5.5. CURVES OF SENT AND RECEIVED CURRENT FOR SHORT ARTIFICIAL LINE

The dotted curve shows the effect of the distributed capacitance near the sending end and the small amount of inductance which would be present in a real line.

In this case the time constant is $\frac{RC}{4}$ and the time required for the received current to build up to a given proportion of the final value is proportional to the product of the resistance and capacitance of the line.

* The mathematical derivation of this and subsequent formulæ are given in the Appendix to this chapter.

If the line is now short-circuited at the sending end, the capacitor discharges, the discharge current at each end being given by

$$I = \frac{E}{R} e^{-\frac{4}{RC}t}$$

It should be noted that during the discharge the direction of current at the sending end is reversed, whereas at the receiving end it is not.

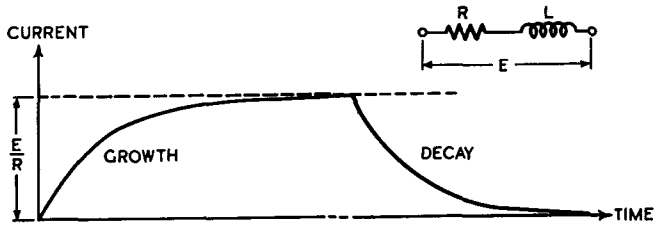


FIG. 5.6. CURVES OF CURRENT IN AN INDUCTIVE CIRCUIT

The curves given in Fig. 5.5 illustrate the foregoing effects.

If the voltage is applied to the line through a resistance of x ohms and the line is terminated by a resistance of y ohms, the formula for the received current becomes

$$I_r = \frac{E}{R + x + y}\left(1 - e^{-\frac{4(R+x+y)}{CR\left[R + 2(x+y) + \frac{4xy}{R}\right]}t}\right)$$

and the time constant is

$$\frac{CR}{4}\left(1 + \frac{x + y + \frac{4xy}{R}}{R + x + y}\right)$$

This shows that the time constant is increased by the presence of resistance at either the sending or receiving end of the line, and therefore the inclusion of resistance will in each case increase the time taken for the current to reach the steady value. It should be noted that as the equation is symmetrical in x and y, the effect of a given resistor is the same whether it is at the receiving or sending end.

The resistance of a 20-mile length of a 20 lb single-wire underground circuit is 880 Ω, and the capacitance to earth 2 μF; the time constant with no external resistance is therefore $880 \times 2 \times \frac{10^{-6}}{4}$ = 0·44 msec.

The current would be within 5 per cent of the steady value after 1·4 msec. If a battery resistor of 300 Ω is used and the resistance at the receiving end is 3,000 Ω, these times become 1·2 and 3·9 msec respectively.

Growth and Decay of Current in an Inductive Circuit. Similar expressions to the foregoing are obtained for the current in a circuit containing resistance and inductance. In the case shown in Fig. 5.6, on switching on the applied e.m.f. the current is prevented from rising immediately to the final value by the opposing e.m.f. created in the inductor. This opposing e.m.f. is at all times proportional to the rate of change of the current.

The equation for the current is

$$I = \frac{E}{R}(1 - e^{-\frac{R}{L}t})$$

where L = inductance in henries.

When the battery is replaced by a short-circuit, the current falls gradually to zero owing to the e.m.f. induced in the inductor. Thus, just as the energy stored in the dielectric is dissipated in the circuit when a capacitor is discharged, so the energy stored in the magnetic field of an inductor is dissipated in the circuit when this field collapses on removal of the applied e.m.f., the expression for the current being of the same form in each case.

The current in the present case is given by

$$I = \frac{E}{R} e^{-\frac{R}{L}t}$$

The time constant for the inductive circuit is $\frac{L}{R}$, and for a given value of inductance this can be reduced by increasing the value of R. If R and E are increased in the same ratio, the final value of the current remains constant. It is therefore possible to reduce the time of operation of a relay by adding resistance in series, and at the same time increasing the applied voltage so as to maintain the value of the current within the operating range of the relay.

Shunted Capacitor in Relay or Electromagnet Circuits. The effect just mentioned can be still further enhanced by shunting the additional resistor by a capacitor. By this means, because at the outset the capacitor is uncharged, a higher voltage is applied to the inductor so still further increasing the rate of growth of the current. Shunted capacitors are for this reason included in the operating circuits of the electromagnets of printing telegraph receivers.

Shunted capacitors are also used at the ends of long telegraph lines to correct the distorting effects of the line: their use in this connexion involves quite different factors and will be considered separately at a later stage.

The mathematical solution of the case where the shunted capacitor is used on a short line or in

the local circuit of a relay is not difficult, but the equations obtained are cumbersome and of very little practical value, and have therefore been excluded from the following treatment.

The values of the resistance and capacitance to be used in any given case are mainly dependent on the voltage to be used, the operating current of the relay, or electromagnet and its inductance. They are also to some extent dependent on the way in which the inductance varies with current, the speed at which the circuit is to be operated, and the mechanical design of the relay or electromagnet.

In general, the voltage will be fixed by considerations of the source of supply and conditions of use. It will be clear from the remarks relating to the growth of current in an inductive circuit that improved performance will be obtained by using a high rather than a low voltage. An 80 V double current supply has been fixed as most suitable for the purposes of the British Post Office. The voltage being fixed, it immediately follows that the resistance should be high enough to limit the current to a value consistent with the sensitivity of the relay or electromagnet. The capacitance will then be adjusted to secure the desired increase in the rate of growth of current.

The effect produced by the capacitor is illustrated in Fig. 5.7, which relates to an electromagnet having an inductance of 6 H. The conditions are given in Table 5.1—

TABLE 5.1

Curve	Voltage	Series Resistance (Ω)	Capacitance (μF)
1	6	nil	nil
2	80	4 000	nil
3	80	4 000	0·2
4	80	4 000	0·5
5	80	4 000	1·0
6	80	4 000	2·0

The effect of the addition of resistance, the voltage being increased to maintain the same steady current, is clearly illustrated by curves 1 and 2. The effect of the capacitor is illustrated by curves 3 to 6. At a certain stage an oscillation due to the interaction of the capacitance and inductance is produced, causing the current to build up to a value in excess of the steady current. The amplitude of this oscillation is increased as the capacitance is increased, and if it is too great it may cause undesirable signal distortion by interfering with the next operation of the electromagnet or relay. It follows that on high-speed circuits less oscillation is permissible than on low-speed circuits.

Curves similar to 3 and 4 are suitable for the operation of telegraph relays in local circuits. A relay such as the Western Electric Permalloy Relay (B.P.O. Relay No. 299) which has anti-chatter springs and a light movement, should not have too violent operation or contact chatter

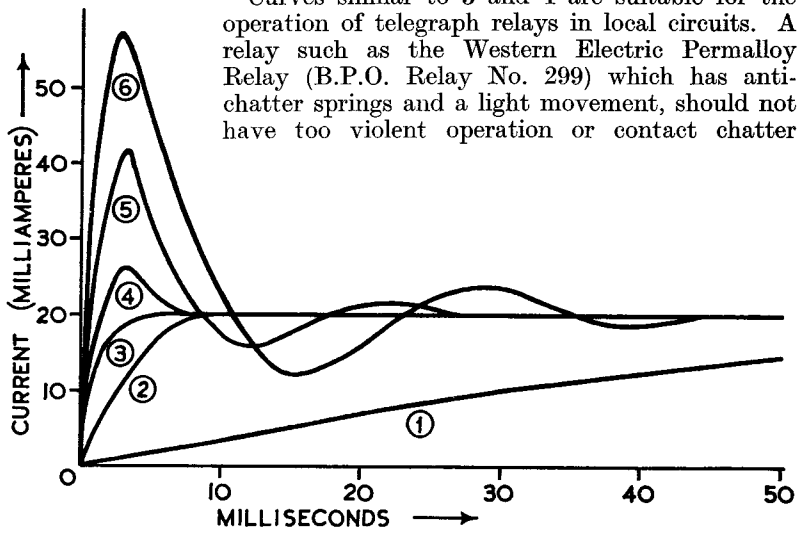


FIG. 5.7. SHUNTED CAPACITOR: EFFECT OF VARYING CAPACITANCE

results, and best results are sometimes obtained with resistance only. Other relays such as the B.P.O. Standard BN Relay give best operation with more "overshoot" such as in curve 4. In the case of the teleprinter where the armature of the electromagnet carries an appreciable mechanical load, overshoot approaching that shown in curve 5 is beneficial so as to supply the energy necessary to obtain a quick transit of the armature between the stops.

In general the best arrangement for any given case is found by experiment, and then standardized.

For Teleprinters Nos. 3 and 7 the values are 4,000 Ω and 4 μF using a double current 80 V supply, but in this case the electromagnet is also shunted by a 2 μF capacitor, and, although this capacitor tends to slow down the build-up of the current in the coils of the electromagnet, this effect is more than compensated by the effect of the large value shunted capacitor chosen. This extra capacitor was originally added because some improvement was obtained when working over long lines, but its use is now retained mainly because it suppresses the harmonics produced in the coils of the electromagnet when the armature moves, which would

otherwise pass out to line and cause interference on telephone circuits working in the same cable.

The Arrival Curve. The whole of the effects considered in the preceding section were the results of transient conditions set up by the presence of capacitance or inductance in the electric circuit preventing the current immediately assuming its final steady value. The transmission efficiency of a long direct current telegraph line is dependent on the extent of the transient condition produced in a

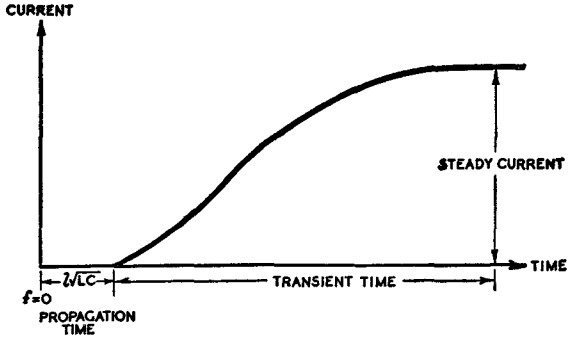


FIG. 5.8. ARRIVAL CURVE FOR A TYPICAL UNLOADED LINE

similar manner by the capacitance of the line. The nature of these transients can be determined from the *arrival curve*.

An arrival curve is a curve showing the building up of the current received at the end of a transmission line when a steady voltage of known value is suddenly applied at the sending end, the line being previously in a state of rest, and the sending and receiving impedances being specified. The shape of the arrival curve determines the response of the system to an applied voltage of any character whatever. Where transient conditions are not of importance, the steady-state response of the line to sinusoidal voltage can be used to determine the performance, but in telegraphy the study of the transmission phenomena from the point of view of the arrival curve is very valuable. Lord Kelvin was first responsible for this method of treating telegraph transmission and the publication in 1855 of his mathematical researches led to the famous "KR" law.

Fig. 5.8 shows the arrival curve for a typical unloaded line, and the transient time is indicated. The propagation time is the time taken for the propagation of an electrical impulse through the medium, and is the time which elapses before any effect occurs at the receiving end. The calculation of the arrival curve in any given case, taking account of the resistance, leakance, inductance, and capacitance of the line and the value of the terminal impedances, is a matter of some complexity, and owing to the considerable amount of labour involved is rarely attempted in practice.

The case of the simple artificial line given earlier, in which only resistance and capacitance are present, can be readily extended to lines having a number of sections.

Lord Kelvin gave the solution in the case of a line without leakance and inductance and when the terminating impedances are zero, as—

$$I = 2\frac{E}{Rl}\left(\tfrac{1}{2} - \theta + \theta^4 - \theta^9 + \theta^{16} - \ldots\right)$$

where $\theta = e^{-\frac{\pi^2 t}{CRl^2}}$

and E = applied voltage at time $t = 0$.
I = received current at time t seconds
R = resistance per mile
C = capacitance per mile
l = length of line in miles.

To a first approximation this may be written

$$I = \frac{E}{Rl}\left(1 - 2e^{-\frac{\pi^2 t}{CRl^2}} + 2e^{-\frac{4\pi^2 t}{CRl^2}}\right)$$

The foregoing equation shows that the time required for the current to rise to a given fraction of the final value is proportional to CRl^2. For example, the current reaches half its final value when $\frac{t}{CRl^2} = 0{\cdot}14$ (approximately), or $t = 0{\cdot}14\,CRl^2$ sec and is almost equal to the steady value for $t = 0{\cdot}55\,CRl^2$.

On this basis the KR law* may be stated as follows—

On a telegraph line of negligible inductance and leakance with zero terminal impedances the time delay of an electrical operation at the receiving end is proportional to CRl^2.

This relationship between CRl^2 and the build-up time has been used to evaluate empirical formulae of the form

$$\text{Maximum speed of working} = \frac{k}{CRl^2}$$

where k is a constant dependent upon the system of working and the terminal apparatus and signal shaping networks. Values for k for submarine and underground cables† have been determined from the result of practical experience and used to a certain extent in the past, but in Land Telegraphy,

* K was the former symbol for capacitance.

† Owing to the much lower capacitance the formula is not applicable to overhead lines where conductor and insulation resistance and external interference play a more important part.

owing to modern developments in the design of relays and telegraph distortion measuring equipment, it is possible to secure performances far in excess of those given formerly and, owing to its limitations, this method of expressing the transmission qualities of a circuit has fallen into disuse. Also, the extensive use of fixed speed systems such as Teleprinter and Multiplex, in which the maximum permissible speed of working the circuit is of no real interest, has rendered the method of still less importance. Nevertheless, although in modern land telegraphy the KR law is of little practical importance, an understanding of the underlying principles is of value in studying telegraph transmission problems, and that alone is the reason for its inclusion here.

Owing to the labour and difficulty of calculating the arrival curve accurately in practical cases, in which the value of the terminal impedances is taken into account, the usual practice is to record it by means of an oscillograph,* using an actual line or an artificial line constructed to represent the case in question.

An interesting general solution of the arrival curve in which all the electrical constants of the line and terminal equipment are taken into account has been given by H. W. Malcolm.† This solution makes use of ordinary steady-state transmission theory as used in telephony, and although it, too, involves considerable labour, it is an important aid to an appreciation of the relation between steady-state and transient phenomena without recourse to abstruse mathematics, and for this reason it will be returned to later after some account has been given of steady-state transmission theory.

Construction of Telegraph Signals from the Arrival Curve. Principle of Superposition Theory. It is possible by use of the method of superposition, employed by Heaviside in his work on transmission problems, to construct the signals received at the end of a line from a knowledge of the arrival curve. In this theory it is assumed that the wave-form of the applied voltage consists of a large number of sudden small increases or decreases in voltage. Each one of the increases is supposed to produce a received current corresponding to the arrival curve, and each decrease—being assumed to be due to the sudden insertion of a voltage in the opposite sense—is supposed to produce therefore an arrival curve of the opposite sense to that for an increase. The summation of the resultant series of arrival curves gives the shape of the received current, provided the values of the resistance, inductance, capacitance and leakance in the circuit are independent of the value and rate of change of the current.

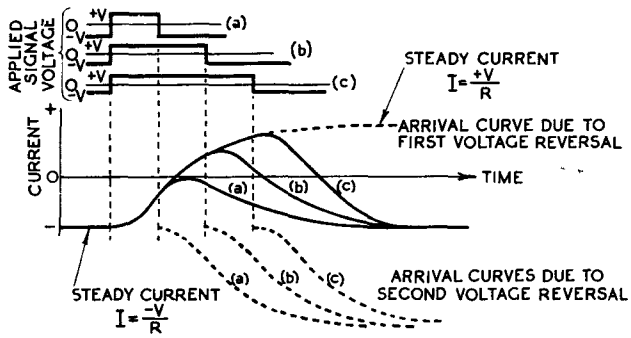


FIG. 5.9. CONSTRUCTED SIGNAL SHAPES FOR THREE SIMPLE SIGNALS

In telegraphy the process is simplified because the signals merely consist of sudden changes or reversals of voltage, and therefore the signal shapes may be constructed fairly readily by graphical means. This is illustrated in Fig. 5.9 for three simple double-current signals. It should be noted that for double-current signals the arrival curve has twice the amplitude of that for a single-current signal using the same voltage. That is, the arrival curve for the reversal of a voltage V, is the same as that for switching on a voltage $2V$ except that the zero current position is displaced as shown in Fig. 5.9 owing to the presence of the steady-current in the line at the commencement.

In the figure the received signal (*a*) was constructed from the arrival curve due to the first

* An *oscillograph* is an instrument used for obtaining a visual or photographic record of the current in a circuit in the form of a curve showing variations in amplitude plotted against time, such as the signal shapes shown in Fig. 5.2. In an electromagnetic oscillograph the current indicator is in effect a moving coil galvanometer in which the coil consists of a single loop of fine wire which carries a small mirror, the whole being usually suspended in oil to damp out mechanical resonance. An intense beam of light is focused on the mirror and reflected as a small spot on to a strip of photographic paper mounted on a drum. To obtain a record the drum is rotated, the position of the spot at any time being determined by the amplitude of the deflexion of the coil which in turn depends on the value of the current. Alternatively the beam of light is reflected from a system of rotating mirrors on to a translucent screen. The rotation of the mirrors causes the spot of light to traverse the screen and so give a picture of the wave shape under examination.

In a *cathode-ray oscillograph* (sometimes called an oscilloscope) a stream of electrons in a cathode-ray tube is deflected by the current or voltage concerned and a picture is secured by arranging for the beam to impinge on a fluorescent screen deposited on the end of the glass container.

† *The Theory of the Submarine Telegraph and Telephone Cable.* H. W. Malcolm, London, 1917.

reversal, and the arrival curve due to the second reversal (shown dotted and labelled (*a*)). To avoid confusion this has been drawn at the bottom of the figure, but should, strictly speaking, commence at the zero current line. The ordinates for this curve are subtracted from those for the first curve to obtain the resultant signal. When both arrival curves have reached the steady-state, the current due to the first is $+ I$ (after allowing for the steady current $- I$ which existed at the outset), and to

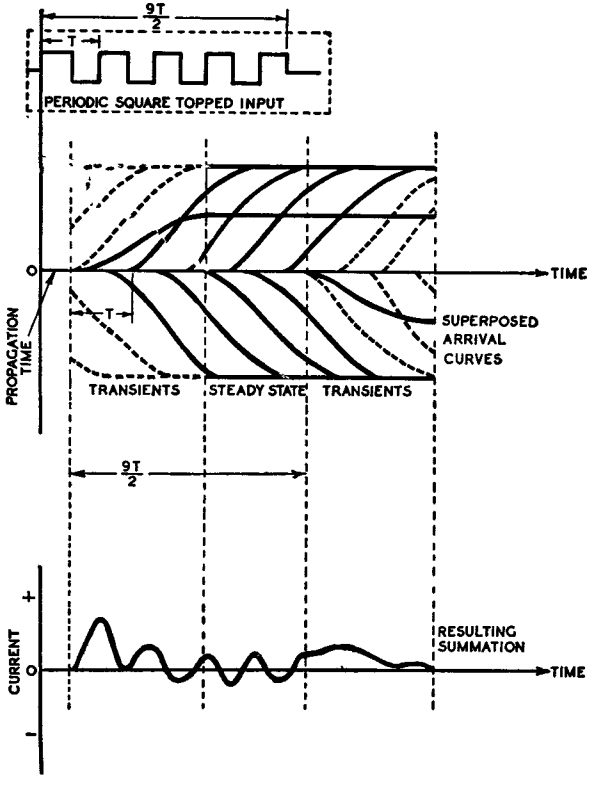


FIG. 5.10. ARRIVAL CURVES DUE TO SQUARE-TOPPED VOLTAGE REVERSALS

the second $- 2I$, and the resultant current is therefore $- I$, that is, the original steady-state value. The figure also shows the effect on the received signal of the relation of the length of the signal to the build-up time of the arrival curve. Signal (*a*) has a duration less than one-quarter of the build-up time, and the received current never actually reverses in direction. The process is further illustrated in Fig. 5.10, in which the series of arrival curves due to square-topped voltage reversals impressed at the sending end of a line is shown. T is the periodic time of the reversals, and they are assumed to be switched on at time $t = 0$ and switched off at time $t = \frac{9T}{2}$. The received current as given by summing the arrival curves is also shown, and it will be seen that not until the first arrival curve has reached the steady value does the received current settle down to symmetrical alternations. This period corresponds to the transient time. On switching off, transients again occur and persist for a like period, the total period during which the current persists in the line being equal to the time of application of the signals plus one transient period. Transients will occur to a greater or less degree in all circuits unless the circuits are completely distortionless, in which case the arrival curve is rectangular and the transient time is obviously zero.

Single-current Signals. If in single-current working the line is looped or earthed at the sending end during intervals of no current, through a resistance equal to that of the battery circuit, the signal shapes will be exactly the same as those obtained in double-current working. This effect would be secured in the circuit shown in Fig. 5.2 if the negative battery were removed and the resistance coil connected directly to earth. The only change in the graphs relating to line current in this figure, if these were then for single-current with a single positive battery, would be that the zero current line would be shifted to the position corresponding to that of the steady negative current in the double-current case. It should be noted that a reversal of current occurs at the sending end, as will be seen by referring to the curve of sending current in Fig. 5.2. This is due to the surge of discharge current on reverting to the no-current conditions. That the single-current signal shapes must be the same as those for double-current working will be apparent if it is supposed that the no-current condition is produced by inserting a battery of equal and opposite voltage to the first battery. Then by the principle of superposition this second battery will produce an arrival curve identical with that due to the first battery but of opposite sense, and the summation of the two curves will give the received signal.

For this method of single-current working, if the receiving relay is biased magnetically or electrically to an extent exactly equivalent to that due to half the steady line current, the operation will be identical with that obtained with double-current working using a voltage half that of the single-current battery. The difficulty of ensuring that at all times the bias of the relay will be equivalent to half the line current explains the superior results obtainable with double-current working.

Closed Circuit Working. This is a system of single

current working used for working between an out office and a head office, and avoids the provision of a line current supply at the out office. A simplified diagram of the arrangement used on the extension circuits to the renter's premises on certain direct current private wires is given in Fig. 5.11. This circuit was extensively employed at one time on the local ends of B.P.O. Tariff "A" circuits. To illustrate the type of transmission obtained, an artificial line suitable to represent an extension circuit of up to about 20 miles in length has been taken, the filter and receiving relay having been omitted for simplicity. Transmission is by opening and closing the circuit at the out office.

When the circuit is closed, the steady state current is equal to $\frac{E}{R}$, and when it is then open-circuited the current at the battery end is given by—

$$I_1 = \frac{E}{R} e^{-\frac{2}{RC}t}$$

When the short-circuit is replaced, the current at the battery end is given by—

$$I_1 = \frac{E}{R}(1 - e^{-\frac{4}{RC}t})$$

and that at the other end by—

$$I_2 = \frac{E}{R}(1 + e^{-\frac{4}{RC}t})$$

These expressions are the same as those given for the artificial line shown in Fig. 5.5, except that the expressions for sent and received current have changed over. This is because when the line is short-circuited the capacitor has already been charged to the full voltage of the battery during the open-circuit condition.

The curves for the current at the battery end of the circuit are given in Fig. 5.11. As the time constant for the open circuit case $\frac{RC}{2}$ is twice that for the closed circuit $\frac{RC}{4}$, this method of working leads to unbalanced signals, and it is necessary to counteract this by increasing the bias current above the normal value of half the steady line current.

In practice the signal shapes are modified by the presence of the filter, relay, and current-limiting resistance. In particular the capacitor in the filter prolongs the discharge through the relay at open circuit and exaggerates the unbalance effect already mentioned, especially on the longer lines.

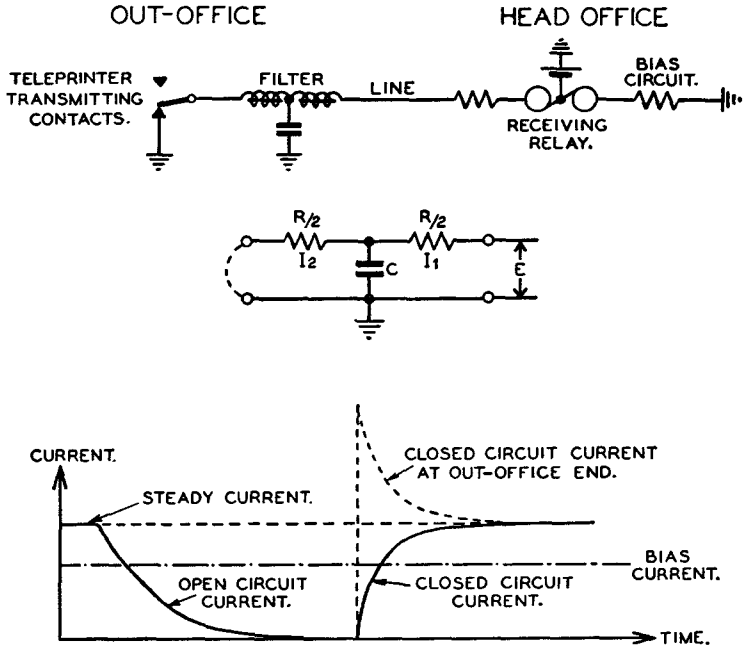


FIG. 5.11. CLOSED CIRCUIT WORKING ON SEND LEG OF TELEPRINTER PRIVATE WIRE LOCAL END

The unbalance effect can be reduced by removing some of the current limiting resistance to the out office. Another method used on a similar type of circuit in America is to insert an inductor in the line, so slowing up the build-up of the current to make it more comparable with the die-away.

In the system of working used in the B.P.O., the second wire of the pair is worked double-current from the head office to the teleprinter at the out office; whereas in another system largely used in America, the circuit is used as a loop, the electromagnet and transmitting contacts being connected in series at the out office. In this case at "break" the current in the electromagnet immediately falls to zero, while at "make" the current does not rise rapidly as indicated by the dotted curve in Fig. 5.11, but in a manner similar to that shown by the full-line curve, owing to the inductance of the electro-magnet.

Aerial Lines: The Effect of Leakage. There are relatively few telegraph circuits of any length working on aerial lines in the B.P.O., and none of sufficient length to cause transient effects to be of importance. The capacitance per mile of an aerial

circuit is about one-sixth of that of an underground circuit, and the resistance is generally lower, because of the heavier gauge conductors used. The time required for the current to rise to 90 per cent of its full value on a 200 mile, 150 lb, copper line with resistors of 150 Ω at each end is less than 2 msec, so that even at high telegraph speeds the transient effects due to the line are unimportant. Of much more consequence are the effects of leakage and external interference. The result of leakage is to reduce the value of the current available at the receiving end. As a limit must be placed on the voltage applied to line, the length of circuit which can be worked without the use of repeaters is largely dependent on the value at which the insulation resistance of the line can reasonably be expected to be maintained, bearing in mind climatic and other relevant factors. The actual effect of the leakage is dependent on whether it is approximately uniformly distributed, or due to abnormal conditions at one or more localized points. Both cases will be dealt with.

Uniformly-distributed Leakage. The effect of leakage in gradually reducing the value of the transmitted current needs no explanation. What is more interesting is its effect in reducing the time-constant or transient time. As the transient time is in any event quite small, this fact is of little more than theoretical interest in the present case but nevertheless it will be instructive to examine it in a little detail.

Steady-state Solution. In the first place the solution for the steady current condition will be given. In this condition the capacitance takes no part, simply carrying a steady charge, and the line may be treated as merely having resistance and leakance. In this case it is unnecessary to refer to a ladder network simulating the line in order to simplify the mathematics. The received current is given by the equation—

$$I_r = \frac{E}{(R_t + R_s)\cosh\sqrt{RG}\,.\,l + \left[R_o + \frac{R_s R_t}{R_o}\right]\sinh\sqrt{RG}\,.\,l}$$

where E = applied voltage;
R = conductor resistance per unit length (ohms);
G = leakance per unit length (mhos);
l = length of line;
R_t = terminating resistor (ohms);
R_s = sending end resistor (ohms);
$R_o = \sqrt{\frac{R}{G}}$ = "characteristic resistance" of line (ohms);

Cosh $\sqrt{RG}\,.\,l = \frac{1}{2}[e^{\sqrt{RG}.l} + e^{-\sqrt{RG}.l}]$ (hyperbolic cosine);*

and

Sinh $\sqrt{RG}\,.\,l = \frac{1}{2}[e^{\sqrt{RG}.} - e^{-\sqrt{RG}.l}]$ (hyperbolic sine).

The foregoing equation is a particular case of the general solution of the steady-state transmission equation which will be dealt with later. The mathematical proof is given in the Appendix and it should, if not already known, be studied at this stage.

It will be seen that from this equation the received current can be calculated for any terminal conditions.

One special case worthy of mention is when $R_s = 0$ and $R_t = R_o$. Substituting these values in the foregoing equation gives

$$I_r = \frac{E}{R_o[\cosh\sqrt{RG}\,.\,l + \sinh\sqrt{RG}\,.\,l]}$$

or $$I_r = \frac{E}{R_o}e^{-\sqrt{RG}.l}$$

To illustrate the use of the full equation, the case will be taken of an aerial line of 200 miles in length having the following constants—

$R = 6\ \Omega$/mile.
$G = 1/60{,}000$ mhos/mile (i.e. insulation resistance = 60,000 Ω/mile).
$R_t = 150\ \Omega$.
$R_s = 150\ \Omega$.

We have

$$R_o = \sqrt{\frac{R}{G}} = 600\ \Omega.$$

$$\sqrt{RG} = 0{\cdot}01.$$

$$I_r = \frac{E}{300\cosh 2 + 637{\cdot}5\sinh 2}$$

The values of cosh and sinh can be obtained from tables of hyperbolic functions and substituting these values we have

$$I_r = \frac{E}{300 \times 3.762 + 637{\cdot}5 \times 3{\cdot}626} = \frac{E}{3{,}438}$$

* The hyperbolic functions which appear in this and other similar equations given later, if they have not been met before, should not be regarded as having any mysterious significance and need only be looked upon as a convenient method of writing and handling the particular combinations of the exponential terms. See also footnote on page 166 and Fig. 5.17.

If the line has no leakance the current at all points in the circuit is given by

$$I = \frac{E}{R_s + R_l + R_t} = \frac{E}{1{,}500}$$

The effect of the leakage is to reduce, therefore, the received current to a value 0·437 of the current without leakage. The corresponding figure for an insulation resistance of 200,000 Ω/mile is 0·765.

The formula shows that the value to which the received current is reduced is dependent on $\sqrt{RG} \,.\, l$, and therefore when the conductor resistance per mile is high the effect of leakage is more serious. Again, the greater the length of the line the more serious the effect of leakage. For a 500-mile length of line the same as the foregoing, the ratios quoted would be 0·022 and 0·14 for 60,000 and 200,000 Ω/mile insulation resistance respectively.

Transient Solution. To obtain a general solution for the growth of current when a battery is suddenly applied to the line is a matter of some mathematical complexity, but the case under consideration can be readily solved by recourse to the artificial line method.

In Fig. 5.12 is shown a network of resistors and capacitors which can, by suitable choice of components, be used to represent for all practical purposes an aerial line of some 200 miles in length, each section representing 50 miles.

The line is assumed to be connected to terminal resistors of $\frac{R_n}{2}$ ohms, where R_n is the resistance of 50 miles of conductor. This value has been chosen merely to simplify the mathematical solution. The equation for the received current when a battery of E volts is applied at the sending end and the leakage and inductance is negligible is

$$I_r = \frac{E}{5R_n}\left(1 - \frac{5}{5-\sqrt{5}}e^{-\frac{1}{2}(3-\sqrt{5})\cdot\frac{t}{C_nR_n}} + \frac{1}{3-\sqrt{5}}e^{-\frac{1}{2}(5-\sqrt{5})\cdot\frac{t}{C_nR_n}} - \frac{5}{5+\sqrt{5}}e^{-\frac{1}{2}(3+\sqrt{5})\cdot\frac{t}{C_nR_n}} + \frac{1}{3+\sqrt{5}}e^{-\frac{1}{2}(5+\sqrt{5})\cdot\frac{t}{C_nR_n}}\right)$$

where R_n = conductor resistance of each section;
C_n = capacitance of each section.

When leakance is included the formula becomes

$$I_r = \frac{E}{R_n a \,.\, b \,.\, c \,.\, d}\left(1 - \frac{b \,.\, c \,.\, d}{5+\sqrt{5}}e^{-a\frac{t}{C_nR_n}} + \frac{a \,.\, c \,.\, d}{5-\sqrt{5}}e^{-b\frac{t}{C_nR_n}} - \frac{a \,.\, b \,.\, d}{5-\sqrt{5}}e^{-c\frac{t}{C_nR_n}} + \frac{a \,.\, b \,.\, c}{5+\sqrt{5}}e^{-d\frac{t}{C_nR_n}}\right)$$

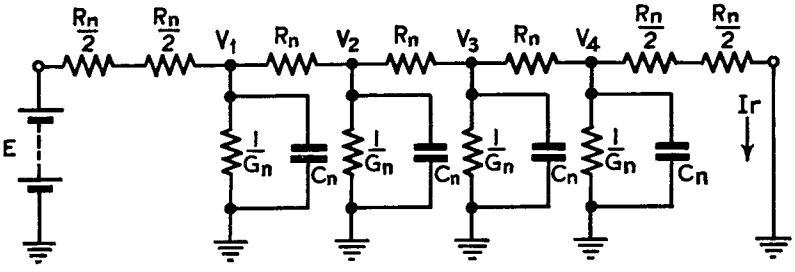


FIG. 5.12. ARTIFICIAL LINE WITH LEAKANCE AND CAPACITANCE

where $a = R_nG_n + \frac{1}{2}(3 - \sqrt{5})$;
$b = R_nG_n + \frac{1}{2}(5 - \sqrt{5})$;
$c = R_nG_n + \frac{1}{2}(3 + \sqrt{5})$;
$d = R_nG_n + \frac{1}{2}(5 + \sqrt{5})$;
and G_n = the leakance per section.

(*Note.* $R_nG_n = RG$, and $C_nR_n = \frac{CRl^2}{16}$ where R, G, and C are the values per mile.)

It will be seen that the time constant of each of the exponential terms has been decreased by the introduction of the leakage factor; for example that for the first term is

$$\frac{C_nR_n}{\frac{1}{2}(3-\sqrt{5})} \text{ (without leakage),}$$

and $$\frac{C_nR_n}{R_nG_n + \frac{1}{2}(3-\sqrt{5})}$$ when leakage is present.

The effect of the leakage is therefore to reduce the duration of the transient effects and improve the received signal shapes. It is well known from alternating current transmission theory that leakance reduces the distortion due to the capacitance of the line, and the above simple example confirms this fact.

Although the transient time is reduced, the value of received current is also reduced in the ratio of

$\frac{a \cdot b \cdot c \cdot d}{5}$. Both effects are dependent on the product $R \times G$. To make the effects clearer, the results will be given for the same case as before, that of an aerial line, 200 miles in length, having a conductor resistance of 6 Ω/mile and a capacitance of 0·015 μF/mile. The insulation resistance will

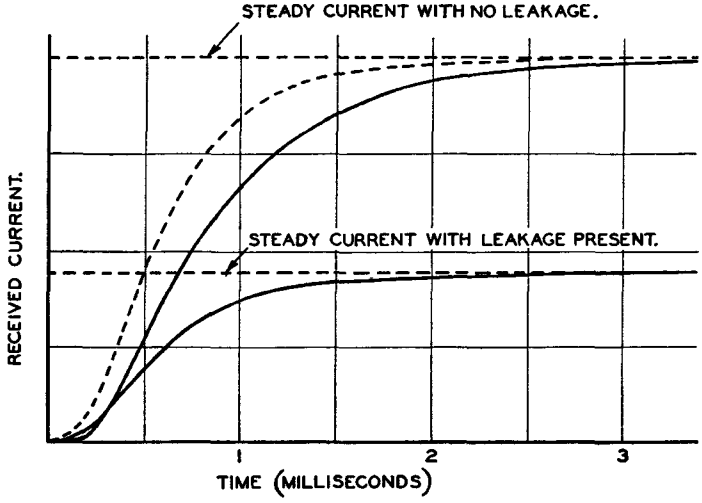


FIG. 5.13. ARRIVAL CURVES FOR AERIAL LINE WITH AND WITHOUT LEAKANCE

The dotted curve represents the arrival curve with leakance, but having the ordinates increased in the ratio 11.43 : 5.

first be taken as infinity, and then 60,000 Ω/mile. For the 50 miles sections therefore—

$$R_n = 300\ \Omega;$$
$$C_n = 0{\cdot}75\ \mu\text{F};$$
$$G_n = \frac{1}{1{,}200}\ \text{mho};$$
$$R_n G_n = 0{\cdot}25.$$

In the first case

$$I_r = \frac{E}{300 \times 5}\left(1 - 1{\cdot}81\, e^{-\frac{10^3 t}{0{\cdot}59}} + 1{\cdot}31\, e^{-\frac{10^3 t}{0{\cdot}16}} - 0{\cdot}69\, e^{-\frac{10^3 t}{0{\cdot}09}} + 0{\cdot}19\, e^{-\frac{10^3 t}{0{\cdot}06}}\right)$$

and in the second case

$$I_r = \frac{E}{300 \times 11{\cdot}43}\left(1 - 2{\cdot}5\, e^{-\frac{10^3 t}{0{\cdot}36}} + 2{\cdot}53\, e^{-\frac{10^3 t}{0{\cdot}14}} - 1{\cdot}44\, e^{-\frac{10^3 t}{0{\cdot}08}} + 0{\cdot}41\, e^{-\frac{10^3 t}{0{\cdot}06}}\right)$$

The curves given by these equations are shown in Fig. 5.13. To show the comparative shapes of the curves the dotted curve has been drawn to represent the case where the applied voltage has been increased in the ratio $\frac{11{\cdot}43}{5}$ to compensate for the leakage current. The improved shape is at once apparent.

The steady current received when leakage is present is $\frac{5}{11{\cdot}43} = 0{\cdot}437$ times the current without leakage, and it should be noted that this ratio is the same as that given in the preceding section when it was obtained by the use of the general steady-state formula.

Effect of Low Insulation Resistance Faults. The value of insulation resistance of 60,000 Ω/mile was taken in the preceding paragraphs as being the lowest value tolerated in this country under the most adverse conditions. A minimum value of 200,000 Ω/mile is the standard aimed at under normal conditions. Where the loss of current is mainly due to a localized fault or bad section of line, its seriousness will depend on its position.

When the insulation resistance is high compared to the fault resistance the received current is given by

$$I_r = \frac{EF}{RR_1 + F(R + R_1)}$$

where E = applied voltage;
R = resistance to the fault (including terminal resistance);
R_1 = resistance beyond fault (including terminal resistance); and
F = resistance of fault.

The conditions are illustrated in Fig. 5.14. The only factor depending on the position of the fault is RR_1, which is a maximum, and therefore the current a minimum, when $R = R_1$, that is, when the resistance each side of the fault is the same. RR_1 is a minimum, and therefore the current a maximum, when R or R_1 is smallest, that is, when the fault is at the end of the circuit where the terminal resistance is smallest. When both terminating resistors are the same, as would probably be the case for a duplex circuit, the received current is a minimum when the fault is at the centre of the line. On a simplex circuit where the receiving resistance may be much higher than the sending resistance, the current will be a maximum when the fault is at the sending end, and the point for minimum received current will be nearer the receiving end. If the receiving resistance is equal

to or greater than the sum of the line and sending resistance, the received current will be a minimum when the fault is at the receiving end of the line.

Alternating Current Transmission Theory

General. In the preceding section the transmission theory given was mainly concerned with transient conditions. Ordinary a.c. transmission theory is, on the other hand, mainly concerned with the steady-state conditions existing when an alternating e.m.f. which is a repeating function of time, is impressed on a transmission line, and all transient conditions have subsided. In telephony and a.c. telegraphy the transmission links are usually designed so that transient conditions are reduced to negligible importance, and the steady-state response of a circuit is therefore, in general, an adequate guide to its performance.

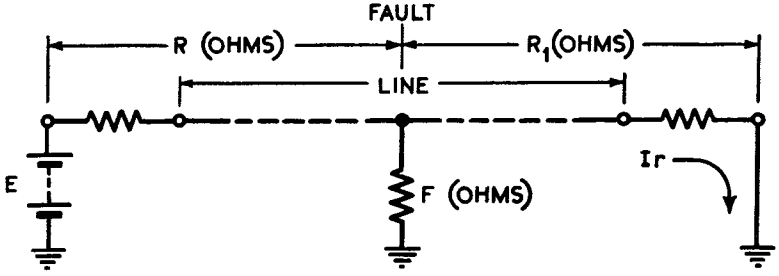


FIG. 5.14. LINE WITH LOCALIZED INSULATION RESISTANCE FAULT

The fact that only steady-state conditions are to be considered involves the condition that the applied e.m.f. must be a periodic function of time, that is to say, that any variations in amplitude which the e.m.f. undergoes must be cyclic in character. It is well known from Fourier's Theorem that any periodic function can be represented as the sum of a series of simple sinusoidal functions of suitable amplitude, phase, and period. Thus, within certain limits, the response of a transmission line to a complex periodic e.m.f. may be examined by determining its steady-state response to sine wave e.m.f.'s of suitable frequency. In order therefore to establish the performance of the line, it is only necessary to know its response to those frequencies which will be contained in the signals or wave forms it is desired to transmit. This fact forms the basis of alternating-current transmission theory as used in telephony and a.c. telegraphy. Furthermore, the assumption of a sine wave e.m.f. considerably simplifies the mathematics.

Simple Sine Function. The equation

$$e = E \sin \omega t \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

relates to a simple harmonic or sine wave where

e is the amplitude at any instant;
E is the maximum amplitude of the wave;
t is the time;

and ω is a constant depending upon the frequency with which the wave repeats itself.

An explanation of the characteristics of a sine function has already been given in Chapter 1.

Fourier Analysis of Periodic Signals. By way of example as to how periodic signals or waves may be resolved into a series of sine curves, the case of ordinary square-topped voltage reversals will be taken. This is illustrated in Fig. 5.15.

The Fourier series corresponding to periodic reversals of amplitude E is given by

$$y = \frac{4E}{\pi}(\sin \omega t + \tfrac{1}{3} \sin 3\,\omega t + \tfrac{1}{5} \sin 5\,\omega t + \tfrac{1}{7} \sin 7\,\omega t + \tfrac{1}{9} \sin 9\,\omega t + \text{etc.}) \quad . \quad (2)$$

where $\omega = \dfrac{2\pi}{T} = 2\pi f$

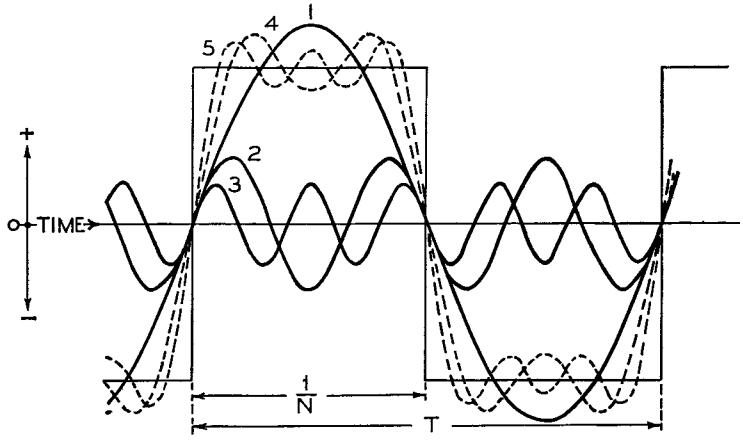


FIG. 5.15. SINE-WAVE COMPONENTS OF SQUARE-TOPPED REVERSALS

T = the period in seconds of one complete cycle, and
f = the number of cycles per second.

The first three terms of this series are plotted as curves 1, 2, and 3 of Fig. 5.15. The first term represents the fundamental frequency of the wave and has the same frequency as the reversals but $4/\pi$ times the amplitude. The remainder of the terms

are the odd harmonics of this fundamental and it will be noted that they have progressively diminishing amplitudes.

The accurate representation of the reversals would require these terms to be continued to infinity. Curve 4 of Fig. 5.15 is the sum of the first two terms, and Curve 5 is the sum of the first three. It will be seen how the resultant approximates more nearly to the square-topped curve as additional terms are included.

It should be noted that the number of signal elements per second (or bauds) is equal to twice the frequency of the fundamental sine wave. Thus—

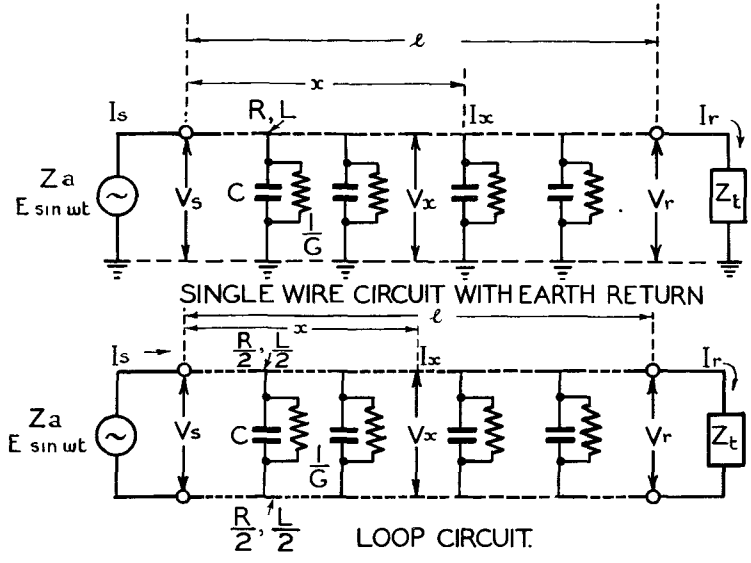


FIG. 5.16. DIAGRAMMATIC REPRESENTATION OF TRANSMISSION CIRCUITS

if N = telegraph speed in bauds,

we have

$$\frac{1}{N} = \tfrac{1}{2}\,T \text{ and } N = 2f,$$

where T and f have the same significance as before.

When reversals are transmitted over a long telegraph line, owing to the losses suffered in the line by the higher frequencies these are received at such a small amplitude that only the fundamental frequency remains, and the reversals are received as almost a pure sine wave. This is illustrated in Fig. 5.10 in which it will be seen that during the steady-state condition the received current is approximately sinusoidal.

To reproduce the square-topped signals faithfully at the receiving end would necessitate the transmission of all frequencies up to infinity. Such reproduction is, however, unnecessary. In practice all frequencies except the fundamental can be eliminated without detriment to the efficiency of the telegraph transmission.

All periodic signals can similarly be resolved into sine wave components, the fundamental frequency always being equal to the number of times the periodic cycle is repeated per second.

It is apparent therefore how the solution of the behaviour of a line in response to sinusoidal waveforms is a legitimate method of attack to obtain a knowledge of the response to more complicated wave forms.

The Classical A.C. Transmission Equations. The mathematical problem in a.c. transmission theory is that of finding expressions for the voltage and current at any point in the line, under given conditions of terminal impedance, when a sinusoidal e.m.f. is applied at one end of the circuit. As this is intended to be a practical rather than a mathematical development of the subject, proofs of the various formulae will not be given here. The derivation of some of the equations—necessarily in a condensed form—has, however, been given in the Appendix, and this would repay examination at this juncture.

In Fig. 5.16 a single-wire and a loop circuit are represented. The circuits are assumed to be uniform throughout their length as regards their electrical characteristics. By reason of its physical configuration, the line is inherently possessed of four electrical characteristics, called the *primary constants*, viz. resistance, inductance, capacitance, and leakance. The resistance and leakance give rise to loss of the transmitted power by transformation into heat, while the inductance and capacitance, or rather the electromagnetic and electrostatic fields associated with the signal currents, take part in the propagation of the electric waves.

The fundamental a.c. transmission equations derived from a study of the response of the line to an impressed sinusoidal e.m.f. are

$$\left.\begin{aligned} V_x &= V_s \cosh px - I_s Z_0 \sinh px \\ I_x &= I_s \cosh px - \frac{V_s}{Z_0} \sinh px \end{aligned}\right\}^{*} \qquad (3)$$

* See footnotes *re* Hyperbolic functions on p. 124 and p. 166 of Appendix. Also Fig. 5.17.

where V_x, I_x = voltage and current (sinusoidal) at any point distance x from the sending end;

V_s, I_s = sending end voltage and current;

$p = \sqrt{(R + j\omega L)\ (G + j\omega C)}$ and is called the *propagation constant* of the line;

$Z_0 = \sqrt{\dfrac{R + j\omega L}{G + j\omega C}}$ and is called the *characteristic impedance* of the line;

R, L, G, C = primary constants per unit length;

$\omega = 2\pi f$, where f is frequency of impressed sine wave;

$j = \sqrt{-1}$.

From equations (3) can be calculated the voltage and current at any point in the line for any given terminal conditions. The voltage and current at the receiving end is obtained by putting $x = l$ in equations (3), l being the length of the line, as follows—

$$\left.\begin{aligned} V_r &= V_s \cosh pl - I_s Z_0 \sinh pl \\ I_r &= I_s \cosh pl - \frac{V_s}{Z_0} \sinh pl \end{aligned}\right\} \qquad (4)$$

By introducing the term

Z_t = terminating impedance at end of line and noting that

$$\frac{V_r}{I_r} = Z_t$$

we can, by substituting this value in equations (4), obtain the following

$$I_r = \frac{V_s}{Z_t \cosh pl + Z_0 \sinh pl} \qquad (5)$$

$$I_s = \frac{V_s}{Z_0} \cdot \frac{Z_0 \cosh pl + Z_t \sinh pl}{Z_t \cosh pl + Z_0 \sinh pl} \qquad (6)$$

Equation (5) gives the value of the received current in terms of the sending voltage and the terminating conditions of the line. If we introduce the further terms

Z_a = impedance of source;

E = e.m.f. of source

we have

$$V_s = E - I_s Z_a$$

and therefore

$$I_r = \frac{E}{(Z_a + Z_t) \cosh pl + \left[Z_0 + \dfrac{Z_a Z_t}{Z_0} \right] \sinh pl} \qquad (7)$$

Equation (7) gives the received current in terms of the applied e.m.f. and should be compared with that given for the leaky line for the d.c. case.

Infinite Line Conditions (Line Terminated in Characteristic Impedance Z_0). To determine the conditions of complete uniformity in the transmission it is assumed that the line is continued without change to an infinite length. In this case pl is infinitely great.

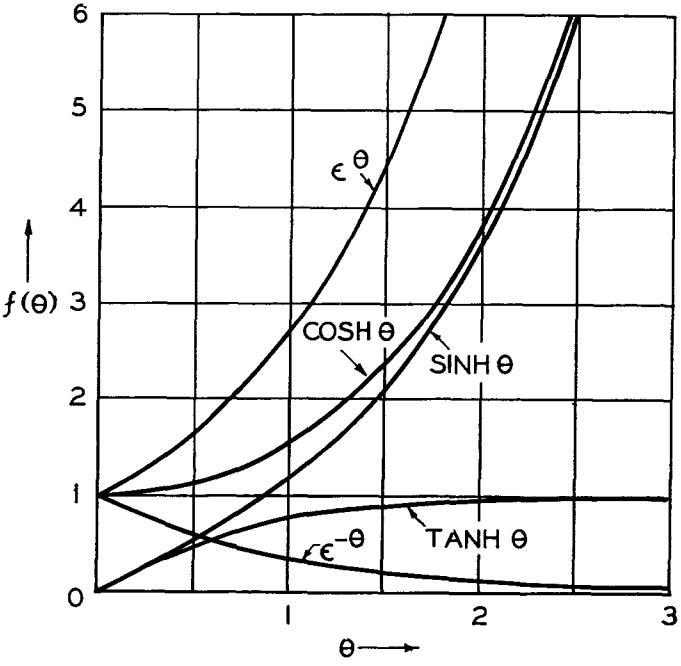


FIG. 5.17. CURVES OF HYPERBOLIC FUNCTIONS

Dividing the numerator and denominator in equation (6) by cosh pl gives—

$$I_s = \frac{V_s}{Z_0} \cdot \frac{Z_0 + Z_t \tanh pl}{Z_t + Z_0 \tanh pl}$$

When pl is infinitely large, tanh pl is equal to 1 and therefore

$$I_s = \frac{V_s}{Z_0}$$

Under these conditions therefore the impedance presented by the line, that is the ratio $\dfrac{V_s}{I_s}$, is the characteristic impedance Z_0.

Referring to Fig. 5.17, from the graph of tanh θ it will be seen that for values of θ of 3 and upwards, tanh θ is very nearly equal to 1. Thus so long as pl

approaches or exceeds 3, the input impedance of the line is independent of the terminating conditions.

The infinite line conditions can be reproduced by making the terminating impedance equal to Z_0.

Substituting this value in equation (6) again gives the relation

$$I_s = \frac{V_s}{Z_0}$$

Also from equations (3) by substituting this ratio we get

$$V_x = V_s (\cosh px - \sinh px)$$
$$I_x = I_s (\cosh px - \sinh px)$$
$$\therefore \frac{V_x}{I_x} = \frac{V_s}{I_s} = \frac{V_r}{I_r} = Z_0$$

Under these conditions the ratio of volts to current is constant throughout the line and equal to Z_0.

Termination of the line by an impedance other than the characteristic impedance of the line leads to reflection of the electric wave and consequently increased power losses, and therefore it is usually arranged for a.c. telecommunication transmission lines to be terminated by an impedance as nearly equal to their characteristic impedance as practicable.

Any change of the ratio $\frac{V}{I}$ brought about by change of impedance owing to discontinuity or change in the characteristics of the line leads to a reflection wave with consequent loss of power. Such changes are therefore avoided as far as possible.

Attenuation and Phase Constants. We have seen that when the line is terminated in an impedance equal to the characteristic impedance, equations (3) may be written

$$V_x = V_s (\cosh px - \sinh px)$$
$$I_x = I_s (\cosh px - \sinh px)$$
$$\therefore \frac{V_x}{V_s} = \frac{I_x}{I_s} = \cosh px - \sinh px$$

Substituting the exponential expressions for cosh and sinh gives

$$\frac{V_x}{V_s} = \frac{I_x}{I_s} = \frac{e^{px} + e^{-px}}{2} - \frac{e^{px} - e^{-px}}{2}$$
$$\therefore \frac{V_x}{V_s} = \frac{I_x}{I_s} = e^{-px}$$

Similarly

$$\frac{V_r}{V_s} = \frac{I_r}{I_s} = e^{-pl}$$

or

$$\frac{V_s}{V_r} = \frac{I_s}{I_r} = e^{p}$$

It will be seen that under these conditions a comparatively simple relationship exists between the sending voltage and current and the voltage and current at any point in the circuit. Furthermore, as these are the conditions under which lines are normally assumed to be worked, the foregoing simple relationship alone will be considered in what follows.

The propagation constant p is obtained from the formula

$$p = \sqrt{(R + j\omega L)(G + j\omega C)}$$

where R, L, G, and C are the primary constants of the line per unit length, p being the propagation constant per unit length, i.e. per mile of line in Great Britain.

The propagation constant is therefore a vector quantity and may be resolved into real and imaginary components thus—

$$p = a + jb$$

and

$$\frac{I_r}{I_s} = \frac{V_r}{V_s} = e^{-(al + jbl)} = e^{-al}\, e^{-jbl}$$

The factor e^{-al} determines the ratio, while the factor e^{-jbl} determines the phase of the sine wave, at the point considered, with respect to the sent wave.

Remembering that the voltages and currents in the whole of this treatment are sine waves we can write the expressions in full as follows—

$$I_r = e^{-al} I_s \sin(\omega t - bl)$$

and

$$V_r = e^{-al} V_s \sin(\omega t - bl)$$

where bl is the angular phase difference in radians between the sent and received sine waves.

Graphs of the exponential functions e^{θ} and $e^{-\theta}$ (or $\frac{1}{e^{\theta}}$) are given in Fig. 5.17, and how the amplitude of the current or voltage wave is gradually reduced as the length of line increases will be clear from the curve for $e^{-\theta}$.

The significance of a change of phase between sine waves was illustrated in Fig. 1.7. The negative sign before the angle bl indicates that the phase of the received current lags behind that of the sent current as would be expected. As the angle is proportional to the length of line it is clear that the change of phase is progressive and linear, as distinct from the change of amplitude which is logarithmic. When the distance l between two points is such that $bl = 2\pi$, the sine waves at these points are at the same phase, as 2π corresponds to one complete cycle. Thus when the voltage or current is at a maximum at the first point it is also at a maximum at the second point. The distance l required to give

this condition is called the *wavelength*, and is given by the relation.

$$\text{Wavelength} = \frac{2\pi}{b}$$

For this reason b is sometimes called the *wavelength constant*. It is also called the *phase constant*.

a is called the *attenuation constant* as it determines the amount by which the signal wave is attenuated during transmission.

These constants can be obtained from the relation

$$p = a + jb = \sqrt{(R + j\omega L)(G + j\omega C)}$$

Separating real and imaginary quantities gives

$$a = \sqrt{\tfrac{1}{2}\{\sqrt{(R^2+\omega^2L^2)(G^2+\omega^2C^2)} + (GR - \omega^2LC)\}} \quad (8)$$

$$b = \sqrt{\tfrac{1}{2}\{\sqrt{(R^2+\omega^2L^2)(G^2+\omega^2C^2)} - (GR - \omega^2LC)\}} \quad (9)$$

Useful approximate formulae for loaded cable conductors for which ωL is great compared to R, and G is negligible compared to ωC, are—

$$a = \frac{R}{2}\sqrt{\frac{C}{L}} \quad . \quad . \quad . \quad . \quad . \quad (10)$$

$$b = \omega\sqrt{CL} \quad . \quad . \quad . \quad . \quad . \quad (11)$$

For unloaded cable conductors the inductance and leakance may be neglected at frequencies in the audio range, giving the approximate formulae.

$$a = b = \sqrt{\tfrac{1}{2}\omega CR} \quad . \quad . \quad . \quad . \quad (12)$$

The corresponding approximate formulae for the characteristic impedance are—

Loaded cable conductors

$$Z_0 = \sqrt{\frac{L}{C}} \quad . \quad . \quad . \quad . \quad . \quad (13)$$

Unloaded cable conductors

$$Z_0 = \sqrt{\frac{R}{\omega C}}\,\angle 45^\circ \quad . \quad . \quad . \quad . \quad . \quad (14)$$

The capital letters P, A, and B are used to denote the total propagation, attenuation, and phase characteristics of a transmission path and therefore for a uniform transmission line of length l miles.

$$P = pl,\ A = al, \text{ and } B = bl$$

Distortionless Transmission. The occurrence of the ω terms in equation (8) indicates the dependency of the attenuation constant on the frequency of the applied voltage. Formula (12) shows this more clearly, and it is apparent that as the frequency increases so does the attenuation. It is obvious that complex waveforms or signals cannot be transmitted over such a line without distortion due to the reduction in amplitude of the higher frequency components with respect to the lower frequency components. Therefore a complex waveform cannot be transmitted faithfully unless the attenuation is the same for all the component frequencies.

Similarly equations (9) and (12) show that the phase constant is dependent on frequency. For distortionless transmission the various frequencies must appear at the receiving end with the same relative phases as they have in the initial complex wave-form. This condition is only fulfilled if the phase constant is proportional to frequency.

Heaviside saw that making the ratio $\frac{R}{L} = \frac{G}{C}$ would give the conditions necessary for distortionless transmission. Thus if we rewrite the formulae for the propagation constant and characteristic impedance as follows—

$$p = \sqrt{LC}\sqrt{\left(\frac{R}{L} + j\omega\right)\left(\frac{G}{C} + j\omega\right)}$$

$$Z_0 = \sqrt{\frac{L}{C}}\sqrt{\frac{\frac{R}{L} + j\omega}{\frac{G}{C} + j\omega}}$$

it is easy to see that putting $\frac{R}{L} = \frac{G}{C}$ gives

$$p = \sqrt{LC}\left[\frac{R}{L} + j\omega\right] = \sqrt{\frac{C}{L}}\,[R + j\omega L]$$

and $Z_0 = \sqrt{\frac{L}{C}}$ . . . . . (15)

and is therefore independent of frequency.

Also

$$p = a + jb = R\sqrt{\frac{C}{L}} + j\omega\sqrt{CL}$$

Whence the attenuation constant is given by

$$a = R\sqrt{\frac{C}{L}} = \sqrt{RG} \quad . \quad . \quad . \quad . \quad (16)$$

and is independent of frequency. The phase constant is given by

$$b = \omega\sqrt{CL} = 2\pi f\sqrt{CL} \quad . \quad . \quad . \quad (17)$$

and is therefore proportional to frequency.

The conditions for distortionless transmission are thus satisfied.

The primary constants for a pair in an underground paper core cable having 20 lb conductors are approximately—

$$R = 88\ \Omega/\text{mile}$$
$$L = 1\ \text{mH/mile}$$
$$G = 1\ \mu\text{mho/mile}$$
$$C = 0{\cdot}062\ \mu\text{F/mile}$$

Thus

$$\frac{R}{L} = \frac{88}{10^{-3}} = 88{,}000$$

and

$$\frac{G}{C} = \frac{1}{0{\cdot}062} = 16{\cdot}1$$

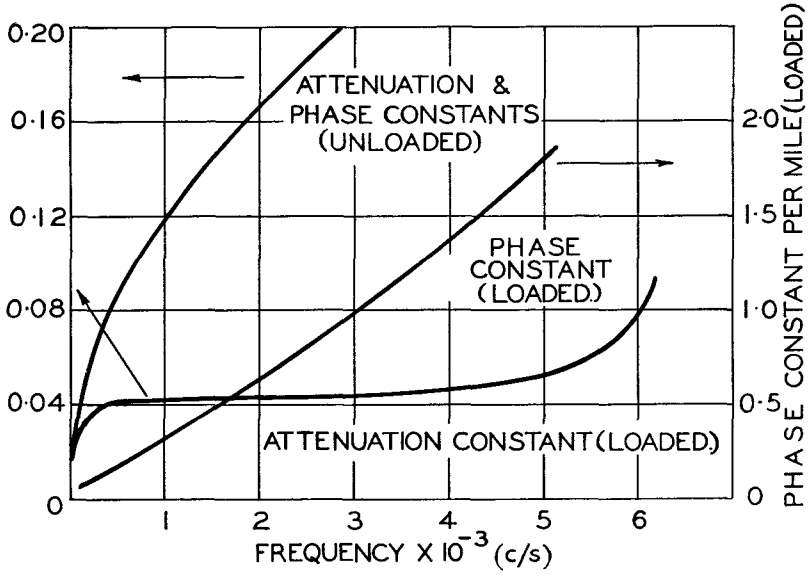


FIG. 5.18. ATTENUATION AND PHASE CHARACTERISTICS FOR 25 LB CABLE PAIR CIRCUIT

(*a*) Unloaded (*b*) Loaded with 44 mH loading coils at 2,000 yd spacing

It will be seen that for such a circuit the distortionless condition can only be approached with a very large increase in the inductance or leakance.

Increasing the leakance has the disadvantage of increasing the attenuation, and the method adopted is to increase the inductance.

Loading. Theoretically the minimum attenuation is secured when the distortionless condition is attained, but in practice inductance cannot be added to the circuit without affecting other constants. In a continuously loaded cable, in which the conductors are loaded by a wrapping of magnetic material, the resistance losses and capacitance are increased. In a coil-loaded cable the resistance losses are increased. Above a certain limit therefore the addition of inductance increases the attenuation.

Since the advent of the thermionic valve repeater, the securing of the minimum attenuation in the cable circuits has ceased to be of primary importance except in the case of long submarine cables. The problem is now one of securing the correct balance between cost of cable and loading and repeater stations.

The coil loading of transmission circuits is complicated by the fact that a coil-loaded circuit acts as a low-pass filter and does not transmit any frequencies above a certain critical point called the *cut-off frequency*, and given approximately by the formula

$$f_c = \frac{1}{\pi\sqrt{L_1 C_1}}$$

where L_1 is the inductance and C_1 the capacitance per loading section. Thus for a given cut-off frequency, if the inductance of the loading coils is increased, the distance between them must be correspondingly reduced so as not to vary the product L_1C_1.

Alternatively, where it is required to transmit a wide band of frequencies such as on music and multi-channel carrier telephone circuits, the loading is reduced or even dispensed with altogether.

Fig. 5.18 gives the attenuation and phase characteristics for a typical underground cable circuit. Loaded circuits of this type are used for 18-channel voice-frequency telegraphy. It will be seen that when loaded the attenuation is almost constant over the range of frequencies 300 to 4,000 c/s, and the phase constant is almost proportional to frequency showing how, with the added inductance, the distortionless condition is approached.

Transmission Units. In practice it is necessary to have some means of assessing the transmission efficiency of circuits. The circuits are normally designed so that the attenuation is approximately constant over the band of frequencies to be transmitted, and phase distortion is negligible. If these conditions are fulfilled, the efficiency of the circuit can be measured by the ratio of the received power to the input power at some given representative

frequency, usually 800 c/s for audio-frequency circuits. The transmission units in use are based on this assumption.

Neglecting phase difference, we have for a properly terminated line

$$\frac{I_r}{I_s} = \frac{V_r}{V_s} = e^{-al} = e^{-A} \quad . \quad . \quad . \quad (18)$$

Also assuming non-reactive characteristic impedance the ratio of received to sent power is given by

$$\frac{W_r}{W_s} = \frac{I_r V_r}{I_s V_s} = e^{-2al} = e^{-2A} \quad . \quad . \quad (19)$$

By way of example suppose a line has an attenuation constant of 0·11 per mile. The ratios for various lengths of line are given in Table 5.2. (The value 0·11 has been chosen to show the point more clearly.)

TABLE 5.2

Length of Line (miles)	al ($a = 0{\cdot}11$)	$\frac{I_r}{I_s} = \frac{V_r}{V_s} = e^{-al}$	$\frac{W_r}{W_s} = e^{-2al}$
10	1·1	$\frac{1}{3}$	$\frac{1}{9}$
20	2·2	$\frac{1}{9}$	$\frac{1}{81}$
30	3·3	$\frac{1}{27}$	$\frac{1}{729}$
40	4·4	$\frac{1}{81}$	$\frac{1}{6561}$

Because $e^{-1{\cdot}1} = 0{\cdot}33$ (approximately), the received current at the end of ten miles is one-third of the sent current. The addition of a second length of ten miles again reduces the current to one-third of that at the end of the first ten miles, giving an overall ratio of $\frac{1}{9}$.

Thus if we wish to know the total transmission efficiency of two lengths of line, one having an attenuation value of 1·1 and the other 2·2, we can add these attenuation values, giving 3·3, but must multiply the current or power ratios.

$$\frac{I_r}{I_s} = \tfrac{1}{3} \times \tfrac{1}{9} = \tfrac{1}{27}$$

$$\frac{W_r}{W_s} = \tfrac{1}{9} \times \tfrac{1}{81} = \tfrac{1}{729}$$

As it would be inconvenient to multiply the various ratios when determining the combined effect of various lines and apparatus, the transmission units are based on the attenuation values so that they can be added together.

The Decibel. The unit of transmission used in the United Kingdom and America is the *decibel* (db) formerly called a *transmission unit* (T.U.). The fundamental unit is the *bel* (so named after Alexander Graham Bell) which can be defined as follows—

A transmission path for which the ratio of the power input to the received power is 10, *is said to have a transmission equivalent of one bel.*

Equation (19) can now be written.

$$\frac{W_r}{W_s} = e^{-2A} = 10^{-b}$$

or

$$\frac{W_s}{W_r} = e^{2A} = 10^{b}$$

where b is the attenuation factor measured in bels.

It has been found convenient to make the practical unit one decibel which is, as its name implies, one-tenth of a bel, whence

$$\frac{W_s}{W_r} = 10^{\frac{\text{db}}{10}} \quad . \quad . \quad . \quad . \quad . \quad (20)$$

where db is the number of decibels.

Equation (20) may also be written

$$\text{db} = 10 \log_{10} \frac{W_s}{W_r}$$

It will be seen that by the choice of the unit for a ratio of 10 the base has been changed from e to 10. This simplifies the mental calculation of ratios for a given number of decibels and also enables ratios to be found by direct reference to ordinary logarithmic tables.

It is easy to see that for 20 db the ratio

$$\frac{W_s}{W_r} = 10^2 = 100$$

For 30 db

$$\frac{W_s}{W_r} = 10^3 = 1{,}000$$

and so on.

Assuming that the ratio

$$\frac{I_s}{I_r} = \frac{V_s}{V_r}$$

holds good, we have

$$\frac{I_s}{I_r} = \frac{V_s}{V_r} = \sqrt{\frac{W_s}{W_r}}$$

Thus

$$\frac{I_s}{I_r} = \frac{V_s}{V_r} = \sqrt{10^{\frac{\text{db}}{10}}} = 10^{\frac{\text{db}}{20}}$$

or

$$\text{db} = 20 \log_{10} \frac{I_s}{I_r}$$

Thus for 20 db, $\frac{I_s}{I_r} = 10$, and for 40 db, $\frac{I_s}{I_r} = 100$.

The attenuation factor, A for 1 db can be found as follows—

$$\frac{I_s}{I_r} = e^A = 10^{\frac{\text{db}}{20}}$$

Table 5.3, of current and power ratios, gives values from zero to 49 db. It will be seen that an increase of 10 db increases the power ratio by ten times, so that from the ratios for 1 to 10 db can be found the power ratio for any other number of db.

TABLE 5.3

Table of Current, Voltage and Power Ratios for Various Transmission Equivalents

db	0	1	2	3	4	5	6	7	8	9
$\frac{I_s}{I_r}$ or $\frac{V_s}{V_r}$.	1	1·122	1·259	1·413	1·585	1·778	1·995	2·239	2·512	2·818
$\frac{W_s}{W_r}$.	1	1·259	1·585	1·995	2·512	3·162	3·981	5·012	6·310	7·943
db	10	11	12	13	14	15	16	17	18	19
$\frac{I_s}{I_r}$ or $\frac{V_s}{V_r}$.	3·162	3·548	3·981	4·467	5·012	5·623	6·310	7·079	7·943	8·913
$\frac{W_s}{W_r}$.	10	12·59	15·85	19·95	25·12	31·62	39·81	50·12	63·10	79·43
db	20	21	22	23	24	25	26	27	28	29
$\frac{I_s}{I_r}$ or $\frac{V_s}{V_r}$.	10	11·22	12·59	14·13	15·85	17·78	19·95	22·39	25·12	28·18
$\frac{W_s}{W_r}$.	100	125·9	158·5	199·5	251·2	316·2	398·1	501·2	631·0	794·3
db	30	31	32	33	34	35	36	37	38	39
$\frac{I_s}{I_r}$ or $\frac{V_s}{V_r}$.	31·62	35·48	39·81	44·67	50·12	56·23	63·10	70·79	79·43	89·13
$\frac{W_s}{W_r}$.	1,000	1,259	1,585	1,995	2,512	3,162	3,981	5,012	6,310	7,943
db	40	41	42	43	44	45	46	47	48	49
$\frac{I_s}{I_r}$ or $\frac{V_s}{V_r}$.	100	112·2	125·9	141·3	158·5	177·8	199·5	223·9	251·2	281·8
$\frac{W_s}{W_r}$.	10,000	12,590	15,850	19,950	25,120	31,620	39,810	50,120	63,100	79,430

Now $\log_{10} e = 0{\cdot}4343$

or $10^{0{\cdot}4343} = e$

$\therefore\ 10^{0{\cdot}4343A} = 10^{\frac{\text{db}}{20}}$

and $A = \dfrac{\text{db}}{8{\cdot}686} = 0{\cdot}1151$ db;

or the attenuation factor A for a line having a transmission equivalent of 1 db = 0·1151.

For example, the power ratio for 1 db is 1·259, for 11 db, 12·59, and for 21 db, 125·9.

For the current ratios a difference of 20 db in the transmission equivalent gives a difference of 10 times in the ratio, while a difference of 10 db gives a difference of 3·162 (i.e. $\sqrt{10}$) times.

The Neper. The attenuation unit used on the European Continent is the *neper*, which is based on

the current ratio instead of the power ratio and is obtained simply from the equation

$$\frac{I_s}{I_r} = e^N, \text{ or } N = \log_e \frac{I_s}{I_r}$$

where N is the attenuation in nepers.

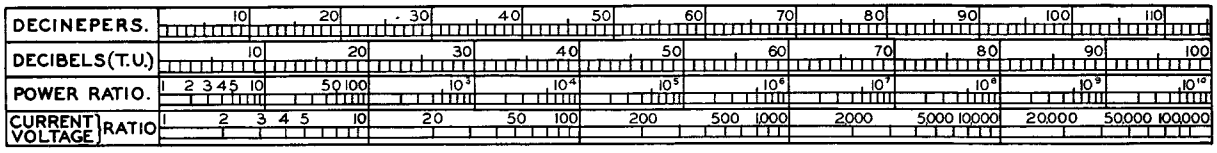


Fig. 5.19. Scale of Transmission Units and Corresponding Ratios

The ratio of sent to received current for an attenuation of 1 neper is therefore

$$\frac{I_s}{I_r} = e = 2{\cdot}7183$$

It will be seen that this unit has been obtained directly by replacing al by N in equation (18), and for this reason the neper is sometimes called the *natural attenuation unit.*

To convert decibels to nepers, or vice versa, we have—

1 neper = 8·686 decibels

1 decibel = 0·1151 neper

Fig. 5.19 is a scale showing the relative magnitudes of the transmission units and the corresponding power, current and voltage ratios.

Use of Transmission Units for Expression of Repeater Gains and Transmission Levels. The gain of a repeater or amplifier may be expressed as a negative attenuation. Thus a repeater giving a gain in power ratio of 100 times would be said to give a gain of 20 db. This enables the overall equivalent of a repeatered trunk circuit to be calculated by deducting the total gains of all repeaters from the total losses.

The transmission level or value of power at any point in a circuit when a given power is applied to one end is also quoted in decibels, the levels being quoted as — or + depending upon whether the power is smaller or greater than the input. A typical level diagram is shown in Fig. 5.20. It refers to a repeatered circuit having three repeater sections. The attenuations of the three sections are 9, 12, and 18 db, while the gains given by the three repeaters are 13, 13, and 7 db respectively. The overall transmission equivalent is therefore 39 — 33 = 6 db. The corresponding level diagram gives the power level at any point in the circuit for zero level at the sending end (taken as 1 mW for testing purposes).

Relation between Steady-state and Transient Conditions

In the case of the distortionless line all frequencies are transmitted with equal attenuation and the same relative phase displacement. Thus any complex wave form applied at the sending end will be reproduced faithfully at the receiving end, as all the component frequencies will be transmitted with the correct relative amplitudes and phases.

In such a case the square-topped wave form shown in Fig. 5.15 would be transmitted without distortion. If we imagined that the speed of the reversals were extremely slow, they would appear for all practical purposes as isolated reversals of the battery at the sending end. The shape of the current curve at the receiving end would then

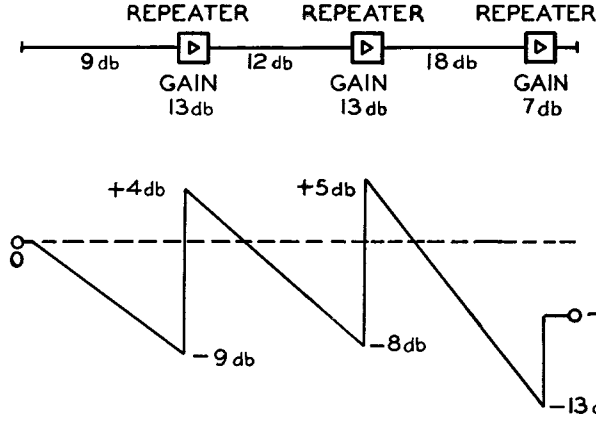


Fig. 5.20. Typical Level Diagram

correspond to the arrival curve. Thus for the distortionless line the arrival curve rises vertically to the steady value of the current, and there is no transient time.

A circuit which is distortionless according to a.c. steady-state theory—that is, for sinusoidal wave forms—is distortionless therefore for all wave forms, and there are no transient effects. It is clear also that the more a circuit departs from the distortionless condition the longer the transient conditions will persist; in other words the longer will be the time required for the received signals to build up to the steady state. It has been shown in the

section on direct current transmission how telegraph distortion is related to the build-up time of the arrival curve. It is obvious therefore that there is a close relationship between the a.c. steady-state characteristics of the line (variation of attenuation and phase constants with frequency) and telegraph distortion. Devices such as shunted capacitors and magnetic shunts are used on long d.c. telegraph lines to improve the shape of the received signals and reduce the telegraph distortion. In so far as these devices reduce the telegraph distortion by decreasing the effective build up time of the signals, they can be regarded as having achieved this by virtue of having improved the steady-state characteristics of the line, and this constitutes the readiest theoretical explanation whereby their action can be understood and the theory applied to practice.

Before pursuing the explanation of the action of distortion correction devices the connexion between steady-state and transient conditions will be further illustrated by reference to a method of obtaining the arrival curve direct from ordinary a.c. transmission theory.

Determination of Arrival Curve from the Steady-state Solution. The method about to be briefly explained and which has been dealt with fully by H. W. Malcolm* was used by Breisig in 1900 to calculate the arrival curve of an Emden-Vigo cable.

It will be clear from what has been given earlier regarding the construction of telegraph signals that if square-topped reversals are sent into a circuit at a slow enough rate, the received current will to all intents and purposes build up to its final steady value between each reversal of the voltage, and the shape of the build-up curve will correspond to that of the arrival curve. Now considering the square-topped reversals as being composed of the harmonic series of sine waves as illustrated in Fig. 5.15 and given by equation (2), it will be apparent that the shape of the arrival curve can be obtained by calculating the amplitude and phase of the individual received sine waves of which the signals are composed. These calculations can be made by means of the ordinary steady-state formula which in its fullest form is—

$$I_r = \frac{E}{(Z_a + Z_t)\cosh pl + \left(Z_0 + \frac{Z_a Z_t}{Z_0}\right)\sinh pl} \quad (7)$$

This formula takes account of the terminal impedances at each end and all constants of the circuit.

* H. W. Malcolm, *The Theory of the Submarine Telegraph and Telephone Cable.* Benn, London, 1917.

It will be remembered that the Kelvin solution for the arrival curve neglects leakance and inductance and also assumes zero terminal impedances. This severely limits the practical use of the formula, because in the case of all lines where the shape of the arrival curve becomes of importance, special terminal networks are used to improve the signal shape, and thus the arrival curve obtained in practice would bear little resemblance to the Kelvin curve.

The equation for periodic reversals of the battery may be written

$$Ef(t) = \frac{4E}{\pi}\sum_{m=0}^{m=\infty}\frac{1}{2m+1}\sin(2m+1)\,\omega t \quad (21)$$

where the sign Σ indicates the summation of the terms with all values $m = 0$, 1, 2, 3, etc., to infinity.

Substituting in equation (7) gives

$$I_r = \frac{4E}{\pi}\sum_{m=0}^{m=\infty}\frac{\frac{1}{2m+1}\sin(2m+1)\,\omega t}{(Z_a + Z_t)\cosh pl + \left(Z_0 + \frac{Z_a Z_t}{Z_0}\right)\sinh pl} \quad (22)$$

where $\omega = \frac{2\pi}{T} = 2\pi f$; and

T = the period in seconds of one complete cycle.

The values of Z_a, Z_t and p must be calculated for each term in the series, the values of ω used being ω, 3ω, 5ω, etc.

Equation (22) is the complete solution for the response of a circuit to square-topped reversals, and if T is taken sufficiently large for the current to be sensibly equal to the final steady-state value in the duration $\frac{T}{2}$ sec of one half-cycle, it becomes a solution for the arrival curve. As such it is of more importance from the facts that can be learnt from an examination of the factors contained in it than from its use for the actual calculation of the arrival curve. Save in certain exceptional cases the terms of the series converge but slowly, and the labour in the arithmetical computation is considerable.

The first point of interest which emerges from equation (22) is that it is symmetrical in Z_a and Z_t, which shows that the effect of a given terminal impedance on the arrival curve is independent of whether it is at the sending or receiving end. This should be compared with the d.c. solution for a line with resistance at the sending and receiving ends which shows the same effect of symmetry.

For most cases in practice, and in all cases where the shape of the arrival curve is of primary importance, the line is so long that pl is great enough for sinh pl to be taken as equal to cosh pl, and equation (22) simplifies to—

$$I_r \doteq \frac{4E}{\pi} \sum_{m=0}^{m=\infty} \frac{\frac{1}{2m+1} \sin (2m+1)\,\omega t}{\frac{1}{2}\left(Z_a + Z_t + Z_0 + \frac{Z_a Z_t}{Z_0}\right) e^{pl}} \quad (23)$$

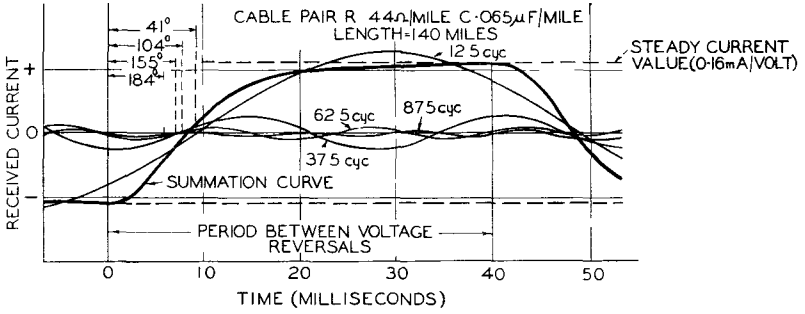


FIG. 5.21. ARRIVAL CURVE CONSTRUCTED FROM SINE-WAVE COMPONENTS OF SQUARE-TOPPED REVERSALS (ZERO TERMINAL IMPEDANCES)

or if Z_a, as is very frequently the case, is small compared to Z_0 and Z_t we have

$$I_r \doteq \frac{4E}{\pi} \sum_{m=0}^{m=\infty} \frac{\frac{1}{2m+1} \sin (2m+1)\,\omega t}{\frac{1}{2}(Z_0 + Z_t)e^{pl}} \quad . \quad (24)$$

It is obvious that it is the denominator of the term under the summation sign in equations (22), (23), and (24) which controls the mode of build-up of the arrival curve. It will be seen that apart from varying the constants of the line itself, the only method of improving the received signals is by manipulation of the terms Z_a and Z_t, that is, the sending and receiving terminal impedances. This will be illustrated by reference to an actual case

Calculation of Arrival Curve with Zero Terminal Impedances (Kelvin Curve). Fig. 5.21 gives the arrival curve for an underground cable pair having the following constants—

$$R = 44\ \Omega/\text{mile}$$
$$C = 0{\cdot}065\ \mu\text{F/mile}$$
$$l = 140\ \text{miles}$$

(Leakance and inductance negligible.)

Such an arrival curve can, of course, be calculated readily from the Kelvin equation given in the preceding section, but to illustrate the use of terminal correcting networks it is preferable to use the steady-state method.

We have $CRl^2 = 56 \times 10^{-3}$
$= 56$ msec
and $0{\cdot}55CRl^2 = 31$ msec

When $t = 0{\cdot}55CRl^2$, the current will have almost reached the steady value. This relation between t and CRl^2 was given in the section on direct current transmission.

To calculate the arrival curve let it be assumed therefore that square-topped reversals are impressed at the sending end of the line, the time interval between reversals being 40 msec. This gives the periodicity of the reversals as $\frac{1{,}000}{80} = 12{\cdot}5$ c/s, and the current will build up to the steady value within the half-period of 40 msec.

From equation (24) we have

$$I_r = \frac{4E}{\pi} \sum_{m=0}^{m=\infty} \frac{\frac{1}{2m+1} \sin (2m+1)\,\omega t}{Z_0\,(\frac{1}{2}e^{al}\,e^{jbl})}$$

For $m = 0$, $f = 12{\cdot}5$ c/s and $\omega = 78{\cdot}5$.

Z_0, a and b can be calculated from the approximate formulae

$$Z_0 = \sqrt{\frac{R}{\omega C}}\,\underline{/45^\circ} = 2{,}940\,\underline{/45^\circ}$$

$$al = bl = l\sqrt{\tfrac{1}{2}\omega CR} = 1{\cdot}5$$

bl gives the angular phase displacement of the sine wave in radians.

We have therefore for the fundamental frequency of the reversals

$$I_r = \frac{1{\cdot}27\,E \sin 78{\cdot}5\,t}{2{,}940\,\underline{/45^\circ} \times 2{\cdot}35\,\underline{/86^\circ}}$$
$$= \frac{1{\cdot}27\,E \sin 78{\cdot}5\,t}{6{,}900\,\underline{/41^\circ}}$$

Similarly for the third, fifth, and seventh harmonics we have—

$$I_r = \tfrac{1}{3}\frac{1{\cdot}27\,E\sin 3\omega t}{1{,}700\angle 45^\circ \times 6{\cdot}73\,\angle 149^\circ}$$

$$I_r = \tfrac{1}{5}\frac{1{\cdot}27\,E\sin 5\omega t}{1{,}300\angle 45^\circ \times 16{\cdot}6\,\angle 200^\circ}$$

$$I_r = \tfrac{1}{7}\frac{1{\cdot}27\,E\sin 7\omega t}{1{,}100\angle 45^\circ \times 27{\cdot}3\,\angle 229^\circ}$$

The value of the steady current is given by $\frac{E}{6{,}160}$.

If we take the value of the steady current as unity, the amplitude and phase of each frequency is as follows—

12·5 c/s $\quad I_r = 1{\cdot}21\angle 41^\circ \sin \omega t$

37·5 ,, $\quad I_r = 0{\cdot}24\angle 104^\circ \sin 3\omega t$

62·5 ,, $\quad I_r = 0{\cdot}08\angle 155^\circ \sin 5\omega t$

87·4 ,, $\quad I_r = 0{\cdot}04\angle 184^\circ \sin 7\omega t$

The correct relative amplitudes of the harmonics with respect to the fundamental as they would appear in the square-topped reversals would be 0·4, 0·24, and 0·17 respectively.

These sine waves are plotted in Fig. 5.21.

It will be observed how the increasing attenuation at the higher frequencies causes the harmonics to be reduced to an increasing degree as the frequency increases. Also, because the phase constant b is not proportional to frequency, the higher frequencies have a smaller phase displacement and are therefore out of phase with the fundamental.

The combined effect of this distortion is to slow up the build-up of the received wave, represented by the summation curve. It will be observed that the seventh harmonic is very much reduced and has little effect on the received current.

Fig. 5.21 shows clearly the effect of attenuation distortion and phase distortion on the arrival curve.

Distortion-correcting Networks. Shunted Capacitor. Fig. 5.22 has been drawn for the same line, terminated by a shunted capacitor and telegraph relay having the following constants—

Capacitor	4 μF
Shunting resistor . . .	4,000 Ω
Inductance of relay . .	2 H
Resistance of relay . . .	350 Ω

The formula in this case is equation (24).

The a.c. impedance of a shunted capacitor is given by—

$$\frac{R(1 - j\omega CR)}{1 + \omega^2C^2R^2} = \frac{R}{\sqrt{1 + \omega^2C^2R^2}}\angle \tan^{-1} - \omega CR$$

and the impedance of the relay, by

$$R_x + j\omega L$$

The separate and combined impedances of these two elements at the requisite frequencies are given below—

Frequency (c/s)	Impedance (approx.) (Ω)		
	Shunted Capacitor	Relay	Combined
12·5	1,540 − *j*1,930	350 + *j*160	1,890 − *j*1,770
37·5	260 − *j*990	350 + *j*480	610 − *j*510
62·5	105 − *j*640	350 + *j*800	455 + *j*160
87·5	50 − *j*440	350 + *j*1,100	400 + *j*660

Due therefore to the presence of the shunted capacitor the value of the terminal impedance falls with rise of frequency, and the value of the term $(Z_0 + Z_t)$ of equation (24) at the various frequencies is as follows—

Frequency (c/s)	$Z_0 + Z_t$
12·5	$5\,500\angle 45^\circ$
37·5	$2\,480\angle 43^\circ$
62·5	$1\,580\angle 29^\circ$
87·5	$1\,200\angle 6^\circ$

The added terminal resistor reduces the steady current value to

$$\frac{E}{10{,}510}$$

Again taking this value as unity gives—

Frequency (c/s)	I_r
12·5	$1{\cdot}03\angle 41^\circ$
37·5	$0{\cdot}26\angle 106^\circ$
62·5	$0{\cdot}10\angle 171^\circ$
87·5	$0{\cdot}06\angle 223^\circ$

The correct relative amplitudes of the harmonics would in this case be 0·34, 0·21, and 0·15 respectively. The improvement obtained by use of

the shunted capacitor is therefore apparent. Some improvement in phase displacement is also secured, the angles being more nearly proportional to frequency. It will be seen that although the shunted capacitor reduces the distortion, there is some reduction in amplitude of the signals, the amplitude in the first case being 0·16 mA/V whereas in the second case it is reduced to 0·10 mA/V.

The sine waves are plotted in Fig. 5.22 and the improvement in the arrival curve will be seen. The effective build-up time has been reduced by about 30 per cent. In making this comparison it should also be remembered that the curve in Fig. 5.21 refers to the case when the receiving end was short-circuited.

It will be clear from equation (22) and the remarks relating to it that distortion can equally be counteracted by the use of a shunted capacitor at the sending end.

This use of the shunted capacitor will be recognized as that of bridge duplex with resistance arms shunted by a capacitor.

In submarine cable practice the resistor may be omitted altogether to secure the maximum attenuation at low frequencies.

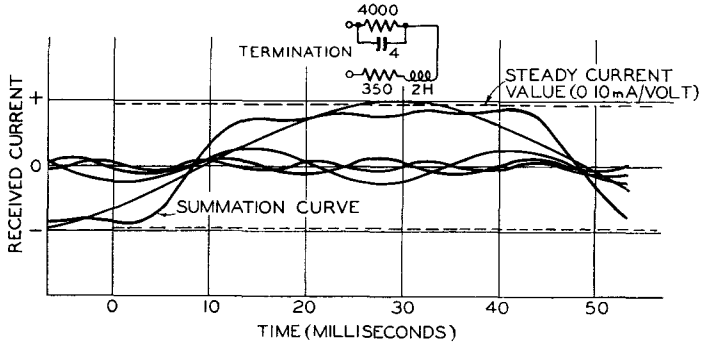


FIG. 5.22. ARRIVAL CURVE CONSTRUCTED FROM SINE-WAVE COMPONENTS OF SQUARE-TOPPED REVERSALS (SHUNTED CAPACITOR AND RELAY TERMINATION)

Inductive Shunt (or Magnetic Shunt). Similar effects to those of the shunted capacitor may be secured by shunting the relay by a resistor and inductor in series. In this case, instead of connecting an impedance in series, which falls with frequency, an impedance which rises with frequency is connected in parallel. This shunt path absorbs a considerable proportion of the low-frequency components, but at higher frequencies a large proportion of the received current passes through the relay.

Similarly to the shunted capacitor the inductive shunt may be used at the sending end. In order that the shunting effect shall be produced on the current sent to line, it is necessary for a suitable impedance to be included in the battery circuit; otherwise the inductive shunt would have practically no effect, merely imposing a heavy load on the battery.

The sending end inductive shunt is a convenient method of distortion correction on differential duplex circuits. Where this method has been used in the B.P.O., on account of the heavy drain imposed on the source by the shunt, rectifier units have been used and the power taken direct from the supply mains.

Adjustment of Distortion-correcting Networks. The best value of components to be used in any given case depends on the speed at which the circuit is to be worked. In the case of long circuits, proper correction over a wide range of frequencies so as to cover various working speeds would necessitate the use of complicated networks.

It is of course the shorter signals which suffer the most distortion; for example, in the teleprinter code an isolated 20 msec signal would be most seriously affected and the network would be adjusted particularly to take care of such signals. If a vibrating relay circuit were in use, this would look after the 20 msec signals, and any distortion correcting network would most probably be adjusted with more reference to 30 msec (stop) and 40 msec signals. Care has to be taken, however, in setting the values of the components in such cases of selective distortion correction on long lines, because the network may not produce true distortion but rather introduce a form of anti-distortion by increasing the amplitude of certain selected frequency components of the signals. It is thus possible to adjust the network so that signal elements of a certain length are received with practically no distortion, while other elements may be adversely affected, and in general the values of components are a compromise obtained by making tests on all representative signal combinations, including long and short signal elements.

It has been found that by far the best results are secured for the purposes of land telegraphy by adjusting the networks while observing the received signals on a telegraph distortion-measuring set, the best all-round value being chosen from observations on various signal combinations.

Electrical Wave Filters

An electrical wave or frequency filter consists of an arrangement of electrical components, generally

inductors and capacitors, having two input and two output terminals, through which currents of certain selected frequencies can pass with very little loss of energy, while all other frequencies are attenuated to such an extent as to be of negligible account in the output. Filters are used extensively in telecommunications; in particular multi-channel telephone and telegraph systems depend for their success on the use of efficient filters.

The various types of filters are low-pass, high-pass, band-pass and band-stop.

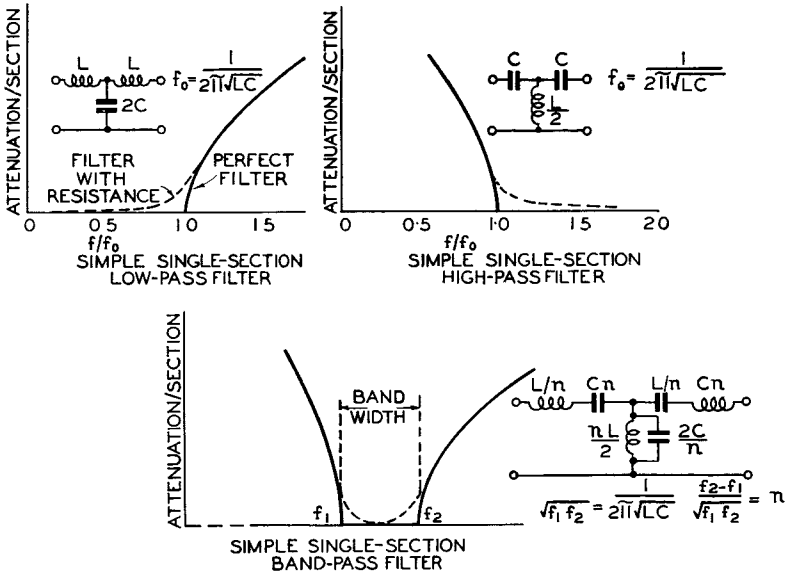


FIG. 5.23. ATTENUATION CHARACTERISTICS OF SIMPLE FILTER SECTIONS

A *low-pass filter* will pass freely all frequencies from zero up to the cut-off frequency.

A *high-pass filter* will pass freely frequencies above the cut-off frequency, frequencies between zero and the cut-off frequency being attenuated.

A *band-pass filter* only passes frequencies in a band between two frequencies, viz. the upper and lower cut-off frequencies of the filter. A band-pass filter is in effect a combination of low- and high-pass filter, the cut-off of the low-pass overlapping that of the high-pass.

A *band-stop filter* passes freely all frequencies outside a band between the upper and lower cut-off frequencies.

The attenuation characteristics of simple basic filter sections are given in Fig. 5.23. In practice the rate of increase of attenuation at the cut-off frequency can be improved by making use of modified forms of the basic sections. As the attenuation is proportional to the number of sections, improved discrimination against the unwanted frequencies can be obtained using filters composed of several sections.

Filters only behave properly if they are worked between impedances approximately equal to their own input and output impedance.

Elements of Filter Theory. The simplest form of filter is the so-called *tuned circuit* consisting of an inductance and capacitance in series or parallel. Such an arrangement can be used as a band-pass filter, as in a radio receiver, or as a band-stop filter to eliminate certain unwanted frequencies from a signal wave.

Series Tuned Circuit. The impedance of the series tuned circuit shown in Fig. 5·24 is given by

$$Z\angle\underline{\theta} = R + j\left[\omega L - \frac{1}{\omega C}\right]$$

$$= \sqrt{R^2 + \left[\omega L - \frac{1}{\omega C}\right]^2}\ \Big/\tan^{-1}\frac{\left[\omega L - \frac{1}{\omega C}\right]}{R}$$

R is the resistance of the inductor and should be as small as possible for most efficient results.

The condition of resonance is given when

$$\omega L = \frac{1}{\omega C},$$

$$\text{and } \omega = \sqrt{\frac{1}{LC}} \text{ or } f = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}$$

When the frequency is such as to satisfy this

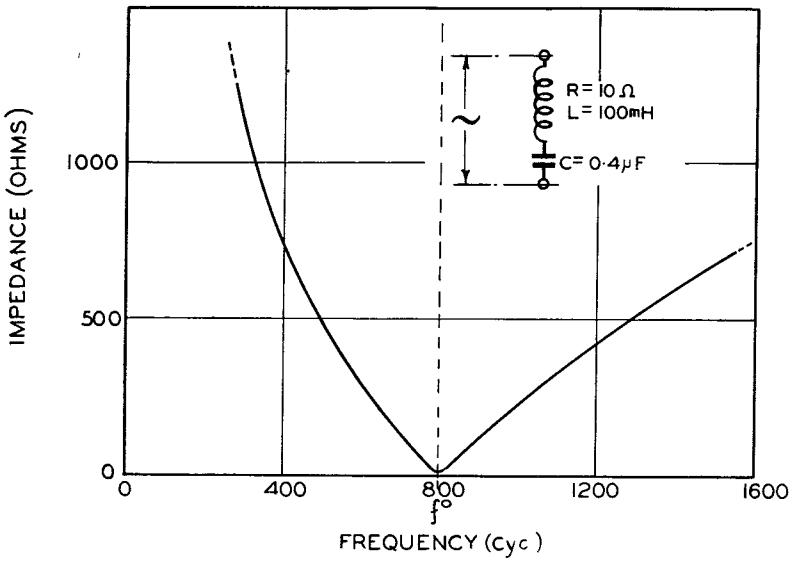


FIG. 5.24. SERIES RESONANT CIRCUIT

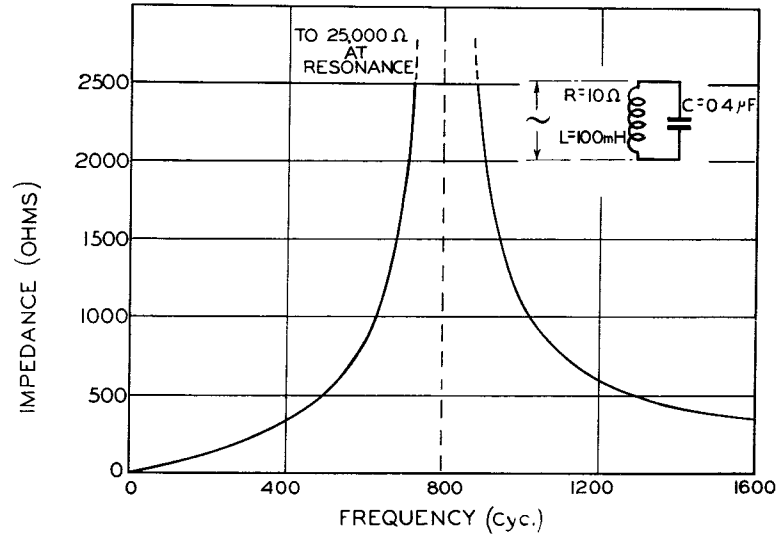


FIG. 5.25. PARALLEL RESONANT CIRCUIT

equation the impedance is non-reactive and equal to R, and if R is very small the circuit is virtually short-circuited.

A graph of the modulus of the impedance of a series resonant circuit is given in Fig. 5.24. The following values have been taken—

$L = 0{\cdot}1$ H;
$C = 0{\cdot}4 \times 10^{-6}$ F i.e. $(0{\cdot}4\ \mu\text{F})$;
$R = 10\ \Omega$.

The resonant frequency is given by

$$f = \frac{1}{2\pi}\sqrt{\frac{1}{LC}} = \frac{1}{2\pi}\sqrt{\frac{1}{4 \times 10^{-8}}} = 796 \text{ c/s.}$$

Parallel Tuned Circuit. The same components arranged as a parallel resonant circuit are shown in Fig. 5.25 together with the relative impedance frequency characteristic.

The impedance in this case is given by

$$Z\underline{/\theta} = \frac{\sqrt{R^2 + \omega^2[L(1 - \omega^2LC) - CR^2]^2}}{(1 - \omega^2LC)^2 + \omega^2C^2R^2} \underline{/\frac{\tan^{-1}\omega[L(1 - \omega^2LC) - CR^2]}{R}}$$

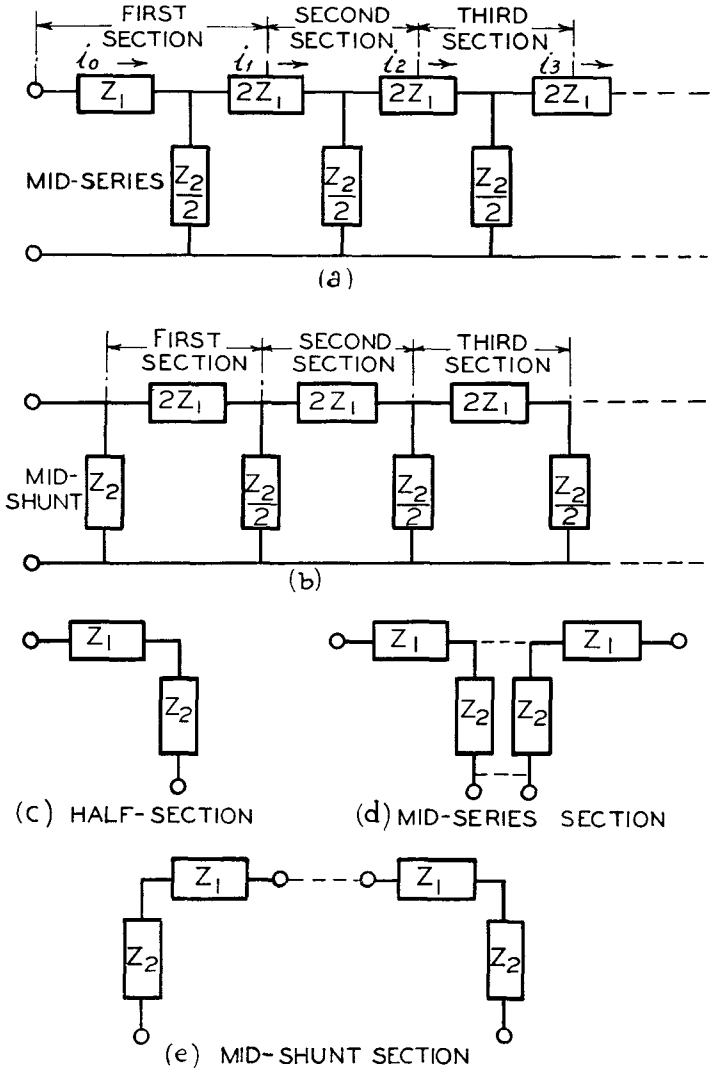


FIG. 5.26. LADDER NETWORKS (UNBALANCED TYPES)

When $\omega L = \frac{1}{\omega C}$

$$Z\underline{/\theta} = \frac{R\sqrt{1 + \omega^2C^2R^2}}{\omega^2C^2R^2}\underline{/\tan^{-1}\omega CR}$$

In general, $\omega^2C^2R^2$ is very small compared to unity; for example, with the present components it is 4×10^{-4}, and the impedance at resonance is very nearly

$$Z = \frac{1}{\omega^2C^2R} = \frac{\omega^2L^2}{R},$$

for $L = 0{\cdot}1$ H;
$C = 0{\cdot}4 \times 10^{-6}$F;
$R = 10\ \Omega$.

The impedance at the resonant frequency is therefore 25,000 Ω.

When R is very small, terms containing R may be neglected except at frequencies close to resonance, which gives the impedance as

$$Z = \frac{\omega L}{1 - \omega^2LC}$$

except close to resonance.

If the inductance were perfect and R therefore zero, the impedance would be infinite at resonance. At all frequencies below resonance the network would behave as an inductance and at frequencies above as a capacitance.

In both the foregoing circuits the effects at resonance are due to the coincidence of the supply frequency with the natural oscillation frequency of the tuned circuit.

Recurrent Networks. The theory of electric wave filters is best developed by reference to the theory of recurrent networks.

Fig. 5.26 shows the structure of recurrent ladder networks, (*a*) being a network with *mid-series* termination, and (*b*) with *mid-shunt* termination. These networks can both be made up from the same "half-section" shown at (*c*), having a series arm impedance Z_1 and shunt arm impedance Z_2. The networks can be considered as made up of half-sections back to back in pairs commencing as in (*d*) or (*e*). In either case the resultant shunt impedance in the ladder network is $\frac{Z_2}{2}$.

By considering these networks to be continued indefinitely, expressions may be deduced for their characteristic impedance and propagation constant.*

For the mid-series termination, shown in Fig.

* See Appendix to this chapter for proof of formula.

5.26 (*a*), the characteristic impedance is given by—

$$Z_{01} = \sqrt{Z_1^2 + Z_1 Z_2} \quad . \quad . \quad . \quad . \quad (25)$$

and for the mid-shunt termination, Fig. 5.26 (*b*) by

$$Z_{02} = \frac{Z_1 Z_2}{\sqrt{Z_1^2 + Z_1 Z_2}} \quad . \quad . \quad . \quad . \quad (26)$$

As in the case of ordinary transmission lines, infinite line conditions can be obtained by terminating the network by the proper impedance. In practice, therefore, a filter only behaves properly if its characteristic impedance is approximately equal to that of the circuit in which it is connected.

Balanced and Unbalanced Networks. The networks shown in Fig. 5.26 are of the unbalanced type. The balanced type are shown in Fig. 5.27. The balanced type are obtained by dividing the series impedance of the corresponding unbalanced type equally between the two sides of the network.

It will be seen that the component impedances have all been related to the impedances Z_1 and Z_2 of the unbalanced half-section. This method gives uniformity in the formulae for the impedance and cut-off frequencies in all types of filters and has been followed throughout.

Filters result when the impedances Z_1 and Z_2 contain reactive components. If the inductors and capacitors used were perfect, that is to say, the impedances Z_1 and Z_2 were wholly re-active, the filters would pass frequencies in the pass range without any attenuation whatsoever, while at the cut-off frequency the attenuation would rise suddenly and steeply as shown in Fig. 5.23.

In practice, although the losses in the capacitors may be negligible, some resistance loss is inevitable in the inductors and a small amount of attenuation is present in the pass range, and the attenuation commences to rise, as shown by the dotted curves in Fig. 5.23 before the cut-off frequency is reached.

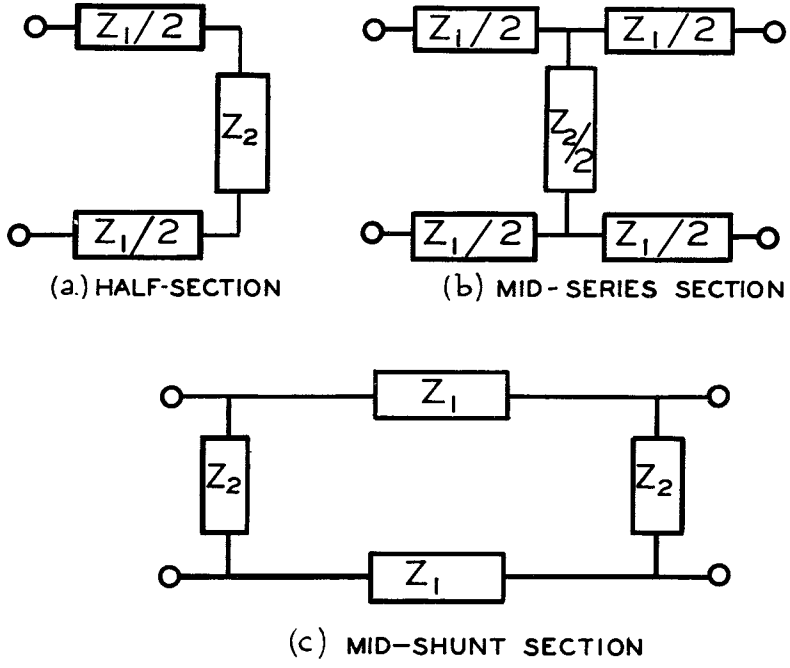


FIG. 5.27. LADDER NETWORKS (BALANCED TYPES)

Resistance losses will, however, be neglected in the following treatment.

Low-pass Filters. If the series impedance Z_1 of the ladder network consists of a perfect inductor, and the shunt impedance Z_2 a capacitor, we have—

$$Z_1 = j\omega L$$

$$Z_2 = \frac{1}{j\omega C}$$

$$\therefore \; Z_{01} = \sqrt{\frac{L}{C} - \omega^2 L^2}$$

$$= \sqrt{\frac{L}{C}}\sqrt{1 - \omega^2 LC} \quad . \quad . \quad (27)$$

$$\text{and } Z_{02} = \frac{\sqrt{\frac{L}{C}}}{\sqrt{1 - \omega^2 LC}} \quad . \quad . \quad . \quad (28)$$

In each of the foregoing the negative sign results because of the product of the two imaginary terms j (i.e. $\sqrt{-1}$).

It will be seen that when ω has such a value that

$$\omega^2 LC = 1$$

the mid-series impedance is zero and the mid-shunt infinity.

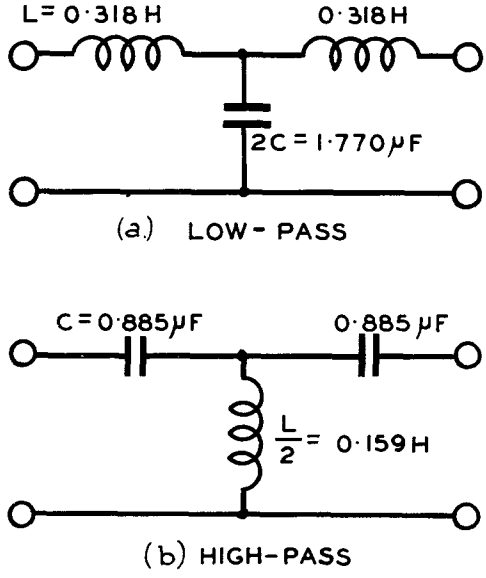


FIG. 5.28. SIMPLE MID-SERIES FILTER SECTIONS
Cut-off frequency (f_0) = 300 c/s; Impedance (R_0) = 600 Ω

Calling this value ω_0 we have

$$\omega_0 = \frac{1}{\sqrt{LC}} = 2\pi f_0$$

$$\text{or } f_0 = \frac{1}{2\pi\sqrt{LC}} \quad . \quad . \quad . \quad . \quad . \quad (29)$$

f_0 is the cut-off frequency.

For values of ω less than ω_0, $\omega^2 LC$ is less than unity, and the impedances Z_{01} and Z_{02} are real or non-reactive. When $\omega^2 LC$ is greater than unity the expression under the root sign becomes negative and the factor j, i.e. $\sqrt{-1}$ re-appears, showing that the characteristic impedance is now wholly re-active and the network ceases to transmit power at the applied frequency.*

When the value of ω is small compared to ω_0, $\omega^2 LC$ is small compared to unity and the characteristic impedance is given approximately by

$$R_0 = \sqrt{\frac{L}{C}} \quad . \quad . \quad . \quad . \quad . \quad (30)$$

The value of R_0 is equivalent to a resistance, and in designing a filter the values L and C are chosen so that R_0 is equal to the impedance of the circuit in which the filter is to work.

From the two formulae

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

and

$$R_0 = \sqrt{\frac{L}{C}}$$

the values of L and C required in any given case can be calculated.

We have

$$L = \frac{R_0}{2\pi f_0}; \text{ and}$$

$$C = \frac{1}{2\pi f_0 R_0}$$

By way of example, the values of L and C for a low-pass filter having a cut-off frequency of 300 c/s and impedance of 600 Ω are as follows—

$$L = \frac{600}{6{\cdot}28 \times 300} = 0{\cdot}318 \text{ H}$$

$$C = \frac{1}{6{\cdot}28 \times 300 \times 600} = 0{\cdot}885 \times 10^{-6}$$

$$= 0{\cdot}885 \ \mu\text{F}$$

It should be remembered that the values L and C are those for a half-section. For a mid-series full section such as shown in Fig. 5.26 the capacitor would be 1·770 μF, that is, two shunt impedances in parallel. Such a filter is shown in Fig. 5.28.

The characteristic impedance of a basic type low-pass filter is shown in Fig. 5.30. This is the impedance that would be measured if a large number of sections was connected in series to give "infinite line" conditions.

High-pass Filters. In this case the series impedance Z_1 consists of a capacitor, while the impedance Z_2 consists of an inductor and we have

$$Z_1 = \frac{1}{j\omega C};$$

$$Z_2 = j\omega L;$$

* See Appendix to this chapter for a formal explanation of the behaviour of filters, based on the effect of frequency on the propagation constant.

and

$$Z_{01} = \sqrt{\frac{L}{C} - \frac{1}{\omega^2 C^2}}$$

$$= \sqrt{\frac{L}{C}}\sqrt{1 - \frac{1}{\omega^2 LC}} \quad . \quad . \quad . \quad (31)$$

$$Z_{02} = \frac{\sqrt{\frac{L}{C}}}{\sqrt{1 - \frac{1}{\omega^2 LC}}} \quad . \quad . \quad . \quad . \quad (32)$$

Again, when $\omega^2 LC = 1$ the mid-series impedance is zero and the mid-shunt infinite, and we have

$$\omega_0 = \frac{1}{\sqrt{LC}},$$

$$\text{and } f_0 = \frac{1}{2\pi}\sqrt{LC} \quad . \quad . \quad . \quad . \quad (33)$$

$$\text{also } R_0 = \sqrt{\frac{L}{C}} \quad . \quad . \quad . \quad . \quad . \quad (34)$$

In this case, however, for values of ω greater than ω_0, that is, for frequencies higher than the cut-off frequency (f_0), $\frac{1}{\omega^2 LC}$ is less than unity, and the expression under the root sign is positive and the impedance is resistive. For frequencies less than f_0 the term $\frac{1}{\omega^2 LC}$ is greater than unity, and the impedance is therefore re-active at frequencies below the cut-off frequencies.

The filter therefore only transmits frequencies above the cut-off.

The values of L and C are given as before by—

$$L = \frac{R_0}{2\pi f_0};$$

$$C = \frac{1}{2\pi f_0 R_0}$$

For a high-pass filter with a cut-off frequency of 300 c/s and impedance of 600 Ω we have again

$$L = 0{\cdot}318 \text{ H};$$
$$C = 0{\cdot}885\ \mu\text{F}$$

In this case, however, for a mid-series section the capacitors used are equal to C, whereas the inductance is equal to $\frac{L}{2}$, that is 0·159 H. Such a filter is shown in Fig. 5.28.

The characteristic impedance is shown in Fig. 5.30.

Band-pass Filters. Band-pass filters may be made up in a variety of ways. It is obvious that a band-pass filter can be made up of a low-pass filter and high-pass filter in series, the cut-off frequency of the low-pass filter being above that of the high-pass filter, the pass band being that lying between the two cut-off frequencies. Where a wide band of frequencies is to be passed, this method would usually be adopted.

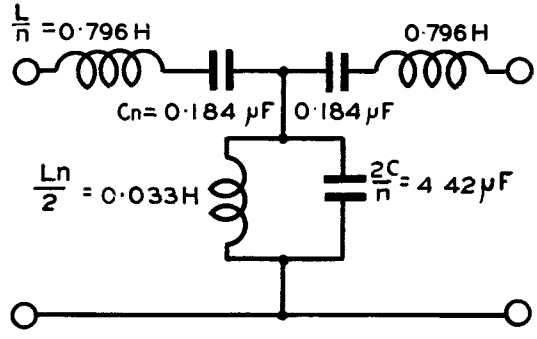


FIG. 5.29. BASIC TYPE BAND-PASS FILTER
Mid-band frequency = 420 c/s; Frequency band = 120 c/s
Impedance (R_0) = 600 Ω

The basic type of band-pass filter is shown in Fig. 5.29 in which the series impedance Z_1 is a series resonant circuit, and the shunt impedance Z_2 is a parallel resonant circuit. This arrangement of elements acts as a band-pass filter so long as the product of the series inductance and capacitance is equal to the product of the shunt inductance and capacitance.

We have therefore

$$Z_1 = \frac{j\omega L}{n} - \frac{j}{\omega Cn};$$

$$Z_2 = \frac{-jn\frac{L}{C}}{\omega L - \frac{1}{\omega C}}$$

Therefore

$$Z_{01} = \sqrt{\frac{L}{C}}\sqrt{1 - \frac{(1 - \omega^2 LC)^2}{\omega^2 LCn^2}} \quad . \quad . \quad (35)$$

$$Z_{02} = \frac{\sqrt{\frac{L}{C}}}{\sqrt{1 - \frac{(1 - \omega^2 LC)^2}{\omega^2 LCn^2}}} \quad . \quad . \quad . \quad (36)$$

The cut-off frequencies are in this case given by the formulae

$$\sqrt{f_1 f_2} = \frac{1}{2\pi\sqrt{LC}} \quad \text{and} \quad \frac{f_2 - f_1}{\sqrt{f_1 f_2}} = n$$

f_2 being the higher and f_1 the lower cut-off frequency.

Also we have

$$R_0 = \sqrt{\frac{L}{C}}$$

As before the values of the inductances and capacitances can be calculated from the required cut-off frequencies and the impedance which is desired for R_0.

Thus

$$L = \frac{R_0}{2\pi\sqrt{f_1 f_2}};$$

$$C = \frac{1}{2\pi R_0\sqrt{f_1 f_2}}$$

$$\therefore \frac{L}{n} = \frac{R_0}{2\pi(f_2 - f_1)}; \quad Cn = \frac{f_2 - f_1}{2\pi f_1 f_2 R_0}$$

$$\frac{Ln}{2} = \frac{R_0(f_2 - f_1)}{4\pi f_1 f_2}; \quad \frac{2C}{n} = \frac{1}{\pi R_0(f_2 - f_1)}$$

It will be observed that the value $\frac{L}{n}$ of the series inductance and $\frac{2C}{n}$ of the shunt capacitance is only dependent on R_0 and the band-width of the filter.

An example of a band-pass filter is shown in Fig. 5.29.

Taking a band width of 120 c/s, a mid-band frequency of 420 c/s, and an impedance of 600 Ω we have—

$$L = \frac{600}{6{\cdot}28\ \sqrt{360 \times 480}}$$
$$= 0{\cdot}23 \text{ H}$$

$$C = \frac{1}{6{\cdot}28 \times 600\ \sqrt{360 \times 480}}$$
$$= 0{\cdot}639\ \mu\text{F}$$

$$n = \frac{120}{\sqrt{360 \times 480}} = 0{\cdot}289$$

$$\frac{L}{n} = 0{\cdot}796 \text{ H}; \quad Cn = 0{\cdot}184\ \mu\text{F}$$

$$\frac{Ln}{2} = 0{\cdot}033 \text{ H}; \quad \frac{2C}{n} = 4{\cdot}42\ \mu\text{F}$$

The characteristic impedance of basic-type band-pass filters is shown in Fig. 5.30.

Band-pass filters having somewhat different attenuation characteristics can be obtained by omitting any one of the four elements composing the impedances Z_1 and Z_2 of the basic type filter.

Derived Filter Sections. Variations from the basic filter sections can be used to obtain special attenuation characteristics or to obtain an input impedance which is practically constant throughout the pass band of the filter. The derivation of such sections is however beyond the scope of the present treatment.

Design and Construction of Filters. It has already been shown how the value of inductance and capacitance required for any given case can be calculated.

The lower the losses in the components, the lower will be the attenuation in the pass range and the higher the attenuation in the attenuating range. The inductors should therefore have as low an effective resistance as possible, consistent with cost and size, and mica di-electric capacitors are generally used to obtain low losses and constancy.

The attenuation of a filter is proportional to the number of sections, and two or three sections may be used if a high attenuation is required in the attenuating range.

Inductors. The usual type of inductor coil used for high quality audio-frequency filters are dust-cored toroidal coils similar to loading coils. By this means the variation of inductance with current and frequency is kept to a low value, while the losses also are relatively small.

For low frequency filters such as the low-pass filters used in sub-audio telegraphy where large inductors are required, and which have to carry the fairly large telegraph currents, cores consisting of high permeability stampings (mumetal, permalloy, radiometal, or rhometal) give the best results.

The inductors in narrow-band voice-frequency filters must be constructed to a high degree of accuracy, the accuracy specified usually being ± 1 per cent of the correct value.

The inductors used in the filters on the multi-channel voice-frequency telegraph system used in the B.P.O. are wound on permalloy dust cores.

Capacitors. For stability and low losses, mica dielectric capacitors meet all the requirements for audio- and carrier-frequency filters. They are usually constructed to an accuracy of ± ½ per cent of the correct value.

For low frequency low-pass filters used for sub-audio telegraphy, accuracy is not so important, and as large value capacitors may be required (over 10 μF), paper dielectric capacitors are used

since the space and cost per microfarad is much less than that of mica capacitors.

Band-pass Filters used in the Multi-channel Voice-frequency Telegraph System. The nominal band-width of the filters used in the multi-channel voice-frequency telegraph system used in the B.P.O. is 120 c/s. The receiving filters are designed so that the attenuation ± 35 c/s from the mid-band frequency is not more than 2·5 db above that at the mid-band frequency. The attenuation ± 120 c/s from the mid-band frequency (i.e. at the carrier frequency of the adjacent channels) is at least 30 db greater than that at the mid-band frequency.

The filters are directly made up from the basic filter section. However, to obtain more convenient values for the shunt inductor and capacitors, an internal impedance transformation is effected by the use of an additional shunting capacitor connected between the series inductor and capacitor.

Balanced and Unbalanced Filters. Filters are usually made up as unbalanced networks to economize components. In such cases it is desirable that the short-circuit side of the filter be at earth potential. If balanced conditions are required, they are frequently obtained by interposing a transformer between the unbalanced filter and the balanced circuit.

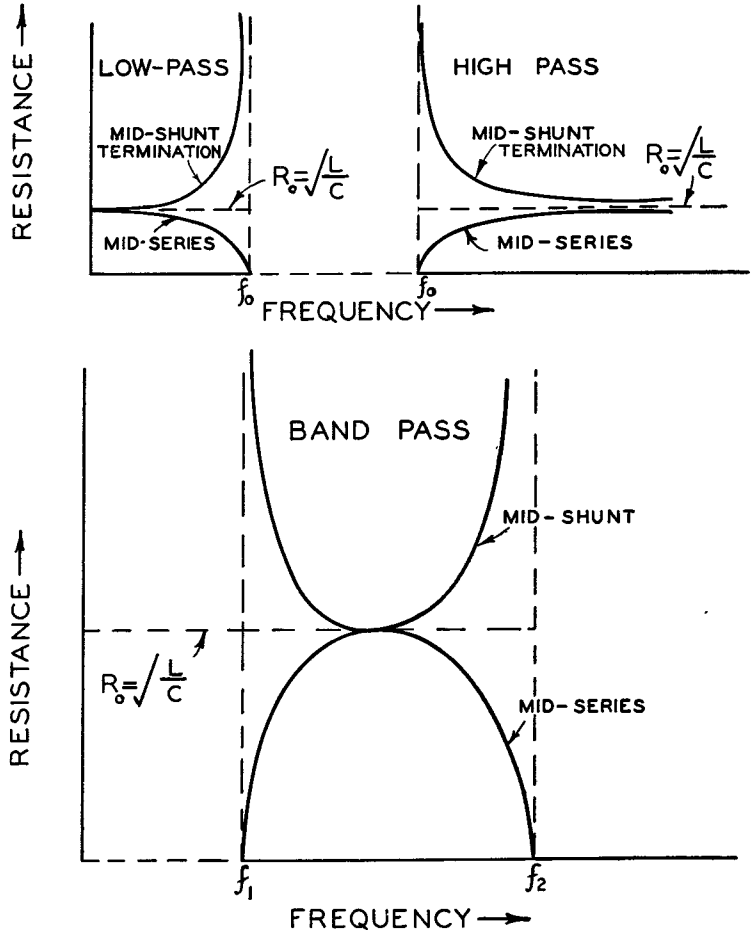


FIG. 5.30. CHARACTERISTIC IMPEDANCE IN PASS-RANGE OF BASIC-TYPE FILTERS

Uses of Filters. The following are amongst the many uses of filters in telecommunications—

Low-pass filters having a cut-off frequency of about 140 c/s are inserted in the sending end of direct current telegraph circuits which work in the same cables as telephone circuits so as to eliminate the audio-frequency components of the telegraph signals to prevent noise in the telephone circuits.

The use of such a filter enables single-wire telegraph circuits to be worked in telephone cables without any appreciable noise occurring in adjacent telephone circuits. Normally a single-section filter is used, suitable values for the inductances being 1·35 H and for the capacitor 2 μF.

Low-pass filters are also used in a similar manner on sub-audio telegraph circuits.

In supra-acoustic telegraphy a low-pass filter is used to prevent the telegraph signals reaching the telephone terminals on the common transmission circuit.

High-pass filters are used to segregate the telephone and telegraph channels on a sub-audio telegraph system. They are also used to prevent the telephone speech currents reaching the telegraph receiver on a supra-acoustic telegraph system.

Band-pass filters are mainly used in multi-channel systems both telegraph and telephone.

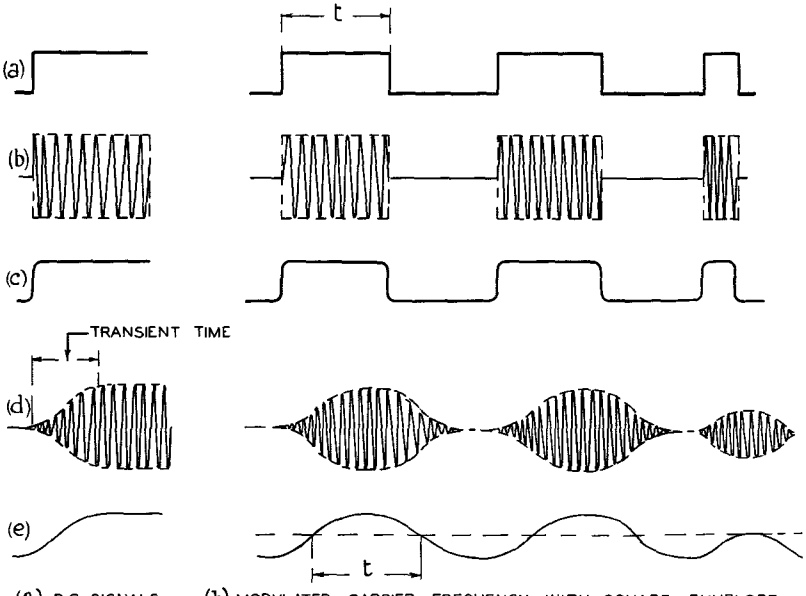


FIG. 5.31. D.C. TELEGRAPH SIGNALS AND CORRESPONDING A.C. AND RECTIFIED A.C. SIGNALS

Transmission of A.C. Telegraph Signals

Effect of Build-up Time. It has been shown that with d.c. telegraph transmission the quality of received telegraph signals is dependent upon the transient time, i.e. the time required for the arrival curve to build up to the steady current value. Exactly the same conditions apply in a.c. telegraphy, when an alternating carrier current is modulated, or interrupted, in accordance with the telegraph code, and subsequently rectified to produce the direct current signals necessary to operate the receiving relay or telegraph instrument. This is illustrated in Fig. 5.31, where d.c. signals and the corresponding a.c. and rectified a.c. signals are shown. Any ripple in the rectified signal due to the carrier frequency is assumed to have been smoothed out.

It will be seen that the shape of the rectified signal conforms to that of the envelope of the carrier signal. If the carrier signals are transmitted through a line or network which introduces transient effects the build-up of the signal will be prolonged and the rectified signal will be delayed in building up to the steady value. So long as the build-up time is not greater than the duration of the shortest signal element, a properly biased receiving relay will give out signals of the same duration as the sent signals. It will be appreciated that to respond to the rectified signals the receiving relay must be biased either mechanically or electrically so that the bias has exactly the same effect as a current half the magnitude of the operating current. The biasing point is shown dotted in Fig. 5.31, and it is obvious that if the relay were biased above or below this line the output signals at the relay contacts would be too short or too long as the case may be.

It is apparent that the relation between build-up time and telegraph distortion in a.c. transmission is exactly the same as that in d.c. transmission, as already explained and illustrated in Fig. 5.2. The effect is further illustrated in Fig. 5.31, in which it is shown that if the duration of the sent signal is appreciably less than the build-up time the signal will have no effect on the receiving relay. If a train of such short signals (spacing and marking elements being equal) were sent, the received carrier frequency and rectified current would build up to half the normal value and remain close to this value until the signals ceased.

Frequencies Present in Amplitude Modulated Carrier. It is apparent that the rectified signals shown at (*c*) in Fig. 5.31 must have a similar frequency spectrum to the original d.c. signals, and that frequencies corresponding to these must have been transmitted with the carrier.

The frequencies present in square-topped reversals were illustrated in Fig. 5.15 and given mathematically in equation (2). The case for similar single current signals is illustrated in Fig. 5.32, and the equation is obtained from equation (2) by adding a constant term to displace the negative side of the signals to the zero line as follows—

$$y_1 = \frac{a}{2} + \frac{2a}{\pi}[\sin \omega_s t + \tfrac{1}{3}\sin 3\omega_s t \ . \ . \ .]$$

where a = amplitude of single current signals;

$$\omega_s = \frac{2\pi}{T} = 2\pi f_s;$$

f_s = number of signal pulses per sec

The expression for the modulated carrier frequency is

$$y_2 = y_1 \sin \omega_c t$$

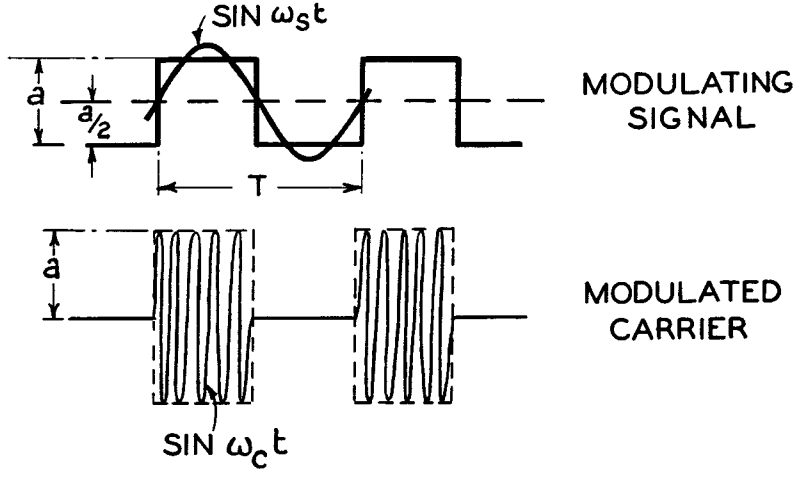


FIG. 5.32. CARRIER FREQUENCY, MODULATED BY PERIODIC SQUARE-TOPPED SIGNALS

Where y_1 represents the amplitude of the carrier; and

$$\frac{\omega_c}{2\pi} = f_c = \text{frequency of carrier}$$

We have therefore—

$$y_2 = \frac{a}{2}\sin \omega_c t + \frac{2a}{\pi}\sin \omega_c t[\sin \omega_s t + \tfrac{1}{3}\sin 3\omega_s t \ . \ . \ .]$$

To show more clearly the frequencies present in the modulated carrier wave the expression for the square wave may be written in the following alternative form—

$$y_1 = \frac{a}{2} + \frac{2a}{\pi}[\cos \omega_s t - \tfrac{1}{3}\cos 3\omega_s t + \tfrac{1}{5}\cos 5\omega_s t - \tfrac{1}{7}\cos 7\omega_s t + \ . \ . \ .]$$

The result of modulating the carrier by the square wave can therefore be represented by the following expression—

$$y_2 = \frac{a}{2}\sin \omega_c t + \frac{2a}{\pi}[\sin \omega_c t \cos \omega_s t - \tfrac{1}{3}\sin \omega_c t \cos 3\omega_s t + \ . \ . \ .]$$

which can be rewritten—

$$y_2 = \frac{a}{2}\sin \omega_c t + \frac{a}{\pi}[\sin (\omega_c + \omega_s)t + \sin (\omega_c - \omega_s)t - \tfrac{1}{3}\sin (\omega_c + 3\omega_s)t - \tfrac{1}{3}\sin (\omega_c - 3\omega_s)t + \ . \ . \ .]$$

Therefore the modulated wave consists of a series of sine wave components with the following frequencies—

Lower Side Band	*Carrier*	*Upper Side Band*
$f_c - f_s$		$f_c + f_s$
$f_c - 3f_s$	f_c	$f_c + 3f_s$
$f_c - 5f_s$		$f_c + 5f_s$
etc.		etc.

It will be seen that any frequency present in the modulating signals is reproduced in the modulated signal as two frequencies represented by the sum and difference of the carrier and signal frequency. These frequencies make up what are termed the *upper* and *lower* side-bands. It follows therefore that signals containing a band of frequencies from zero up to any frequency f_0 will produce frequencies ranging from $f_c - f_0$ to $f_c + f_0$ when used to modulate a carrier frequency f_c, and the frequency band will now be $2f_0$. As in the case of a.c. telegraph transmission, it is usual to transmit both side-bands: it will be seen that the frequency band required is twice that for d.c. signals.

Frequency Band Required. In multi-channel a.c. telegraphy, carrier waves of different frequencies are used for each channel, and the signals segregated by means of band-pass filters at the terminals

of the common transmission line. It is obvious that the narrower the band of frequencies occupied by each channel, the more are the channels which can be operated on a transmission line capable of transmitting a given range of frequencies. In a properly designed system therefore the band-width of the channel filters will be no wider than is necessary for the speed of signalling required.

When square-topped modulated signals such as those shown in Fig. 5.32 are passed through a band-pass filter, the effect of the consequent curtailment

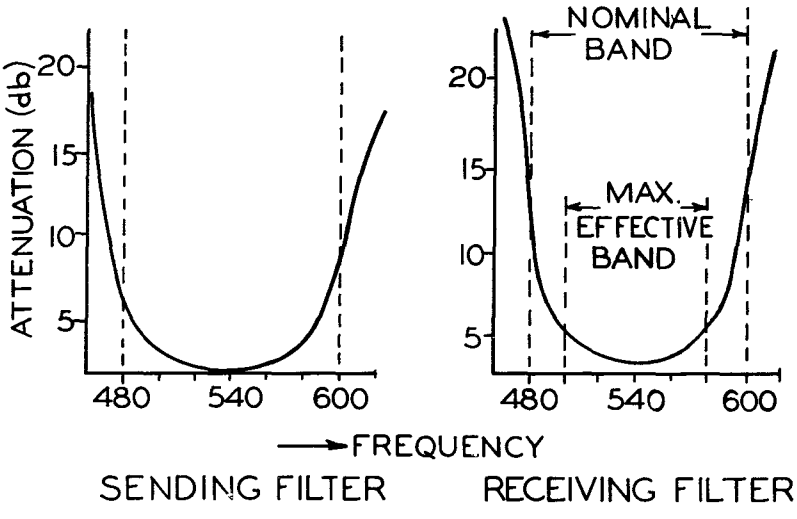


FIG. 5.33. TYPICAL ATTENUATION CHARACTERISTICS OF FILTERS OF MULTI-CHANNEL VOICE-FREQUENCY SYSTEM

of the side-bands is to delay the building up of the signal envelope in a manner somewhat like that shown at (*d*) in Fig. 5.31.

It can be shown that for a band-pass filter, the time required for a carrier at the mid-band frequency to build-up to the steady value is approximately equal to the inverse of the effective band-width.

$$\text{Thus } t \doteqdot \frac{1}{f_2 - f_1}$$

where t = build-up time in sec; and

f_2, f_1 = *effective* cut-off frequencies

It follows that signals having a duration of less than t sec will not be transmitted properly, and therefore the limiting telegraph speed in bauds is given by—

$$N = \frac{1}{t} = f_2 - f_1$$

where N, the speed in bauds, is given by the inverse of the shortest signal element in seconds.

There is therefore a very simple relationship between frequency band required and the speed of signalling. It has been shown that the frequency band required for a modulated carrier frequency is twice that of the modulating or d.c. signals, and therefore the relationship between signalling speed and frequency band can be stated as follows—

The minimum band of frequencies required for d.c. telegraph signals is equal to half the telegraph speed in bauds, and for modulated a.c. signals it is equal to the speed in bauds.

It follows from this that, other things being fixed, the effective band-width required in any given case is directly proportional to the speed of working required. It does not follow, however, that the number of channels obtainable on a given transmission line is inversely proportional to the speed at which the channels are to be worked.

Referring to Fig. 5.33, it will be seen that the maximum effective band-width of the receiving filter is approximately 80 c/s, giving a maximum speed of signalling of approximately 80 bauds. The fundamental frequency of reversals at a speed of 80 bauds is 40 c/s, and therefore if the carrier frequency of 540 c/s is modulated by this frequency, the side-band frequencies will be 580 and 500 c/s.

At higher speeds the amplitude of the side-band frequencies would be attenuated and eventually the signals would be imperceptible at the receiving end.

In practice, distortion due to other effects, such as external interference, bias, variation of transmission level, are present, and it is not satisfactory to attempt to work channels, either d.c. or a.c., too near the limiting speed. Also in the case of a.c. transmission, any variation of the carrier-frequency from the mid-band frequency is more serious when working at high speeds.

It will be appreciated therefore that the speed of working is not the only factor which determines the frequency band per channel, and therefore the number of channels which can be obtained in any given case.

Factors Affecting the Frequency Spacing for Multi-channel A.C. Telegraphy. The various factors

which determine the number of channels obtainable on a multi-channel system are as follows—

(*a*) The speed of working required.

(*b*) The ratio of effective to nominal band-width which can be realized in the practical filter.

The smaller the band-width with respect to the mid-band frequency, the more difficult it is to secure a good ratio.

(*c*) The variation in transmission level required to be met without re-adjustment.

The narrower the band-width the smaller the variation in level that can be satisfactorily tolerated.

(*d*) The variation in carrier frequency to be tolerated.

(*e*) The level of the interference currents reaching a detector with respect to the normal signal currents.

Such interference currents may be due to inter-modulation products (harmonics) caused by loading coils and repeaters in the transmission line. They may also be due to external interference or cross-talk.

(*f*) The signal distortion permissible in practice.

The standard frequency spacing adopted for multi-channel voice-frequency telegraph systems is 120 c/s. This enables 18 channels to be worked on a telephone trunk circuit which has a frequency range of 300 to 2,600 c/s.

This standard is based on the use of high-grade trunk circuits on which the cross-talk level is low, and the repeaters are capable of giving an output of 50 mW with very little distortion.

The highest quality magnetic material is also used for the cores of the filter inductors, an effective band-width of 80 c/s being secured.

This choice of frequency spacing constitutes a compromise amongst all the relevant factors, and enables a high quality telegraph service to be provided on existing trunk circuits without any waste of the available frequency spectrum.

The majority of the channels are used for teleprinter working, that is, at a telegraph speed of 50 bauds. At this speed the distortion of the channels under normal conditions is usually about 6 per cent and rarely greater than 10 per cent. This allows an ample margin in service to cover various contingencies.

As already stated, the band-width of 80 c/s permits the channels to be worked up to 80 bauds. At this speed of working, however, the margin of safety is very much reduced and it would be uneconomic to attempt to work other than a few special channels at this limiting speed.

A further factor affecting the minimum permissible band-width for the channels is the need for setting up through connexions by means of voice-frequency channels connected in tandem. Teleprinters may in such cases be required to operate over four or five channels connected in series. The cumulative effect of the distortion contributed by each channel would render this impossible at speeds approaching 80 bauds, but it is quite permissible at the normal teleprinter speed of 50 bauds. The question of tandem working is dealt with in more detail in the section entitled "Transmission Requirements for Telegraph Switching Systems," page 157.

Line Requirements for Multi-channel Systems: Inter-channel Interference and Cross Modulation. The transmission qualities necessary for the main line used for a multi-channel voice-frequency telegraph system are essentially the same as those of a high quality trunk-telephone circuit. The attenuation and phase characteristics of a line of the type used are shown in Fig. 5.18. On some lines it may be necessary to use an attenuation equalizer to secure a uniform attenuation over the band of frequencies required, that is from 60 c/s below the bottom channel frequency to 60 c/s above the top channel frequency. It is important that the received level for any channel should not be appreciably lower than that for others, particularly those adjacent, otherwise the channel is liable to be affected by interference currents from other channels.

Non-linearity of the phase characteristic is of secondary importance, as a difference of phase between channels is of no importance and a channel band itself is so narrow that no appreciable relative phase displacement occurs over this small range. This is fortunate since equalization of phase is more difficult on long loaded lines than equalization of attenuation.

Noise on the main line would need to be rather worse than that normally expected on telephone lines before interference would be caused to the telegraph signals.

The remaining factor effecting M.C.V.F. telegraph operation is cross modulation. This arises from amplitude distortion of the wave form due to the presence of non-linear components in the line, that is, components in which the ratio of voltage to current is not constant, but dependent on the value of the voltage and/or its direction. Iron-cored inductors and transformers are non-linear due to curvature of the B/H curve, the effect being that the magnetic flux is not absolutely directly proportional to the current and the inductance varies as the current rises and falls. The effect is independent of the direction of the current and is, therefore, the same for positive and negative half-cycles of the alternating current.

A similar effect is produced by curvature in valve characteristics, but in this case a rectifying action can also be present due to the positive half-cycle being amplified to a greater extent than the negative half-cycle, or vice versa.

This non-linearity is productive of harmonics, that is, spurious frequencies, which are multiples of the applied frequencies. Symmetrical distortion

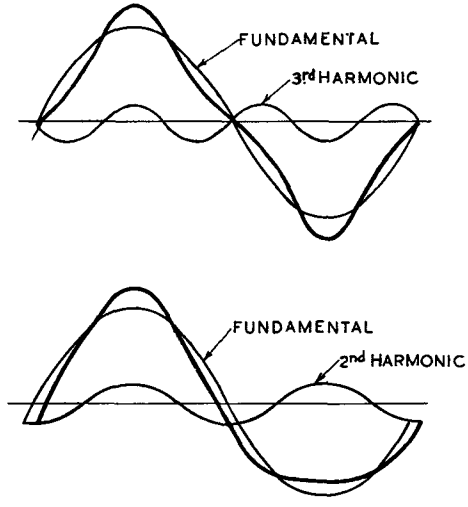


FIG. 5.34. PRODUCTION OF HARMONICS BY DISTORTION OF WAVE-FORM

of the positive and negative half-cycles produces odd harmonics while asymmetrical distortion (rectifying effect) produces even harmonics. This is illustrated in Fig. 5.34 in which is shown a peaky, but symmetrical, wave which is equivalent to a sine wave with a third harmonic, and an asymmetrical wave which is equivalent to a sine wave with a second harmonic.

In practice the use of very high quality iron-dust cores reduces non-linearity effects in transformers and loading coils to a very low order, and the valve characteristics are such that even harmonics are the most important result of non-linearity.

When more than one frequency is transmitted over the line the effect is somewhat more complicated. If there are two frequencies present these will beat together and the combined effect is to produce a wave whose amplitude varies at a frequency equal to the difference between the two original frequencies. This is illustrated in Fig. 5.35. The resultant is somewhat similar to an amplitude modulated wave, and any rectifying action in the valves will cause frequencies equal to the difference and sum of the two original frequencies to appear at the output. The fact that both sum and difference frequencies are produced will be clear from analogy with the normal case of amplitude modulation, the modulation of a frequency f_2 by a frequency f_1 producing the side-band frequencies $f_2 - f_1$ and $f_2 + f_1$. Then if both odd and even harmonics are produced, when two frequencies f_1 and f_2 are transmitted together the harmonics $2f_1$, $3f_1$, $4f_1$, etc., and $2f_2$, $3f_2$, $4f_2$, etc., will be produced together with all the sum and difference frequencies resulting from the beating together of these frequencies; which gives $f_1 - f_2$, $2f_1 - f_2$, $2(f_1 - f_2)$, etc., also $f_1 + f_2$, $2f_1 + f_2$, $2(f_1 + f_2)$, etc.

Thus multiples of the original frequencies are produced together with the sum and difference of the frequencies and their multiples. In practice asymmetrical distortion is usually greater than symmetrical distortion; the distortion products are therefore mainly the even harmonics and the resulting sum and difference frequencies. The first order products $2f_1$, $2f_2$, $f_1 - f_2$ and $f_1 + f_2$ are those having the greatest amplitude, while harmonics having frequencies outside the range of the V.F. system are of course of no account.

The choice of odd multiples of a common frequency for the channel frequencies in M.C.V.F. telegraphy means that even harmonics and sum and difference frequencies tend to fall between the channels where they cause less disturbance. If too high a level of transmitted power is used for the

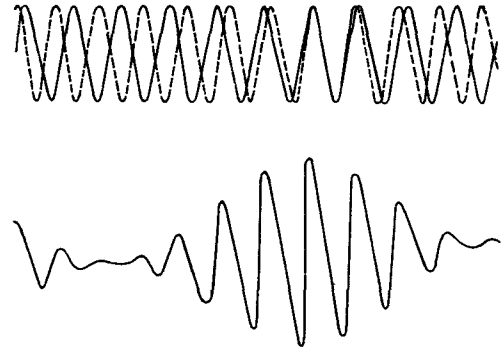


FIG. 5.35. EFFECT OF ADDING TWO WAVES OF DIFFERENT FREQUENCIES
(*a*) Applied E.M.F.s (*b*) Resultant Wave-form

channel frequencies, overloading of the valves will occur and serious distortion of the wave-form will then result; the level is therefore maintained at a value well within the output capacity of the repeater valves.

Cross modulation effects are reduced when feedback type amplifiers are used. Since the effect of the feed back is to maintain the gain constant for all values of signal amplitude, amplitude distortion is reduced to very small proportions.

Cross modulation products arising at various points in the line are not necessarily additive. Owing to the relative changes in phase of the various frequencies due to phase distortion, spurious frequencies produced by one repeater are unlikely to be of the same phase as corresponding frequencies produced by some earlier repeater. The combined effects for any particular spurious frequency are therefore not likely to be directly additive and may even result in a decrease.

In practice so long as attenuation equalization is adequate, the interference products are at such a low level that the performance of V.F. channels is not seriously affected by the length of the line.

Effect of Variation in the Level of the Received Signals. The ordinary method of voice-frequency telegraph working by keying a tone is analogous to single current working in that the receiving relay has to be biased to an extent equivalent to half the amplitude of the received signal. If the amplitude of the signals operating the relay varies, then signals given out by the relay will show a bias. This is illustrated in Fig. 5.36, which shows the bias produced in the signals if the amplitude of the rectified signals increases but the relay biasing current remains unchanged. In practice the effect

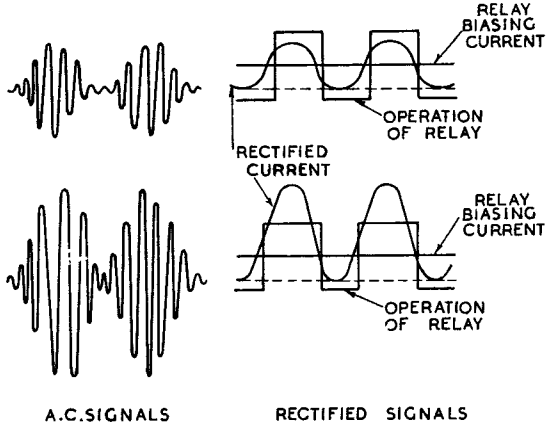


FIG. 5.36. PRODUCTION OF BIAS BY CHANGE IN AMPLITUDE

is reduced by means of automatic gain control in the amplifier-detector, and with "tone-on" working a range of level of the received signal of up to 15 db can readily be accommodated, and with special arrangements up to 40 db can be catered for. With "tone-off" working the range is reduced to 6 db. With tone-on working, where signalling is by interruption of an otherwise steadily transmitted tone, the gain control must remain relatively steady during the longest break in tone which occurs during signalling. Even with the largest practicable time-constant for the gain control circuit some recovery is bound to occur when no tone is present to maintain the biasing voltage and a limit is, therefore, set for the range of permissible level variation. With tone-off working, the tone is normally cut off and only transmitted during signalling. During idle periods the amplifier returns

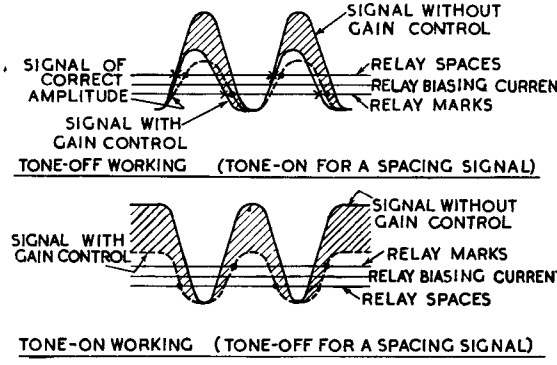


FIG. 5.37. GAIN CONTROL ACTION IN VOICE-FREQUENCY TELEGRAPHY

to maximum sensitivity and thus, during the commencement of the signal, the gain control does not come into operation.

Fig. 5.37 illustrates the case where the rectified signal has twice the amplitude of that required to give undistorted signals, therefore corresponding to a level change of 6 db. In the tone-on case the effect of the gain control is to bring the rectified signal to the correct amplitude before signalling commences, and little change results in the signal shape, which remains reasonably symmetrical. In the tone-off case, no effect is produced until the signal rises above the value at which the gain control comes into operation; thus the relay operates to spacing sooner than it would on a signal of smaller amplitude. Unless the time at which the relay operates to marking is also advanced to correspond, spacing bias will result.

The reduction in amplitude necessary to achieve this effect is indicated by the dotted line in the figure and corresponds to a reduction in gain at this instant of something more than twice the actual change in level of the signal.

As soon as the signal ceases the gain must rapidly return to normal so that when the next signal arrives the amplifier is in the same condition as it was when the first signal arrived. It is clear that this calls for a much more critical performance of the gain control circuit than with tone-on working, and a smaller range of permissible level variation naturally results.

The effects have been illustrated with respect to the signal shapes when signalling at normal speeds on voice-frequency channels. It is clear that for squarer signals, that is, signals with a shorter build-up time, such as would be obtained by widening the band-width, the effect of level variation would be less serious. This explains why, in the system of teleprinting over telephone private wires or exchange connexions where the whole telephone-frequency band is available for one channel, a wide range of level variation is possible. Although it is necessary to have tone-off in the idle

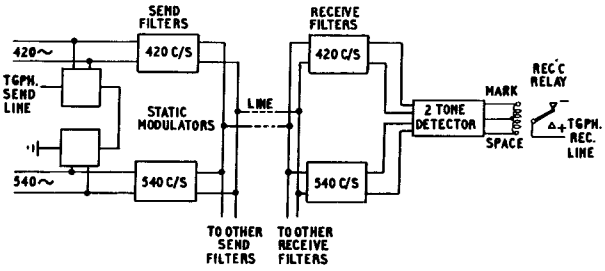


FIG. 5.38. BLOCK SCHEMATIC OF TWO-TONE TELEGRAPHY

condition, because each way working on a single pair of wires is required it is possible to correct for level variations of up to as much as 35 db.

Tone-on working is used on all multi-channel voice frequency telegraph systems in the B.P.O., and has also been standardized for international services.

Multi-tone Working. When multi-channel voice-frequency telegraph systems are operated over radio links or very long overhead lines, large changes in level may be experienced. On a short-wave radio link in particular, the effect of fading is such that the level of the received signal is continuously changing. To meet these conditions two-tone working can be used in which two adjacent channels are combined to form one circuit, and arranged so that one channel transmits tone for a mark and the second channel tone for a space. The receiving relay is arranged to be under the control of both the mark channel and the space channel, giving the effect of double current working. A diagram of one arrangement is given in Figs. 5.38 and 10.44.

When fading conditions are severe, four-tone working can be used. Two "two-tone" channels are used in parallel giving two mark frequencies and two space frequencies. During marking periods the mark frequency which is being received at the higher level takes charge of the output valve, and similarly the stronger signal takes charge during spacing periods. Arranging, in this way, for the stronger signal to take charge prevents noise associated with the weak signal from affecting the output. The type of fading experienced on short-wave radio circuits is such that usually both frequencies will not experience severe fading at the same time and thus the effect of fading is much reduced.

The type of fading whereby one part of the frequency band fades while the remainder of the band is received at a satisfactory level is termed *selective* fading, and the method using two or more tones together by paralleling channels is called *frequency diversity*. Another method of overcoming fading which can also be used is *space diversity*. In this case two or three radio receivers are used each having a separate antenna system, the antennae being so spaced that a given frequency is not likely to fade on all receivers simultaneously. A complete multi-channel voice-frequency telegraph receiving equipment is connected to each receiver, the detectors of each channel being paralleled in the same way as for frequency diversity. If three receivers are used the outputs of the diodes of the second and third detectors are both paralleled across the points *a* and *b* and *a* and *c* of the first detector. (See Fig. 10.44.)

The subject of multi-tone working is dealt with in greater detail in Chapter X.

Frequency Modulation

The foregoing paragraphs have dealt with amplitude modulation of an a.c. carrier wave, and this is the method almost exclusively used for a.c. telegraphy on wire lines. Attention has in recent years been given to an alternative method of modulation, namely frequency modulation (F.M.). In frequency modulation, instead of the modulating signal controlling the amplitude of the carrier it controls its frequency. The effect of the modulating signal is to vary the frequency of the carrier above and below the mean value by an amount depending upon the amplitude of the modulating signal, as illustrated in Fig. 5.39. An important advantage of frequency modulation as compared with amplitude modulation is that a reduction of the effect of noise or interfering currents in the transmission link can be secured. In amplitude modulation such currents have the effect of varying the amplitude of the transmitted wave, and are thus reproduced together with the signal in the rectified output of the receiver. With frequency modulation, although the interfering currents still vary the amplitude of the carrier, these variations in amplitude can be eliminated by means of a limiting stage in the receiver prior to demodulation. Though this does not completely remove the effect of noise, a marked improvement in signal/noise ratio can frequently be obtained.

The foregoing characteristic of frequency modulation is primarily of importance in connexion with the transmission of speech and music by radio on wide-band channels. Conditions are rather different when the problem is that of transmitting telegraph signals on relatively narrow-band channels. In this case, noise is of less consequence, particularly on land lines; on the other hand, with frequency modulation the effect of level variations can be more accurately compensated for than with amplitude modulation.

Since the modulated signal wave sent out by the transmitter has a constant amplitude, it can be passed through a limiter at the receiver which removes all changes in amplitude produced in the transmission link, so long as the level does not fall below that at which limiting takes place.

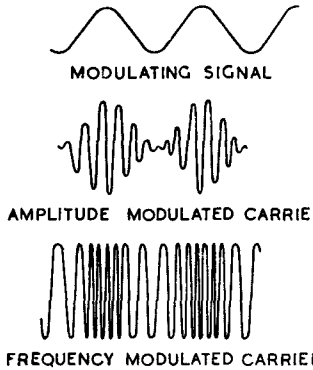


FIG. 5.39. COMPARISON OF AMPLITUDE AND FREQUENCY MODULATION

Very frequently the lines used for multi-channel voice-frequency are contained in underground cables and are thus relatively stable and little subject to noise. However, where systems are operated over long overhead lines or radio links, greater variations in signal strength and higher noise levels are encountered, and frequency modulation of the channel frequencies by the telegraph signals has some advantage over amplitude modulation. In telegraphy frequency modulation has, however, the disadvantage as compared with amplitude modulation that the modulating, demodulating and carrier-frequency generating circuits are more complex, and accuracy of the carrier frequency is of greater importance.

Frequency Band Required for F.M. Telegraphy. A frequency modulated carrier can be resolved mathematically into carrier and side-band components, but the result is considerably more complicated than that for amplitude modulation.

For the simple case of modulation by a single sine-wave if

f_m = modulating frequency;
f_c = carrier frequency;
Δf = frequency deviation or swing either side of the mean carrier frequency,

the modulated carrier will consist of a frequency f_c with side frequencies of

$$f_c + f_m, f_c - f_m, f_c + 2f_m, f_c - 2f_m, f_c + 3f_m, f_c - 3f_m. \ldots$$

and so on to infinity. In theory, therefore, there is an infinite number of side frequencies spaced at intervals equal to the modulating frequency. However, the energy content of side frequencies lying outside the frequencies

$$f_c + f_m + \Delta f \text{ and } f_c - f_m - \Delta f$$

is very small, and the effective band-width of the modulated signal is therefore equal to $2(f_m + \Delta f)$ where f_m is the modulating frequency and Δf the frequency displacement obtained when the modulating signal is at maximum amplitude.

This is illustrated in Fig. 5.40, where the relative amplitude of the carrier and side frequencies for typical sine-wave modulations are shown. The corresponding conditions for amplitude modulation are also given for comparison.

The small amplitude of side frequencies more

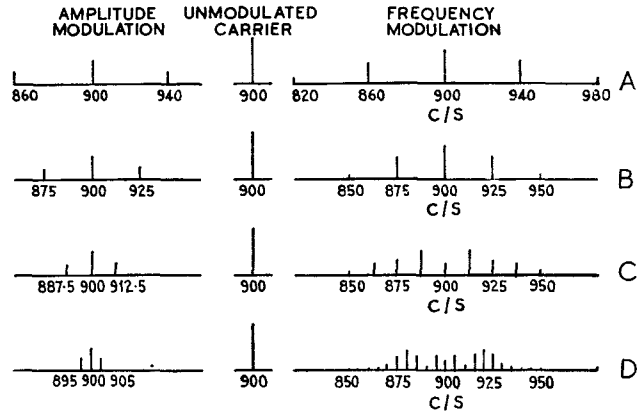


FIG. 5.40. AMPLITUDE OF CARRIER AND SIDE FREQUENCIES IN MODULATED WAVES

A. f_m = 40 c/s (80 bauds), f_c = 900 c/s, Δf = 40 c/s, $\Delta f/f_m = 1$
B. f_m = 25 c/s (50 bauds), Δf = 25 c/s, $\Delta f/f_m = 1$
C. f_m = 12·5 c/s, Δf = 25 c/s, $\Delta f/f_m = 2$
D. f_m = 5 c/s, Δf = 25 c/s, $\Delta f/f_m = 5$

Note: The amplitudes given for A.M. are for "on–off" keying as used in telegraphy, where the peak amplitudes of the modulated and unmodulated waves are the same.

than $(f_m + \Delta f)$ cycles per second from the mean carrier frequency will be observed from the figure, and the fact that the greater part of the energy in the modulated wave is within the band $2(f_m + \Delta f)$ will be clear from the following.

The energy content of any frequency being proportional to the square of the amplitude, we have:

Energy distribution in frequency modulated carrier $\left(\frac{\Delta f}{f_m} = 1\right)$	Relative Amplitude	Relative Energy
Unmodulated Carrier (f_c)	1	1
f_c	0·76	0·5776
$f_c + f_m$	0·44	0·1936
$f_c - f_m$	0·44	0·1936
$f_c + 2f_m$	0·11	0·0121
$f_c - 2f_m$	0·11	0·0121
Sum of carrier and side-frequencies = 0·9890		

When a carrier frequency is modulated by a single sinusoidal frequency the ratio of the frequency deviation (Δf) to the modulating frequency (f_m) is called the *modulation index.*

When a carrier frequency is modulated by mixed signals the conditions are rather more complicated, since each frequency present in the modulating signal contributes something to the total frequency deviation. The term *deviation ratio* is used in this case and denotes the ratio of the maximum carrier-frequency deviation to the maximum frequency present in the modulating wave. The maximum deviation occurs, of course, when the modulating wave is at maximum amplitude.

The relative amplitudes of the carrier- and side-frequency components for single-frequency modulation are dependent on the modulation index. In the first two cases illustrated in Fig. 5.40, the modulation index is unity and the relative amplitudes of the carrier and side frequencies are the same in each case, although, of course, the actual frequencies are different. With increase of modulation index the number of side frequencies of significant magnitude is greater, although if the frequency deviation remains unchanged the effective band-width is reduced, being equal, as already stated, to twice the sum of the frequency deviation and the modulating frequency.

In telegraphy, when it is desired to restrict the band-width of the channels so as to obtain the maximum number of channels on one line, it is possible without undue increase in distortion to use a band not much greater than that necessary to cover the actual frequency deviation of the carrier frequency, provided the maximum keying frequency does not exceed the frequency deviation or, in other words provided the *deviation ratio* is not less than unity. (It will be observed that the term *deviation ratio* is used in this case since we are concerned with the maximum frequency present in mixed signals and not simple sinusoidal modulation.) Taking the first case illustrated in Fig. 5.40, where the modulating frequency is 40 c/s and therefore equal to a signalling speed of 80 bauds, restriction of the band-width to, say, 90 c/s would mean that only the first pair of side frequencies would be transmitted. These frequencies are, in this instance, the same as those which would be obtained with amplitude modulation, although, of course, their amplitude and phase with respect to the carrier are different. It will thus be seen that in telegraphy it is possible to adopt frequency modulation and at the same time use a band-width no greater than that normally used for amplitude modulation.*

The reason for using a deviation ratio of not less than unity is that unless a reasonable amount of frequency swing is employed the signal cannot be satisfactorily demodulated, drift of carrier frequency becomes serious, and also no worth-while improvement over amplitude modulation will be secured.

It will be appreciated that two-tone working and frequency modulation are somewhat similar. Two-tone working has the advantage of using simple modulating and demodulating equipment, but when employing standard channel equipment as used for single-tone amplitude modulation, it uses a band width per channel twice that required for single-tone working. Where neither extreme variations in level nor high noise levels are encountered, frequency modulation can be employed

* It should perhaps be explained that the restriction of band-width cannot be effected without some increase in distortion. Some restriction in band-width could also be permitted in two-tone working, both by narrowing the bands of the filters and also allowing the pass-bands of associated mark and space channels to overlap more than is possible for channels used for separate circuits. The footnote on page 114 explains that a build-up time in excess of the duration of the shortest signal element is theoretically possible without distortion. This fact was ignored in the treatment of the band-width required for ordinary amplitude modulation voice-frequency telegraphy, because if the build-up time exceeded the length of the shortest signal, signals of different length would be of different amplitude, and the automatic gain control would not function properly. Therefore, while in frequency modulation the amplitude changes resulting from restricted band-width can be removed by simple limiting, this is not possible with single-tone amplitude modulation, and restriction of band-width is therefore more objectionable. There are also objections to the use of limiting in two-tone working, and for comparable performances a wider band is required than that for frequency modulation.

with the band-width restricted to that required for amplitude modulation, and consequently no sacrifice in the number of channels is necessary.

Signalling Conditions. When sending mixed signals the conditions are somewhat different from those for simple sinusoidal modulations, but if the d.c. modulating signals are smoothed by means of a low-pass filter the frequency band-width of the F.M. signal is similar to that for sinusoidal modulations. During signalling the frequency will then move up and down smoothly, and, of course, during long signals the frequency will, for the greater part of the signal, remain steady at the mark or space value as the case may be.

The method of producing F.M. signals is to use an oscillator whose tuned circuit contains a component the reactance of which is varied by the applied d.c. modulating current. In this way the resonant frequency of the tuned circuit is varied and therefore that of the oscillator.

A demodulator for F.M. signals is usually called a *discriminator*. The basic circuit of a suitable type is given in Fig. 5.41. Two circuits, LC_1 and LC_2, tuned to frequencies above and below the mean carrier frequency, are connected in series. When the carrier frequency swings towards the frequency to which LC_1 is tuned, the rectified current in diode V_1 increases and that in V_2 falls, the action being reversed when the carrier frequency swings towards the resonant frequency of LC_2. If the output after amplification is differentially applied to the receiving relay a double-current effect is produced. In practice, a limiting stage and a d.c. amplifying stage would be necessary, but for clarity these have not been shown in detail and contain no special features.

It will be clear that any drift of the mean carrier frequency will have the effect of producing a bias. For example, if the frequency drifts towards the spacing side, the output from V_1 will fall and that from V_2 will rise, giving a spacing bias.

In normal V.F. telegraphy, a carrier frequency error of 6 c/s is not of serious consequence, but in F.M. telegraphy using a frequency deviation of, say, 30 c/s this would cause appreciable bias. In this respect two-tone working is superior to F.M. This is of particular importance if the multi-channel system is to be operated over a carrier telephone channel, working with suppressed carrier, and in which the re-inserted carrier is not locked to the same frequency as the original carrier. In this case a difference between the two carrier frequencies will cause a similar shift in the telegraph tone frequencies, and if these are frequency modulated the received telegraph signals will be biased.

Transmission Requirements for Telegraph Switching Systems

The standardization of the teleprinter for the majority of telegraph services and the extensive use of multi-channel voice-frequency telegraphy has led to the widespread introduction of telegraph intercommunication services. In such services, where through connexions may be set up over a number of separate links connected in tandem (i.e. in series) it is necessary that the distortion introduced by each link should be small, or the cumulative effect on the transmitted signals will result in faulty reception. The stability and high quality of service, so easily obtained with voice-frequency channels, meet these requirements and have encouraged development of telegraph switching systems.

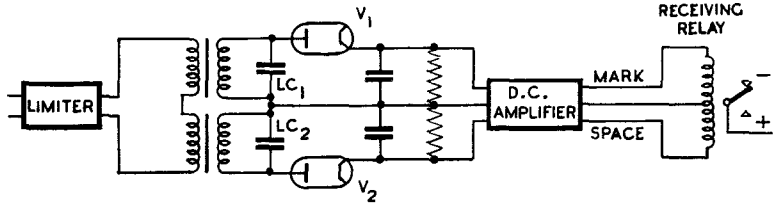


FIG. 5.41. PRINCIPLE OF DISCRIMINATOR FOR F.M. TELEGRAPHY

The cumulative effect on the distortion of telegraph signals by their transmission over successive links depends on the type of distortion concerned.

Characteristic Distortion. If links each having the same type of characteristic distortion are connected in tandem, then the distortion will, in most cases, be additive. For example, if the distortion is of the type where short mark signals following long space signals are shortened (e.g. as illustrated in Fig. 5.2) due to the build-up time exceeding the length of the signal, then, when the signal is repeated by the receiving relay into the next link, the short signal having been already reduced in length will suffer even greater distortion and after several such repetitions may be completely lost. It is clear, therefore, that characteristic distortion must be negligible, or very small, on the individual links forming part of a switching network.

Bias Distortion. If bias distortion is present in tandem-connected links the effect will only be additive if the bias is of the same sign in each link, and there will be a net reduction if the bias in one or more of the links is of opposite sign to the others. For the case of four links in tandem the chance of the bias in all links being the same sign is 1 in 8.

assuming equal probability of marking and spacing bias, and in most cases the resultant total bias distortion will only be about twice that for a single link. While, therefore, the cumulative effect of bias distortion is not so serious as that of characteristic distortion it must be kept to a low value because bias distortion affects every signal element and a high overall value could not be tolerated.

Fortuitous Distortion. This type of distortion in a transmission link arises in the main from interfering currents produced by external disturbing sources; and in multi-channel systems interference from other channels in the system causes fortuitous distortion.

Since the distortion produced is quite irregular and only a small proportion of the signal elements receive the maximum distortion and, further, a signal changeover may either be advanced or retarded, the chance of any particular signal suffering maximum distortion of the same kind in each link is very small. In the result if, say, four links each giving a maximum of 10 per cent fortuitous distortion are connected in tandem, the resulting total distortion is rarely likely to exceed 20 per cent. The cumulative effect of fortuitous distortion is therefore of less importance in multi-link connexions than that of either characteristic or bias distortion.

It is very important that channels required to be used in multi-link connexions are not worked at speeds approaching the limit imposed by the bandwidth of the channels. Suppose, for example, that with a signalling speed of 50 bauds, a 20 msec signal has been shortened by 20 per cent when it reaches the third channel in the connexion, it will now be 16 msec in length only, and the effect is as if the signalling speed had been increased to 62·5 bauds. If this higher speed were near the limit of the channel, a big increase in distortion would result.

In the voice-frequency telegraph system used in the B.P.O. the limiting speed is well above the signalling speed of 50 bauds which is the teleprinter signalling speed, and an adequate margin is therefore available. For the same reason the characteristic distortion is very small, and when the channels are properly lined up the distortion is almost wholly confined to fortuitous distortion.

Furthermore, provided the overall attenuation-frequency characteristic of the line is uniform, the channel distortion is practically independent of the length of line, and for practical purposes all channels on an intercommunication network can be regarded as having identical transmission qualities independent of their length. Voice-frequency channels are therefore admirably suited for use in teleprinter switching networks.

Relation between Teleprinter Margin and Permissible Overall Distortion. The factors determining the maximum distortion which can be tolerated on a circuit connecting two teleprinters are—

(*a*) the degree of distortion of the signals given out by the sending teleprinter;

(*b*) the margin of the receiving teleprinter; and

(*c*) the speed difference between the two teleprinters.

A teleprinter transmitter, if in good order, can be relied on to give signals accurate to within 1 msec—that is, the signal changeovers will occur within 1 msec of the correct time measured with respect to the commencement of the start signal.

The margin of a teleprinter is usually measured by means of artificially distorted signals in which the code elements are displaced with respect to the start signal, the effect being produced by lengthening and shortening the start signal. Some teleprinters are equipped with an orientation device (also known as a *range finder*) whereby the operation of the selecting mechanism can be advanced or retarded with respect to the commencement of the start signal, and which can therefore be used to measure the margin of the machine.

A teleprinter is said to have a margin of 40 per cent when the code elements can be advanced or retarded up to 40 per cent of a unit signal element before errors occur.

Some conditions relating to the margin of a teleprinter and signal distortion are illustrated in Fig. 5.42, in which time charts for various conditions are given. The shaded strips indicate the periods during the revolution of the receiving cam when the electromagnet must be definitely set to the position required by the signal code if the character is to be correctly received.

The charts relate to the following conditions—

(1) Correctly adjusted teleprinter—equal margins for marking and spacing signals.

(2) Stop position of receiving cam incorrectly set, selecting periods occurring too late.

(3) Receiving teleprinter 6 per cent fast. (Selecting periods become further advanced with each element.)

(4) Correct reception of letter "*R*."

(5) 20 per cent marking bias on received signal. The space-to-mark transitions are advanced 4 msec (20 per cent of 20 msec) with respect to the mark-to-space transitions. Mark-to-space transitions being of the same type as the start signal remain unchanged with respect to the start signal.

(6) Distorted received signals. The second element is not correctly selected and an error results.

The effect of a difference of speed between the

sending and receiving teleprinter is illustrated in Fig. 5.42. If the speed of the teleprinters on a switched network is within 1 per cent of the correct value, the maximum difference which will occur when any two teleprinters are connected together will be 2 per cent. Such a speed difference is

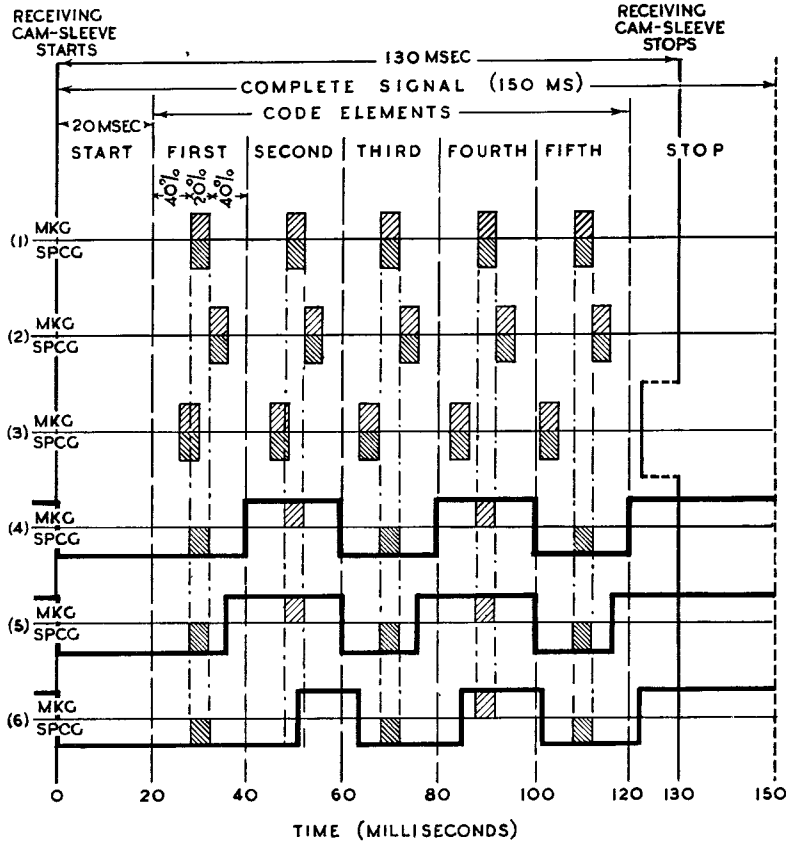


FIG. 5.42. TELEPRINTER MARGIN AND SIGNAL DISTORTION

equivalent to a loss margin of approximately 10 per cent on the fifth code element and 8 per cent on the fourth.

In considering the maximum distortion permissible on multi-link teleprinter connexions, it must be remembered that the chance of all factors being simultaneously of maximum adverseness is very small. Such a case would occur if, for example, a sending teleprinter were 1 per cent slow, and at one and the same time—

(*a*) the transmitter distortion were such that a changeover from space to mark at the commencement of the fifth code element were a full 5 per cent late, this element being also delayed with respect to the start signal by the maximum amount in each channel in the connexion;

(*b*) the receiving teleprinter were 1 per cent fast;

(*c*) the pick-up time of the receiving clutch happened to be a minimum; and

(*d*) all the small irregularities in the mechanical motions acted cumulatively to bring the selecting instant forward by the maximum amount possible.

In practice it is found that the simultaneous occurrence of all extreme conditions is sufficiently rare to be neglected.

Another point to remember is that when we say, for example, that the measured distortion for mixed signals on a channel is 10 per cent, we mean that over the period of observation the maximum value noted for the relative displacement of any pair of signals is 10 per cent; not necessarily that all signals are distorted by 10 per cent. On the other hand if the margin of a teleprinter is given as 40 per cent, it means that when all signals are

consistently distorted by 40 per cent the teleprinter will still continue to give consistently accurate reception.

Distortion Limits for Teleprinter Networks and Switching Services. As a close approximation it may be assumed that where distortion of individual links is relatively small, the probable value of the distortion on a multi-link connexion is equal to the square root of the sum of the squares of the distortion on each link in the connexion. Using this assumption as a basis, it is possible to design a switching plan for a network having various types of links by giving each link a transmission coefficient proportional to the square of the maximum distortion likely to be experienced on the link under normal conditions. It is then arranged that the sum of the coefficients for a through connexion shall not exceed the coefficient corresponding to the square of the maximum permissible overall distortion.

This method is useful where the network is made up of links of various types, such as voice-frequency channels on underground cables, high-frequency carrier on overhead lines, sub-audio telegraph circuits, etc.

An alternative to the foregoing method is to arrange for all links in the system to have a similar transmission performance, when it is only necessary to fix the maximum number of links which may be connected in tandem, irrespective of the length and type of the individual links. This gives a high degree of flexibility, and is the method adopted in Great Britain where all long-distance circuits are voice-frequency channels in underground cables and physical circuits are usually short.

Typical adjustment and design limits used in this way are as follows—

TELEPRINTERS

(Maximum values after adjustment)

Speed error	0·5 per cent
Transmitter distortion	5 ,, ,,

VOICE-FREQUENCY CHANNELS

(Maximum distortion after adjustment)

1 channel	10 per cent
2 channels in tandem	14 ,, ,,
3 channels ,, ,,	17 ,, ,,
4 channels ,, ,,	20 ,, ,,
5 channels ,, ,,	23 ,, ,,

PHYSICAL CIRCUITS

(Maximum distortion)

Wholly physical point-to-point circuits	25 per cent
Physical links in mixed V.F. and physical connexions	10 ,, ,,

On the face of it, if the teleprinter margin is, say, 35 per cent, the limiting figures almost balance on a five-link switched connexion as follows—

Transmitter distortion	5 per cent	Margin	35 per cent
Line distortion	23 ,, ,,	Reduction for 1 per cent speed difference	5 ,, ,,
Total	28 ,, ,,	Total	30 ,, ,,

However, for the reasons already explained the margin and distortion figures are not, strictly speaking, directly comparable, and in practice the law of probability introduces a safety factor which covers the normal falling away from test limits which occurs between the routine readjustments of the equipment.

The design limits for distortion in respect of physical circuits can be translated into the maximum permissible lengths for the various classes of circuit. By suitable distortion tests on typical circuits, limiting lengths can be established for single-wire circuits without receiving relays, for single-wire circuits using receiving relays and for loop circuits using receiving relays. These limits are then used for the purpose of routing circuits and a completely standardized network results. Since physical circuits for inclusion in multi-link connexions have the same limiting distortion as a V.F. channel they may be regarded as equivalent.

The effect of short local physical extensions from voice-frequency systems is negligible and is disregarded.

Regenerative Telegraph Repeaters. These are repeaters which accept distorted telegraph signals in a similar manner to an ordinary receiving telegraph instrument but, instead of converting the signals into printed characters or a perforated tape, retransmit them as undistorted signals. Using such repeaters the number of linked sections can be increased considerably. For example, a ten-link connexion could be operated, provided a regenerative repeater was included between the fifth and sixth sections. Regenerative repeaters can also be used on circuits which exceed the limits laid down for single sections, and such circuits can then be included in the switching network.

The principle employed in the operation of regenerative repeaters is that the repeater examines the polarity of the signals received from line at the theoretical mid-instants of each element of a character and this controls the sense of the signals which are regenerated by the repeater at these instants and retransmitted to line. The timing of the regenerated signals is controlled accurately and thus the regenerated signals can be made substantially free from distortion. It should be noted that the regenerated signals are consistently

retransmitted with a time delay of half a unit interval of modulation.

The majority of regenerative repeaters are nowadays of electronic design as this enables much more precise control of the timing of the signal examination and regeneration. The margin of electronic regenerative repeaters therefore approaches the theoretical maximum of $\pm$ 50 per cent and the distortion of the regenerated signals is extremely small.

A good example of a modern form of electronic start-stop regenerative repeater suitable for land-line and radio-teleprinter circuits is described in the B.P.O. *Electrical Engineers Journal*, January, 1949.

PROOFS OF THE FORMULAE GIVEN IN THE CHAPTER

Charge and Discharge of a Capacitor. Referring to Fig. 5.43 an e.m.f. of E volts is applied to a capacitor C through a non-inductive resistor R.

Taking note of the fact that the voltage across

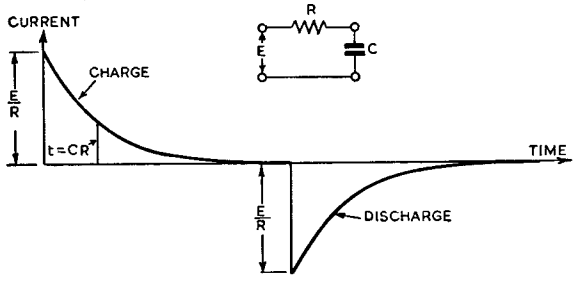


FIG. 5.43. CURVES OF CHARGING AND DISCHARGING CURRENT FOR CAPACITOR AND RESISTOR

the capacitor is at all times equal to $\frac{Q}{C} = \frac{1}{C}\int idt$, we can write—

$$Ri + \frac{1}{C}\int idt = E$$

where i = value of the current at any instant; and
t = time in seconds from instant of switching on the e.m.f.

Differentiating gives

$$R\frac{di}{dt} + \frac{1}{C}i = 0,$$

a differential equation, the solution of which is

$$i = Ae^{-\frac{t}{RC}}$$

where A is some constant determined from the known condition at time $t = 0$.

When $t = 0$, $i = \frac{E}{R}$ because there is no charge on the capacitor.

$$\therefore A = \frac{E}{R} \text{ and}$$

$$i = \frac{E}{R}e^{-\frac{t}{RC}} \quad . \quad . \quad . \quad . \quad (1)$$

The significance of this formula has already been explained and the curve for the current is given in Fig. 5.43.

For the discharge of the capacitor through the resistor R, because the voltage across the resistor is at all times equal to that across the capacitor, we have—

$$Ri + \frac{1}{C}\int idt = 0$$

the solution of which is the same as before, namely—

$$i = \frac{E}{R}e^{-\frac{t}{RC}}$$

Single-section Artificial Line. Referring to Fig. 5.44, the T network shown is a single-section artificial line representing a real line of negligible inductance and leakance having a resistance of R ohms and a total capacitance to earth of C farads.

Suppose an e.m.f. of E volts and negligible internal resistance is applied to one end, the other

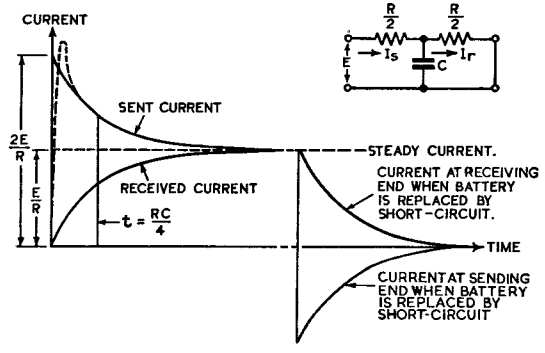


FIG. 5.44. CURVES OF SENT AND RECEIVED CURRENT FOR SHORT ARTIFICIAL LINE

The dotted curve shows the effect of the distributed capacitance near the sending end and the small amount of inductance which would be present in a real line

end being short-circuited. It is desired to find the current at each end of the line.

If V is the voltage across the capacitor at any instant we have—

$$\frac{E - V}{\frac{R}{2}} = I_s = C\frac{dV}{dt} + I_r$$

where $C\frac{dV}{dt}$ is the current flowing into the capacitor at any instant.

$$\therefore \quad \frac{E-V}{\frac{R}{2}} = C\frac{dV}{dt} + \frac{2V}{R}$$

and $$E - V = \frac{CR}{2}\frac{dV}{dt} + V$$

or $$\frac{E}{2} = V + \frac{CR}{4}\frac{dV}{dt}$$

the solution of which is

$$V = \frac{E}{2} + Ae^{-\frac{4}{CR}t}$$

$V = 0$ when $t = 0$;

$$\therefore A = -\frac{E}{2} \text{ and}$$

$$V = \frac{E}{2}\left(1 - e^{-\frac{4}{CR}t}\right)$$

$$\therefore I_s = \frac{E}{R}\left(1 + e^{-\frac{4}{CR}t}\right) \quad . \quad . \quad . \quad (2)$$

$$\text{and } I_r = \frac{E}{R}\left(1 - e^{-\frac{4}{CR}t}\right) \quad . \quad . \quad . \quad (3)$$

(*Note.* When t is very great $V = \frac{E}{2}$ and $I_s = I_r = \frac{E}{R}$.)

If when the capacitor is charged the battery is removed and the line short-circuited, it will discharge through the two resistors in parallel and from equation (1) we have

$$I_s + I_r = \frac{E}{2}\cdot\frac{4}{R}e^{-\frac{4}{CR}t}$$

$$\text{and } I_s = I_r = \frac{E}{R}e^{-\frac{4}{CR}t} \quad . \quad . \quad . \quad . \quad (4)$$

Curves drawn from equations (2), (3), and (4) are given in Fig. 5.44.

Single-section Artificial Line with Terminal Resistors. If in the preceding case the voltage is applied to the line through a resistor of x ohms, and the receiving end of the line is terminated on a resistor of y ohms, the solution for the currents is as follows—

$$\frac{E-V}{\frac{R}{2}+x} = C\frac{dV}{dt} + \frac{V}{\frac{R}{2}+y}$$

$$\therefore \left[E-V\right]\left[\frac{R}{2}+y\right] = \left[\frac{R}{2}+x\right]\left[\frac{R}{2}+y\right]C\frac{dV}{dt} + V\left[\frac{R}{2}+x\right]$$

$$\therefore \frac{E\left[\frac{R}{2}+y\right]}{R+x+y} = \frac{\left[\frac{R}{2}+x\right]\left[\frac{R}{2}+y\right]}{R+x+y}C\frac{dV}{dt} + V$$

$$\therefore \quad V = \frac{\frac{R}{2}+y}{R+x+y}E + Ae^{-\frac{R+x+y}{\left[\frac{R}{2}+x\right]\left[\frac{R}{2}+y\right]}\cdot\frac{t}{C}}$$

$V = 0$ when $t = 0$ so that

$$V = \frac{\frac{R}{2}+y}{R+x+y}E\left[1 - e^{-\frac{R+x+y}{\left[\frac{R}{2}+x\right]\left[\frac{R}{2}+y\right]}\cdot\frac{t}{C}}\right]$$

whence

$$I_r = \frac{E}{R+x+y}\left[1 - e^{-\frac{R+x+y}{\left[\frac{R}{2}+x\right]\left[\frac{R}{2}+y\right]}\cdot\frac{t}{C}}\right]$$

or

$$I_r = \frac{E}{R+x+y}\left[1 - e^{-\frac{R+x+y}{R+2(x+y)+\frac{4xy}{R}}\cdot\frac{4}{CR}\cdot t}\right] \quad (5)$$

Growth and Decay of Current in an Inductive Circuit. If an e.m.f. of E volts is applied to a circuit having a resistance of R ohms and an inductance of L henrys, the sum of the p.d. across the resistance and the opposing e.m.f. generated in the inductance is at all times equal to the applied e.m.f. Since the opposing e.m.f. is, at any instant, proportional to the rate of change of the current, we have

$$E = Ri + L\frac{di}{dt}$$

where i = the current at any instant.

Whence

$$i + \frac{L}{R}\frac{di}{dt} = \frac{E}{R}$$

and

$$i = \frac{E}{R} + Ae^{-\frac{R}{L}t}$$

For $t = 0$, $i = 0$, so that $A = -\frac{E}{R}$ and

$$i = \frac{E}{R}(1 - e^{-\frac{R}{L}t}) \quad . \quad . \quad . \quad (6)$$

If the battery is replaced by a short-circuit after a relatively long interval of time, we have

$$Ri + L\frac{di}{dt} = 0,$$

and $$i = Ae^{-\frac{R}{L}t}$$

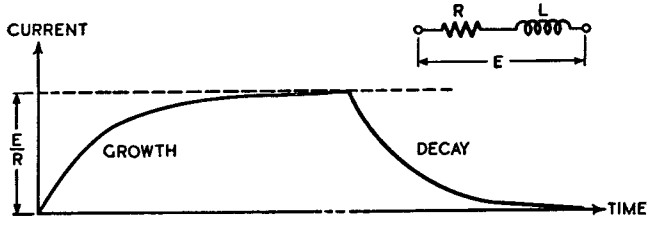


FIG. 5.45. CURVES OF CURRENT IN AN INDUCTIVE CIRCUIT

When $t = 0$, that is, at the instant of short-circuiting, we have

$$i = \frac{E}{R} \text{ and therefore } A = \frac{E}{R},$$

and $$i = \frac{E}{R}e^{-\frac{R}{L}t} \quad . \quad . \quad . \quad (7)$$

which is the equation for the decay of the current.

Curves drawn from equations (6) and (7) are given in Fig. 5.45.

Closed Circuit Working. The solution for the circuit and artificial line shown in Fig. 5.46 is as follows—

When the circuit is closed the current flowing is given by

$I_1 = \frac{E}{R}$, and the voltage across capacitor C is therefore equal to $\frac{E}{2}$.

When the far end of the circuit is opened, the capacitor charges up to the full voltage of the battery.

We have

$$E = \frac{R}{2}I_1 + \frac{1}{C}\int I_1 dt$$

and differentiating

$$\frac{R}{2}\frac{dI_1}{dt} + \frac{1}{C}I_1 = 0$$

So that

$$I_1 = Ae^{-\frac{2}{CR}t}$$

When $t = 0$, that is, at the instant of opening the line $I_1 = \frac{E}{R}$.

$$\therefore A = \frac{E}{R}$$

and $$I_1 = \frac{E}{R}e^{-\frac{2}{CR}t} \quad . \quad . \quad . \quad . \quad (8)$$

If the line is now short-circuited, the capacitor discharges to the voltage $\frac{E}{2}$ again.

If V is the voltage across the capacitor at any instant,

$$\frac{\frac{E-V}{R}}{2} = I_1 = C\frac{dV}{dt} + I_2$$

$$\therefore \quad \frac{\frac{E-V}{R}}{2} = C\frac{dV}{dt} + \frac{2V}{R}$$

$$\therefore \quad \frac{E}{2} = \frac{CR}{4}\frac{dV}{dt} + V.$$

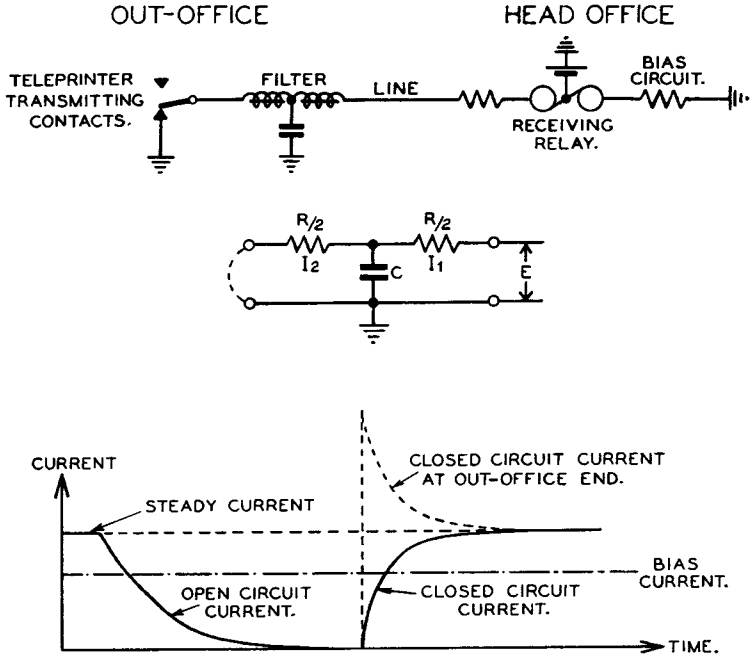


FIG. 5.46. CLOSED CIRCUIT WORKING ON SEND LEG OF TELEPRINTER PRIVATE WIRE LOCAL END

This is the same differential equation as was obtained for the normal single-section artificial line, and the solution is

$$V = \frac{E}{2} + Ae^{-\frac{4}{CR}t}$$

The known conditions are however different in

this case, because for $t = 0$, that is, the instant of short-circuiting the line, the capacitor is charged to the full voltage of the battery and V is equal to E.

$$\therefore A = \frac{E}{2}$$

$$\text{and } V = \frac{E}{2}(1 + e^{-\frac{4}{CR}t})$$

$$\therefore I_1 = \frac{\frac{E - V}{R}}{2} = \frac{E}{R}(1 - e^{-\frac{4}{CR}t}) \quad . \quad (9)$$

$$\text{and } I_2 = \frac{E}{R}(1 + e^{-\frac{4}{CR}t}) \quad . \quad . \quad . \quad (10)$$

The curves obtained from equations (8), (9), and (10) are given in Fig. 5.46.

Steady-state D.C. Solution for a Leaky Line. Fig. 5.47 represents a single-wire line, having uniformly distributed resistance and leakance. The capacitance has been neglected as the steady current condition only is being considered.

The problem is to obtain an expression for the current when a steady voltage is applied to the line and sufficient time has elapsed for the current to assume a steady value. That is to say, all transient effects are neglected.

Let R = resistance per unit length (ohms);
G = leakance per unit length (mhos);
R_s = external resistor at sending end;
R_t = terminating resistor at receiving end;
v = voltage at distance x from sending end;
i = current at distance x from sending end.

If Rdx and Gdx represent the resistance and leakance of an elementary length of line the decrement of line current for such a length at any point distance x from the sending end is given by $vGdx$, and the decrement of voltage, or voltage drop, by $iRdx$, whence

$$\left.\begin{aligned} -\frac{di}{dx} &= vG \\ -\frac{dv}{dx} &= iR \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (11)$$

and differentiating

$$-\frac{d^2i}{dx^2} = \frac{dv}{dx}G$$

$$-\frac{d^2v}{dx^2} = \frac{di}{dx}R$$

Substituting we get

$$\frac{d^2i}{dx^2} = iRG.$$

$$\frac{d^2v}{dx^2} = vRG.$$

The solution of differential equations of this type is of the form—

$$\left.\begin{aligned} i &= A_1e^{-\sqrt{RG}.x} + A_2e^{\sqrt{RG}.x} \\ v &= A_3e^{-\sqrt{RG}.x} + A_4e^{\sqrt{RG}.x} \end{aligned}\right\} \quad . \quad . \quad (12)$$

which can be easily confirmed by differentiating.

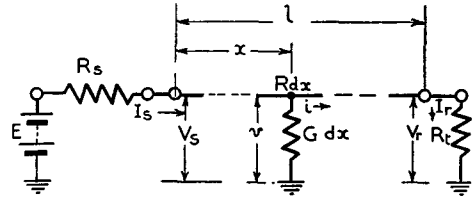


FIG. 5.47. LINE WITH UNIFORMLY DISTRIBUTED LEAKANCE

The constants A_1, A_2, A_3, A_4 are found from the known terminal conditions as follows—

When $x = 0$,
$i = I_s$ and $v = V_s$.

$$\left.\begin{aligned} \therefore I_s &= A_1 + A_2 \\ \text{and } V_s &= A_3 + A_4 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (13)$$

Differentiating equations (12), substituting in equation (11) and again putting $x = 0$, we have

$$V_sG = \sqrt{RG}.A_1 - \sqrt{RG}.A_2,$$

$$I_sR = \sqrt{RG}.A_3 - \sqrt{RG}.A_4.$$

Writing $R_o = \sqrt{\frac{R}{G}}$,

$$\frac{V_s}{R_o} = A_1 - A_2,$$

and $$I_sR_o = A_3 - A_4,$$

whence from equation (13) we obtain

$$A_1 = \tfrac{1}{2}\left(I_s + \frac{V_s}{R_o}\right), \quad A_2 = \tfrac{1}{2}\left(I_s - \frac{V_s}{R_o}\right),$$

$$A_3 = \tfrac{1}{2}(V_s + I_sR_o), \quad A_4 = \tfrac{1}{2}(V_s - I_sR_o)$$

$$\therefore i = \frac{I_s}{2}(e^{-\sqrt{RG}.x} + e^{\sqrt{RG}.x})$$

$$+ \frac{V_s}{2R_o}(e^{-\sqrt{RG}.x} - e^{\sqrt{RG}.x})$$

and $$v = \frac{V_s}{2}(e^{-\sqrt{RG}\,.\,x} + e^{\sqrt{RG}\,.\,x}) + \frac{I_s R_o}{2}(e^{-\sqrt{RG}\,.\,x} - e^{\sqrt{RG}\,.\,x})$$

It is convenient here to introduce the hyperbolic functions* to simplify notation, as follows

$$\left.\begin{aligned} i &= I_s \cosh \sqrt{RG}\,.\,x - \frac{V_s}{R_o}\sinh \sqrt{RG}\,.\,x \\ v &= V_s \cosh \sqrt{RG}\,.\,x - I_s R_o \sinh \sqrt{RG}\,.\,x \end{aligned}\right\} \quad . \quad (14)$$

Eliminating I_r gives

$$I_s = \frac{V_s}{R_o}\cdot\frac{R_o \cosh \sqrt{RG}\,.\,l + R_t \sinh \sqrt{RG}\,.\,l}{R_t \cosh \sqrt{RG}\,.\,l + R_o \sinh \sqrt{RG}\,.\,l} \quad (16)$$

With no external resistor at the sending end $V_s = E$ and

$$I_r = \frac{E}{R_o \sinh \sqrt{RG}\,.\,l + R_t \cosh \sqrt{RG}\,.\,l} \quad . \quad (17)$$

When R_s is not equal to zero we have $V_s = E - I_s R_s$, and substituting in equation (17) gives

$$I_r = \frac{E - I_s R_s}{R_o \sinh \sqrt{RG}\,.\,l + R_t \cosh \sqrt{RG}\,.\,l}.$$

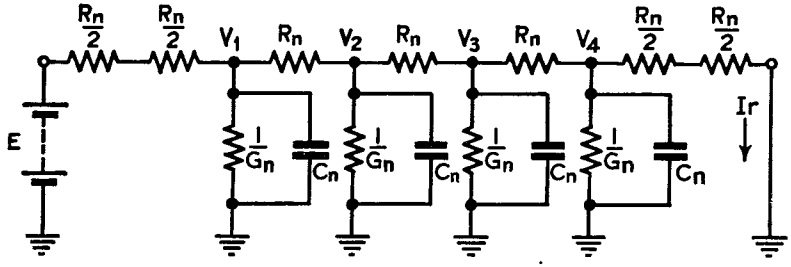


FIG. 5.48. ARTIFICIAL LINE WITH LEAKANCE AND CAPACITANCE

These are the fundamental transmission equations from which the current and voltage at any point in the circuit can be determined. They should be compared with those for an impressed sinusoidal e.m.f. which are given later.

By putting $x = l$ in equations (14), the received current and voltage are given by—

$$I_r = I_s \cosh \sqrt{RG}\,.\,l - \frac{V_s}{R_o}\sinh \sqrt{RG}\,.\,l$$

$$V_r = V_s \cosh \sqrt{RG}\,.\,l - I_s R_o \sinh \sqrt{RG}\,.\,l$$

Noting that $I_r = \frac{V_r}{R_t}$ and eliminating I_s gives

$$I_r = \frac{V_s}{R_o \sinh \sqrt{RG}\,.\,l + R_t \cosh \sqrt{RG}\,.\,l} \quad . \quad (15)$$

Making use of equation (16) we get

$$V_s = \frac{E[R_o \sinh \sqrt{RG}\,.\,l + R_t\,.\cosh \sqrt{RG}\,.\,l]}{(R_t + R_s)\cosh \sqrt{RG}\,.\,l + \left(R_o + \frac{R_s R_t}{R_o}\right)\sinh \sqrt{RG}\,.\,l}$$

and

$$I_r = \frac{E}{(R_t + R_s)\cosh \sqrt{RG}\,.\,l + \left(R_o + \frac{R_s R_t}{R_o}\right)\sinh \sqrt{RG}\,.\,l}$$

Transient Solution for a Leaky Line. To obtain a general solution for the transient conditions as has been done for the steady-state condition is beyond the scope of the present treatment. A solution suitable to the case treated on page 125 can, however, be fairly readily obtained by reference to the artificial line represented in Fig. 5.48.

R_n = conductor resistance of each section (ohms);
C_n = capacitance of each section (farads);
G_n = leakance of each section (mhos);
V_1, V_2, etc. = voltage at each junction;
I_r = received current;
$\frac{R_n}{2}$ = value of terminal resistors.

* Certain hyperbolic functions are analogous to the sine, cosine, tangent, etc., functions of trigonometry. They are called *hyperbolic sine, hyperbolic cosine*, etc., and are written *sinh, cosh*, and so on. They represent a convenient method of handling certain exponential functions. Graphs of sinh θ, cosh θ, and tanh θ are given in Fig. 5.17.

$$\text{Sinh } \theta = \frac{e^{\theta} - e^{-\theta}}{2}.$$

$$\text{Cosh } \theta = \frac{e^{\theta} + e^{-\theta}}{2}.$$

$$\text{Tanh } \theta = \frac{\text{Sinh } \theta}{\text{Cosh } \theta} = \frac{e^{\theta} - e^{-\theta}}{e^{\theta} + e^{-\theta}}.$$

$$\text{Cosh}^2 \theta - \text{Sinh}^2 \theta = 1.$$

Noting that the current passing from the battery is at all times equal to the sum of the received current and the current passing to earth at each leakage path we can write—

$$\frac{E - V_1}{R_n} = G_n(V_1 + V_2 + V_3 + V_4) + C_n\frac{d}{dt}(V_1 + V_2 + V_3 + V_4) + \frac{V_4}{R_n}$$

$$\therefore E = R_n\left(G_n + C_n\frac{d}{dt}\right)(V_1 + V_2 + V_3 + V_4) + V_1 + V_4$$

$$\text{Now } \frac{V_3 - V_4}{R_n} = C_nV_4 + C_n\frac{dV_4}{dt} + \frac{V_4}{R_n}$$

$$\therefore V_3 = R_nG_nV_4 + R_nC_n\frac{dV_4}{dt} + 2V_4$$

$$\text{and } \frac{dV_3}{dt} = R_nG_n\frac{dV_4}{dt} + R_nC_n\frac{d^2V_4}{dt^2} + 2\frac{dV_4}{dt}$$

Similarly

$$\frac{V_2 - V_3}{R_n} = G_nV_3 + C_n\frac{dV_3}{dt} + \frac{V_3 - V_4}{R_n}$$

$$\frac{V_1 - V_2}{R_n} = G_nV_2 + C_n\frac{dV_2}{dt} + \frac{V_2 - V_3}{R_n}$$

Manipulation of the foregoing equations yields a differential equation of the fourth order in V_4, the solution of which is

$$V_4 = \frac{E}{a \cdot b \cdot c \cdot d} + A_1e^{-\frac{a}{C_nR_n}t} + A_2e^{-\frac{b}{C_nR_n}t} + A_3e^{-\frac{c}{C_nR_n}t} + A_4e^{-\frac{d}{C_nR_n}t}$$

where
$a = R_nG_n + \frac{1}{2}(3 - \sqrt{5})$;
$b = R_nG_n + \frac{1}{2}(5 - \sqrt{5})$;
$c = R_nG_n + \frac{1}{2}(3 + \sqrt{5})$;
$d = R_nG_n + \frac{1}{2}(5 + \sqrt{5})$.

$$A_1 = -\frac{1}{a(5 + \sqrt{5})};$$

$$A_2 = \frac{1}{b(5 - \sqrt{5})};$$

$$A_3 = -\frac{1}{c(5 - \sqrt{5})};$$

$$A_4 = \frac{1}{d(5 + \sqrt{5})}$$

I_r is obtained by dividing the foregoing equation by R_n, giving—

$$I_r = \frac{E}{R_nabcd}\left\{1 - \frac{bcd}{5 + \sqrt{5}}e^{-\frac{a}{C_nR_n}t} + \frac{acd}{5 - \sqrt{5}}e^{-\frac{b}{C_nR_n}t} - \frac{abd}{5 - \sqrt{5}}e^{-\frac{c}{C_nR_n}t} + \frac{abc}{5 + \sqrt{5}}e^{-\frac{d}{C_nR_n}t}\right\}$$

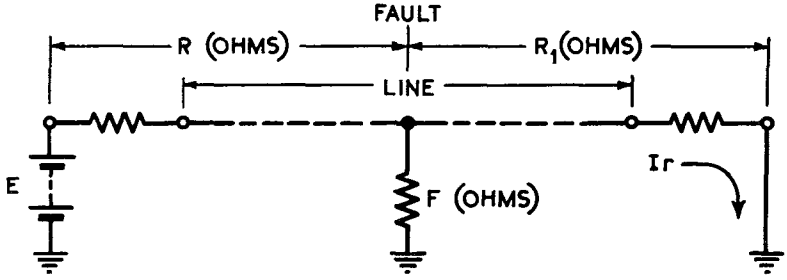


FIG. 5.49. LINE WITH LOCALIZED INSULATION RESISTANCE FAULT

The solution for the case where the leakance is negligible is obtained by putting $G_n = 0$ in the foregoing equation, giving—

$$I_r = \frac{E}{5R_n}\left\{1 - \frac{5}{5 - \sqrt{5}}e^{-\frac{3 - \sqrt{5}}{2}\cdot\frac{t}{C_nR_n}} + \frac{1}{3 - \sqrt{5}}e^{-\frac{5 - \sqrt{5}}{2}\cdot\frac{t}{C_nR_n}} - \frac{5}{5 + \sqrt{5}}e^{-\frac{3 + \sqrt{5}}{2}\cdot\frac{t}{C_nR_n}} + \frac{1}{3 + \sqrt{5}}e^{-\frac{5 + \sqrt{5}}{2}\cdot\frac{t}{C_nR_n}}\right\}$$

Line with Localized Insulation Resistance Fault. This case is illustrated in Fig. 5.49. The fault resistance is assumed to be low compared to the distributed insulation resistance.

Referring to Fig. 5.49—

R = resistance to the fault including any terminal resistance;
R_1 = resistance beyond the fault including the resistance at the receiving end;
F = fault resistance;
I_r = received current.

The voltage at the fault is equal to I_rR_1 and the fault current is therefore given by $\frac{I_rR_1}{F}$.

Thus we have—

$$\frac{E - I_r R_1}{R} = \frac{I_r R_1}{F} + I_r$$

$$\therefore I_r \left[1 + \frac{R_1}{F} + \frac{R_1}{R}\right] = \frac{E}{R}$$

or $$I_r(FR + R_1R + R_1F) = EF,$$

and $$I_r = \frac{EF}{RR_1 + F(R + R_1)}$$

Derivation of the Classical A.C. Transmission Equations. The method of deriving these equations

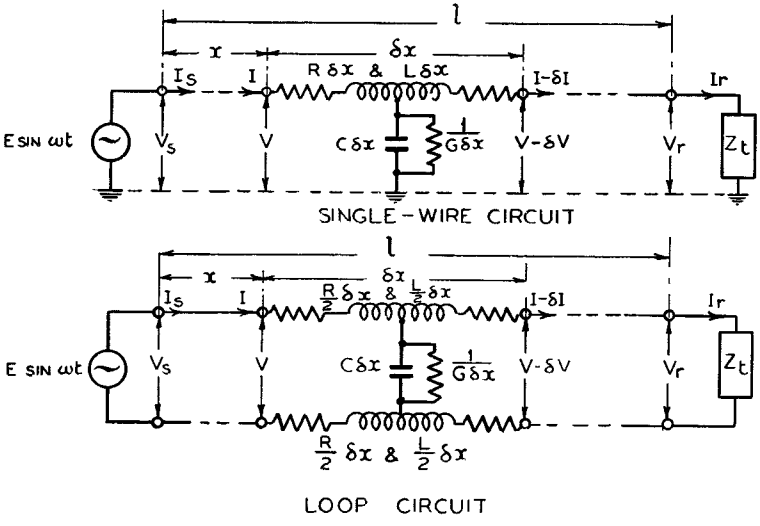


FIG. 5.50. TRANSMISSION CIRCUITS

is essentially similar to that used for obtaining the steady-state solution in the somewhat simpler case of the leaky line which was given earlier.

Fig. 5.50 refers to transmission circuits with uniformly distributed resistance, inductance, capacitance, and leakance. The primary constants are R, L, C, and G per unit length. In the case of the loop circuit, the resistance and inductance are equally divided between the two wires. The following equations apply equally to each circuit.

It is assumed that a sinusoidal e.m.f., $E \sin \omega t$, of frequency f, where $\omega = 2\pi f$, is applied to one end of the circuit, the other end being closed by an impedance Z_t.

The problem is to determine the voltage and current at any point in the circuit when the steady-state conditions have been reached, and all transient effects due to switching on the e.m.f. have subsided.

Consider an elementary length of line δx, distant x from the sending end. The constants of this length of line are $R\delta x$, $L\delta x$, $G\delta x$, and $C\delta x$.

The change in the line current due to the current flowing through the capacitance and leakance of this elementary section of line is given by

$$-\delta I = VG\delta x + \frac{dV}{dt} C\delta x$$

the current passing into the capacitance being proportional to the rate of change of voltage.

Similarly the change of voltage is given by the voltage drop across the resistance and the opposing e.m.f. induced in the inductance, this e.m.f. being proportional to the rate of change of current.

$$-\delta V = IR\delta x + \frac{dI}{dt} L\delta x$$

In the limit when δx is infinitesimally small we have

$$\left.\begin{aligned} -\frac{dI}{dx} &= VG + \frac{dV}{dt} C \\ -\frac{dV}{dx} &= IR + \frac{dI}{dt} L \end{aligned}\right\} . \quad (18)$$

The negative signs before the differentials indicate that the current and voltage decrease as x increases.

Now V and I are sinusoidal; therefore

$$\frac{dV}{dt} = j\omega V, \text{ and } \frac{dI}{dt} = j\omega I$$

Thus

$$\left.\begin{aligned} -\frac{dI}{dx} &= V(G + j\omega C) \\ -\frac{dV}{dx} &= I(R + j\omega L) \end{aligned}\right\} \quad . \quad . \quad . \quad (19)$$

Equations (18) are the fundamental circuit equations, while the equations (19) are the special case of these fundamental equations for a sinusoidal wave form.

Differentiating gives

$$-\frac{d^2I}{dx^2} = \frac{dV}{dx}(G + j\omega C);$$

$$-\frac{d^2V}{dx^2} = \frac{dI}{dx}(R + j\omega L)$$

Substituting the values for $\frac{dV}{dx}$ and $\frac{dI}{dx}$ gives

$$\frac{d^2I}{dx^2} = I(R + j\omega L)(G + j\omega C);$$
$$\frac{d^2V}{dx^2} = V(R + j\omega L)(G + j\omega C);$$

or
$$\left.\begin{aligned}\frac{d^2I}{dx^2} &= p^2I\\ \frac{d^2V}{dx^2} &= p^2V\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (20)$$

where $p = \sqrt{(R + j\omega L)(G + j\omega C)}$ and is called the *propagation constant.*

The solution of differential equations of the type of equations (20) is of the form—

$$\left.\begin{aligned}I &= A_1e^{-px} + A_2e^{px}\\ V &= A_3e^{-px} + A_4e^{px}\end{aligned}\right\} \quad . \quad . \quad . \quad (21)$$

which can be readily proved by differentiating.

The constants A_1, A_2, A_3, A_4 are found from the known terminal conditions as follows—

When $x = 0$
$I = I_s$ and $V = V_s$

$$\left.\begin{aligned}\therefore\ I_s &= A_1 + A_2\\ \text{and}\quad V_s &= A_3 + A_4\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (22)$$

Differentiating equations (21) gives

$$\frac{dI}{dx} = -pA_1e^{-px} + pA_2e^{px};$$
$$\frac{dV}{dx} = -pA_3e^{-px} + pA_4e^{px}$$

Putting $x = 0$ and using equations (19) gives

$$V_s(G + j\omega C) = pA_1 - pA_2;$$
$$I_s(R + j\omega L) = pA_3 - pA_4;$$

$$\left.\begin{aligned}\text{and}\quad \frac{V_s}{Z_0} &= A_1 - A_2\\ I_sZ_0 &= A_3 - A_4\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (23)$$

where $Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$ and is called the *characteristic impedance.*

Equations (22) and (23) give

$$A_1 = \tfrac{1}{2}\left[I_s + \frac{V_s}{Z_0}\right],\ A_2 = \tfrac{1}{2}\left[I_s - \frac{V_s}{Z_0}\right]$$
$$A_3 = \tfrac{1}{2}(V_s + I_sZ_0),\ A_4 = \tfrac{1}{2}(V_s - I_sZ_0).$$

We have therefore

$$I = \tfrac{1}{2}I_s(e^{-px} + e^{px}) + \tfrac{1}{2}\frac{V_s}{Z_0}(e^{-px} - e^{px});$$

$$V = \tfrac{1}{2}V_s(e^{-px} + e^{px}) + \tfrac{1}{2}I_sZ_0(e^{-px} - e^{px});$$

and finally

$$\left.\begin{aligned}I &= I_s\cosh px - \frac{V_s}{Z_0}\sinh px\\ V &= V_s\cosh px - I_sZ_0\sinh px\end{aligned}\right\} \quad . \quad . \quad (24)$$

These are the fundamental a.c. transmission equations giving the steady-state values of the current and voltage at any point in the circuit. It should be remembered that the equations only apply to the case where the current and voltage are sinusoidal.

The application of the equations is given in the main text.

Recurrent Network Theory. *To deduce expressions for the characteristic impedance and propagation constant.*

Fig. 5.51 represents any three sections of a recurrent ladder network having an infinitely large number of sections.

It is apparent that as there is an infinite number of sections, if the network is cut at a given point between any two sections the impedance looking towards the distant end will always be the same. If the networks are cut midway between two shunt sections the mid-series characteristic impedance will be measured. This impedance is indicated by Z_{01} in the following.

Let i_{n-1} = current entering $(n - 1)$th section;
i_n = current entering nth section;
i_{n+1} = current entering $(n + 1)$th section;
We have
$i_{n-1} - i_n$ = current flowing in shunt impedance of $(n - 1)$th section.
$i_n - i_{n+1}$ = current flowing in shunt impedance of nth section.

Thus

$$(i_{n-1} - i_n)\frac{Z_2}{2} = 2Z_1i_n + (i_n - i_{n+1})\frac{Z_2}{2}$$

$$i_{n-1} - i_n = 4\frac{Z_1}{Z_2}i_n + i_n - i_{n+1}$$

$$\therefore \quad \frac{i_{n-1}}{i_n} = 4\frac{Z_1}{Z_2} + 2 - \frac{i_{n+1}}{i_n}$$

Now n is only some arbitrary number, so that if we write $(n + 1)$ for n, which is therefore quite legitimate, we have

$$\frac{i_{n-1}}{i_n} = \frac{i_{(n+1)-1}}{i_{n+1}} = \frac{i_n}{i_{n+1}}$$

So that we can write

$$\frac{i_{n-1}}{i_n} + \frac{i_n}{i_{n-1}} = 4\frac{Z_1}{Z_2} + 2$$

If P is the propagation constant per section we have

$$e^P = \frac{i_{n-1}}{i_n}$$

$$\therefore \quad e^P + e^{-P} = 4\frac{Z_1}{Z_2} + 2$$

Noting that $\frac{e^P + e^{-P}}{2} = \cosh P$ we have

$$\cosh P = 2\frac{Z_1}{Z_2} + 1 \quad . \quad . \quad . \quad . \quad (25)$$

Whence

$$Z_{01} = \sqrt{Z_1^2 + Z_1 Z_2} \quad . \quad . \quad . \quad . \quad (26)$$

Similarly the mid-shunt characteristic impedance can be found by assuming a mid-shunt section terminated as shown in Fig. 5.51 (*c*).

$$Z_{02} = \frac{Z_2\left(2Z_1 + \frac{Z_2 Z_{02}}{Z_2 + Z_{02}}\right)}{Z_2 + 2Z_1 + \frac{Z_2 Z_{02}}{Z_2 + Z_{02}}}$$

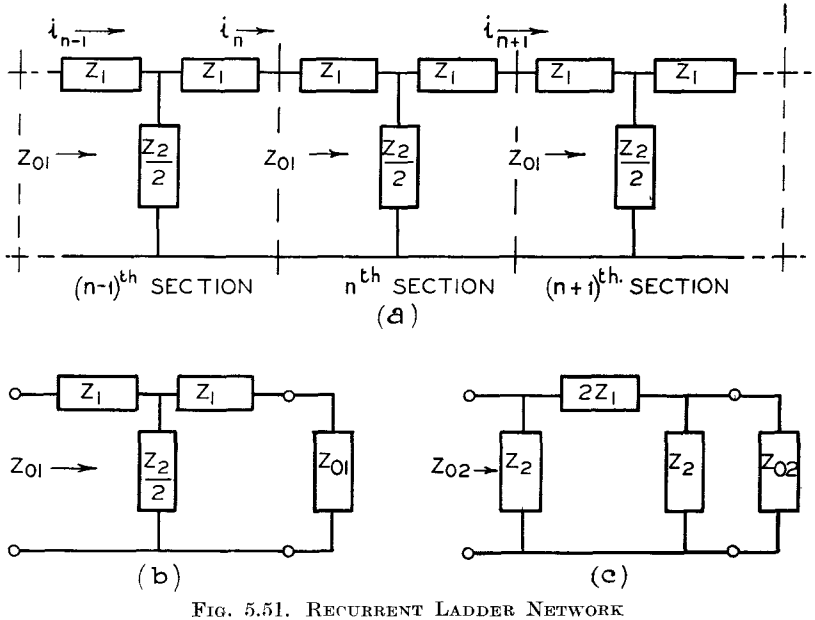


FIG. 5.51. RECURRENT LADDER NETWORK

Also $\frac{i_1}{i_2} = \frac{i_2}{i_3} = \frac{i_3}{i_4} = \ldots = e^P$,

where i_1, i_2, i_3, etc., are the currents entering the 1st, 2nd, 3rd, etc., sections.

Also $\frac{i_1}{i_{n+1}} = e^{nP}$,

where i_{n+1} is the current entering the $(n+1)$th section, or alternatively the current received at the end of a network of n sections terminated in its characteristic impedance.

The mid series-characteristic impedance can be obtained by assuming a mid-series section terminated by its proper impedance as shown in Fig. 5.51 (*b*).

Thus

$$Z_{01} = Z_1 + \frac{\frac{1}{2}Z_2(Z_1 + Z_{01})}{\frac{1}{2}Z_2 + Z_1 + Z_{01}}$$

Whence

$$Z_{02} = \frac{Z_1 Z_2}{\sqrt{Z_1^2 + Z_1 Z_2}} \quad . \quad . \quad . \quad . \quad (27)$$

When the e.m.f. applied to the network is sinusoidal the propagation constant is complex and consists, as in ordinary transmission theory, of an attenuation constant (A) and phase constant (B)

Thus $P = A + jB$

and $\frac{I_1}{I_2} = e^A \times e^{jB}$

or $I_1 = I_2 e^A \underline{/B}$

and $I_1 = I_n e^{nA} \underline{/nB}$.

The real portion A of the propagation constant gives the ratio of the magnitudes of the sent and received currents and the phase constant B gives

the phase difference between the sent and received currents.

Now $\cosh P = \cosh (A + jB)$

$= \cosh A \cosh jB + \sinh A \sinh jB.$

$$\therefore \cosh P = 1 + \frac{2Z_1}{Z_2} = \cosh A \cos B + j \sinh A \sin B \quad . \quad (28)$$

Equation (28) can be used to investigate the behaviour of filters.

Extension of Theory to the Case of Electric Wave Filters. In an ideal filter the impedances Z_1 and Z_2 are wholly reactive and the expression $1 + \frac{2Z_1}{Z_2}$ for the propagation constant is always real.

Equating real and imaginary parts of equation (28) gives

$$\cosh A \cos B = 1 + \frac{2Z_1}{Z_2};$$

$$\sinh A \sin B = 0.$$

We have therefore either

$$\sinh A = 0.$$

$$\text{or } \sin B = 0.$$

When $\sinh A = 0$, $A = 0$ and there is therefore no attenuation through the filter. This corresponds to the pass range of the filter.

When $A = 0$, $\cosh A = 1$ (see Fig. 1.17) and therefore

$$\cos B = 1 + \frac{2Z_1}{Z_2}$$

When $\sin B = 0$, $\cos B = 1$ and

$$\cosh A = 1 + \frac{2Z_1}{Z_2}$$

This corresponds to the attenuating range when the currents are attenuated, but there is no change of phase.

The conditions for each of the various types of filters can be found by substituting the proper values of Z_1 and Z_2.

Low-pass Filter.

$$Z_1 = j\omega L;$$

$$Z_2 = \frac{1}{j\omega C}$$

$$\cosh P = 1 + \frac{2Z_1}{Z_2} = 1 - 2\omega^2 LC.$$

In the pass range we have

$$\cos B = 1 - 2\omega^2 LC.$$

A limiting condition occurs when ω has reached such a value that $\omega^2 LC = 1$, when we have

$$\cos B = -1.$$

This is the condition for cut-off already given in the main text. Thus from $\omega = 0$ to $\omega = \frac{1}{\sqrt{LC}}$ $\cos B$ varies from $+1$ to -1. For higher values of ω the expression $1 - 2\omega^2 LC$ exceeds -1, and the conditions are changed ($\cos B$ cannot exceed ± 1) and $\cos B$ reverts to $+1$ when $\sin B = 0$ and therefore

$$\cosh A = 1 - 2\omega^2 LC.$$

High-pass Filter.

$$Z_1 = \frac{1}{j\omega C};$$

$$Z_2 = j\omega L.$$

$$\cosh P = 1 + \frac{2Z_1}{Z_2} = 1 - \frac{2}{\omega^2 LC}$$

The conditions for cut-off are the same as before, except that it is clear that for values of ω less than $\omega = \frac{1}{\sqrt{LC}}$ the expression $1 - \frac{2}{\omega^2 LC}$ is greater than -1 and therefore the attenuating range is from $\omega = 0$ up to $\omega = \frac{1}{\sqrt{LC}}$

Band-pass Filter.

$$Z_1 = \frac{j\left[\omega L - \frac{1}{\omega C}\right]}{n}$$

$$Z_2 = \frac{n}{j} \cdot \frac{\frac{L}{C}}{\omega L - \frac{1}{\omega C}}$$

$$\cosh P = 1 + \frac{2Z_1}{Z_2} = 1 - \frac{2(1 - \omega^2 LC)^2}{n^2 \omega^2 LC}$$

The conditions for cut-off are

$$\frac{(1 - \omega^2 LC)^2}{n^2 \omega^2 LC} = 1,$$

$$\text{i.e. } 1 - 2\omega^2 LC + \omega^4 L^2 C^2 = n^2 \omega^2 LC,$$

$$\text{or } \omega^4 L^2 C^2 - (n^2 + 2)\omega^2 LC + 1 = 0.$$

$$\therefore \omega^2 LC = \frac{n^2 + 2 \pm \sqrt{(n^2 + 2)^2 - 4}}{2}$$

This gives two positive values for ω namely

$$\omega_1 = \frac{\sqrt{n^2+4} - n}{2\sqrt{LC}};$$

$$\omega_2 = \frac{\sqrt{n^2+4} + n}{2\sqrt{LC}};$$

whence $$\omega_1\omega_2 = \frac{1}{LC};$$

$$\omega_2 - \omega_1 = \frac{n}{\sqrt{LC}};$$

or $$\sqrt{f_1 f_2} = \frac{1}{2\pi\sqrt{LC}}$$

and $$\frac{f_2 - f_1}{\sqrt{f_2 f_1}} = n.$$

It can readily be shown that when ω falls between the values ω_1 and ω_2 the expression for cosh P is less than 1 and therefore the attenuation is zero and cos B passes from -1 through $+1$ to -1 while B passes from $-180°$ through $0°$ to $+180°$.

CHAPTER 6

LINE PLANT

In the United Kingdom and in other densely populated countries all the main line telegraph circuits are provided nowadays by M.C.V.F. telegraph systems. These multi-channel systems operate in the same frequency range as is transmitted for a normal telephone conversation and consequently the circuits for the connexion of these systems are of the same type as those used for speech conversations. Since many telegraph circuits can be carried simultaneously over one telephone circuit the number of circuits required to connect the multi-channel telegraph systems is relatively small, being usually only a fraction of the number of telephone circuits required between any particular towns. Consequently a separate network of lines is no longer provided specially for telegraph use; the telegraph service now shares together with the telephone service a common network of line plant. This arrangement enables considerable savings to be made in the provision and maintenance, enabling a common maintenance staff to be employed.

The circuits used for multi-channel voice frequency telegraph systems are of the four-wire type, that is to say a separate channel is provided for each direction of transmission. Thus on an audio-circuit the "go" signals are transmitted over one pair of wires and the "return" signals over a second pair of wires. Two-wire circuits, i.e. circuits in which the go and return signals pass over the same pair of wires, cannot be employed for the normal type of voice frequency telegraph system but special minor types of systems are in existence in which the voice frequency currents in the two directions occupy different frequency ranges. A four-wire circuit used for speech transmission must be fitted with a two-four wire termination and in rare instances with an echo suppressor, but neither of these two items is required on a circuit used purely for telegraphy.

The band width of modern telephone circuits is from 300 c/s to 3,400 c/s and all new systems are designed to provide this band width. There are however still a great many circuits in use which have a reduced band width of approximately 300 c/s to 2,600 c/s and in more rare instances on very old heavily loaded cables the upper frequency may be less than 2,600 c/s.

Circuits are provided by one of three different methods namely—

(*a*) Audio-circuits, in which the signals are transmitted from end to end without any change of frequency and require individual conductors for each circuit,

(*b*) Carrier, and (*c*) Coaxial methods of transmission, in which a number of different conversations is carried on the same pair of conductors.

Cables for Audio-circuits. The cables used for audio-circuits may be of either the star-quad or multiple-twin types. In the United Kingdom the star-quad type of construction is always used, whereas in many Continental countries the multiple-twin type of construction is still favoured as it enables phantom circuits to be obtained. With the multiple-twin type the paper insulated conductors are first twisted into pairs and two such pairs are then twisted together to form the two pair core or quad. In the star-quad form of construction the four wires of one quad are twisted together about a common axis. The star-quad form of construction has the advantage of being more compact than the multiple-twin and consequently more pairs may be obtained for a given diameter of cable. The capacitance of the derived phantom circuits is high and it is not usual to derive phantoms on star-quad audio-cables. With the multiple-twin form of construction, the capacitance of the phantom circuit is only slightly greater than that of the side circuits and phantom working is common with such types of cables.

Loading. The attenuation of a cable pair increases with frequency as shown in Fig. 6.1. Thus the attenuation of a 20 lb conductor cable pair at 3 kc/s is nearly 2 db per mile. If repeater stations must be situated so that the attenuation between them is not more than 30 db this means placing the stations at intervals of 15 miles. Now the attenuation of a cable pair is given by the formula

$$p = \sqrt{(r + j\omega L)(g + j\omega C)}$$

where r is the resistance per unit length, L the conductance, g the leakance and C the capacitance per unit length. (*Note.* In a cable the capacitance is very much greater than the inductance.) The attenuation may be considerably reduced either by increasing the inductance of the pair or reducing the capacitance by increasing the spacing between wires, or by adding inductance.

One way of increasing the inductance, known as "continuous loading," is to wrap with a close lay a

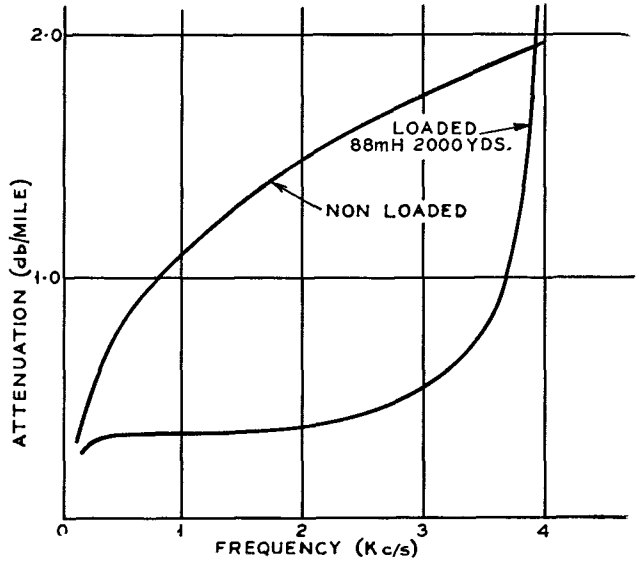


FIG. 6.1. ATTENUATION/FREQUENCY CHARACTERISTICS OF 20-LB NON-LOADED AND LOADED TELEPHONE CABLE PAIRS

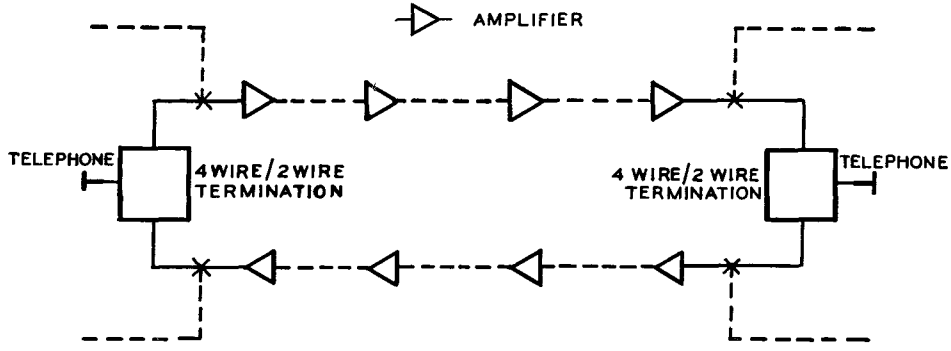


FIG. 6.2. 4-WIRE AUDIO SPEECH CIRCUIT

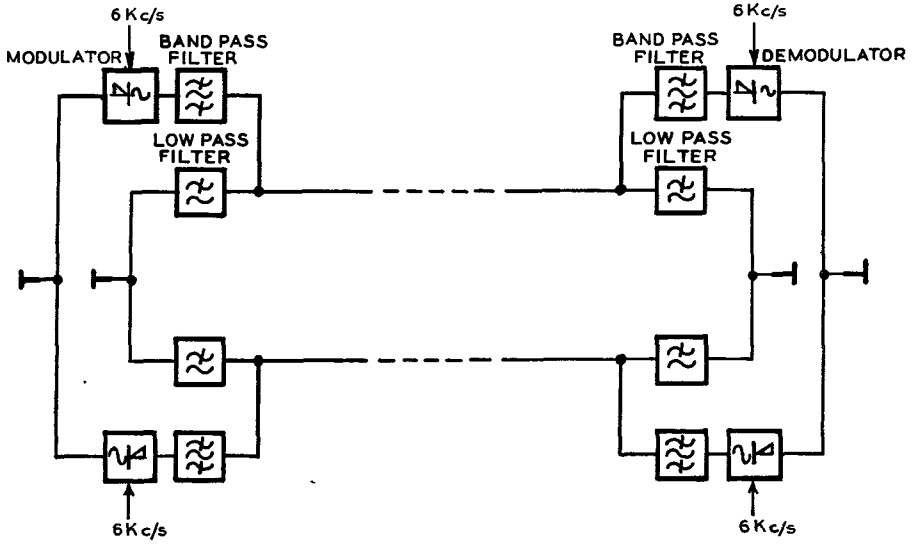


FIG. 6.3. PRINCIPLE OF A SIMPLE 1 + 1 CARRIER TELEPHONE SYSTEM

soft iron wire around each wire but as this method is costly it is no longer used. The most common method is to insert inductance coils at fixed intervals along the line. These coils, known as "loading coils" are arranged to have the maximum inductance for the minimum resistance and must be inserted at uniform intervals throughout the cable length.

Each coil consists of a toroidal core made of compressed iron powder over which is wound the coil, in two halves, one half being connected into each conductor of a pair. The loading coils for all the pairs in the cable are assembled in a solid iron case and are placed in large manholes.

Fig. 6.1 also indicates the attenuation-frequency characteristics of the same 20 lb cable pair when loaded with coils having an inductance of 88 mH and spaced at 2,000 yard intervals. It will be seen that the attenuation of the cable pair has been much reduced at frequencies in the voice range but above 3,000 c/s the attenuation rises rapidly. The reason for this rise is that the inductance coils inserted at fixed intervals form with the cable capacitance a low pass filter which tends to cut off all frequencies above a specific value. The most common type of loading now used is 88 mH at intervals of 2,000 yards and this loading has a cut off at 3,900 c/s.

Audio-amplifiers. Loading is almost universally employed on all audio-cables except those carrying very short distance circuits but it is still necessary to amplify the signals at fixed intervals. The use of loading enables audio-repeater stations to be spaced at intervals of 50 miles. At these stations the speech currents passing over the cable pairs are amplified in thermionic amplifiers to overcome the attenuation of the preceding repeater section of cable. The audio-amplifier now in common use is a single stage, i.e. one valve, amplifier employing negative feedback. The negative feedback has two functions, firstly to stabilize the gain of the repeater against changes in the power supplies and secondly to reduce the harmonic production of the amplifier. It also improves the attenuation-frequency characteristic. The gain of the amplifier is of the order of 30 db.

Fig. 6.2 indicates the arrangement of a normal four-wire audio-speech circuit. Where it is used for a M.C.V.F. telegraph system connexion is made to the circuit at the points marked X and the two-four wire terminations are removed.

Carrier Current Systems. An audio-transmission circuit requires four separate wires between the two terminal points, two for the go direction and two for the return direction. Furthermore, each circuit is amplified at specific distances and two audio-amplifiers, one for each direction of transmission, are required for each circuit. Carrier current working enables more than one circuit to be carried over each pair of wires.

The principle of a simple carrier system is shown in Fig. 6.3. It will be seen that the audio-circuit is unchanged except that a low-pass filter is inserted in both directions of the four-wire path at each end. Speech signals from the telephone connected to the carrier circuit and occupying, for example, the frequency band 300 c/s to 2,600 c/s pass via the two–four wire termination to the input of the modulator. Here the carrier is modulated by the speech currents to produce two sidebands, the upper sideband in the range 6,300 c/s to 8,600 c/s and the lower sideband 3,400 c/s to 5,700 c/s. Only one sideband is necessary to convey the speech intelligence and the lower sideband is used, being filtered out by the band pass filter and then coupled to the same pair of wires as the audio-circuit. The intermediate amplifiers must not only amplify the audio-frequency signal but also the modulated carrier signal. The amplifiers must therefore cover a band width of 300 c/s to 6,000 c/s.

The amplifiers are usually preceded by equalizers which introduce a loss at the lower frequencies and thus enable amplified sections of the cable to have a flat gain characteristic over the whole frequency band in use. At the distant terminal the audio-signal is separated from the carrier signal by the low pass filter and then passes on to the normal two–four wire termination. The carrier channel passes through an inverse (i.e. demodulation) process, to that at the transmitting end. The main items in the terminal equipment of a carrier system are the modulator and demodulator and the filters.

Fig. 6.4 (*a*) shows the principal parts of a modulator and it will be seen that it consists of two transformers and four small copper-oxide rectifiers. A copper-oxide rectifier has the property that its resistance to small alternating currents may be made very small by applying a relatively large direct voltage of one polarity and conversely its resistance to small alternating currents may be made comparatively large by reversing the direct biasing voltage. Thus in the modulator shown, when the carrier supply is in its positive half cycle the rectifiers AA will have a low resistance and the rectifiers BB will have a high resistance. The equivalent circuit is then as shown in Fig. 6.4 (*b*). During the negative half cycle of the carrier current the conditions are reversed, the rectifiers BB are conducting and the rectifiers AA non-conducting. The equivalent circuit is then as shown in Fig. 6.4 (*c*). The rectifier network thus behaves as a reversing switch at the carrier frequency. The output from this type of modulator (sometimes known as the double balanced type)

consists of the upper and lower modulated sidebands of the carrier current together with some distortion components of small amplitude which may be neglected.

Normally line carrier systems transmit only one sideband since this economizes in bandwidth and reduces the power loading on the amplifiers. The sideband to be transmitted (namely, the lower sideband in the simple carrier system shown) is selected by means of a band pass filter. These filters for

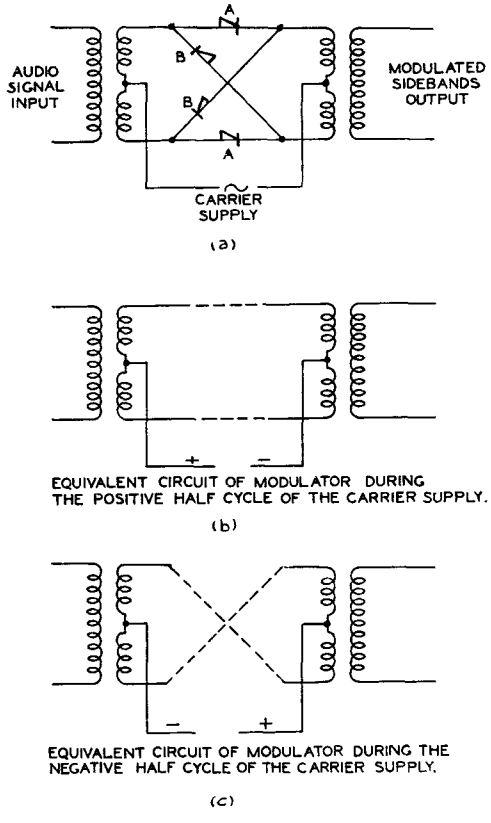


FIG. 6.4. PRINCIPLE OF MODULATOR USED IN CARRIER TELEPHONE SYSTEM

selecting the sidebands may be of the conventional coil and capacitor type or may use quartz crystal elements as employed in some types of 12 circuit carrier systems.

Twelve-circuit Carrier Systems. The elementary type of carrier system which has just been described to illustrate the principles of carrier working is called a 1 + 1 system, i.e. voice plus one carrier circuit. Similarly 1 + 2, 1 + 3 and 1 + 4 systems are employed.

Carrier systems may work over either four wires or two wires. In the two-wire systems the go and return channels of each circuit are carried over the same pair of wires, different frequencies being used for the two directions. Such systems are used principally on open wire routes and systems for working over underground cables usually employ four wires.

As the development of carrier systems proceeded, the carrier channels became of more importance than the voice channel and finally the voice or audio-channel was omitted and special systems for carrier working only were developed. The carrier system which is used very largely at the present time is the twelve-circuit carrier system. This system works over underground cables specially laid for this purpose and the audio-channel is not used. Each of the twelve channels occupies a band of frequencies 4 kc/s wide and the combined frequency band of the twelve circuits is 48 kc/s wide and is transmitted over the cable in the range 12–60 kc/s. Separate cables are used for the go and return direction of transmission.

As already mentioned the cables are specially designed for carrier working and have a looser make up of the paper insulation, thus increasing the spacing between the wires of a pair and thereby reducing the capacitance. This reduces the attenuation as compared with the normal audio-cable but of course fewer pairs can be laid up to form a cable of a given overall diameter. The attenuation of the cable at 60 kc/s is however many times that of an audio-cable, particularly a loaded audio-cable, and therefore repeater stations for the carrier cable must be placed at closer intervals than for audio-cables. The attenuation allowed between successive repeater stations is approximately 60 db and this allows repeater stations to be spaced at 20 mile intervals.

The cross talk between pairs in a cable is roughly proportional to the frequency, thus the higher the frequency the worse is the cross talk. At the higher frequencies employed on the twelve-circuit carrier system therefore special balancing must be carried out when the cable is laid and, at the end of each repeater section, small capacitors are connected between each of the pairs in the cable to neutralize any remaining unbalances. These measures have the effect of reducing the far end cross talk. Two separate cables are used for twelve-circuit systems and one cable carries all pairs used for one direction of transmission and the other cable carries all pairs used for the opposite direction of transmission. Thus near-end cross talk is kept at a minimum by the screening of the cable sheath. A common standard is to have 24 pairs in each cable.

Terminal Modulating Equipment for a Twelve-circuit Carrier System. The terminal equipment

for a twelve-circuit carrier system is as shown in the simplified diagram in Fig. 6.5. In the transmit direction each audio-channel first passes into a modulator of the double balanced type. The carrier currents supplied to the modulators are in multiples of 4 kc/s from 64 kc/s to 108 kc/s. Taking channel 12 as an example, the audio-signal is modulated by the carrier of 64 kc/s and produces sidebands between 60 and 64 kc/s for the lower sideband and 64–68 kc/s for the upper sideband. In modulation to assemble the twelve channels from audio-frequency into the range of the basic twelve-circuit group of 60–108 kc/s.

The frequency range transmitted on the cable of a twelve-circuit system is from 12 to 60 kc/s. The combined output from the channel filters therefore passes next into the group modulator. This modulator is fed with a carrier frequency of 120 kc/s and thus the lower sideband will be in the range 12–60 kc/s. This sideband is selected by a low pass

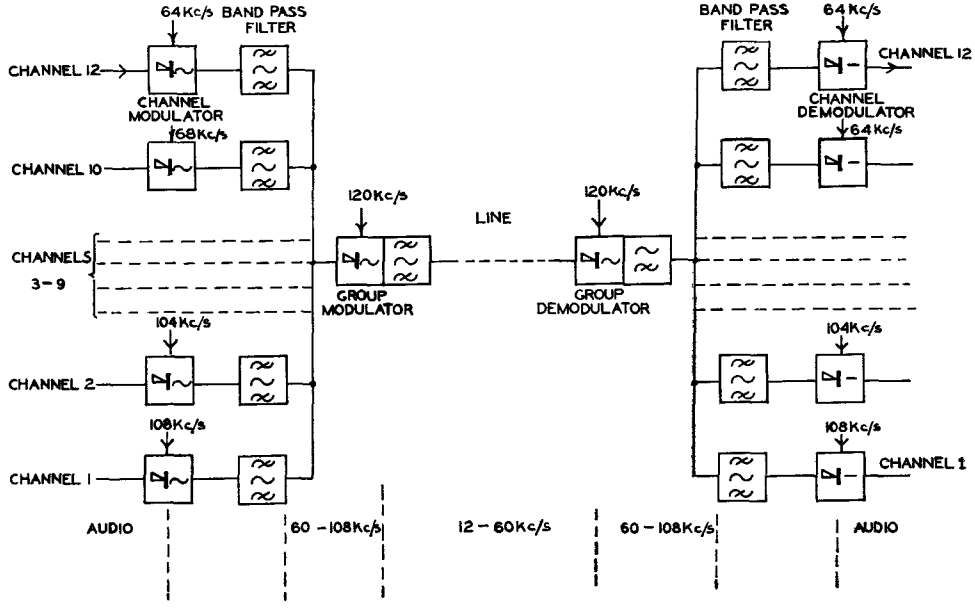


FIG. 6.5. 12-CIRCUIT CARRIER TELEPHONE SYSTEM

the actual system the band width transmitted on each channel is 300–3,400 c/s, which owing to the necessity of allowing some margin in the filters requires a 4 kc/s spacing between the carrier supplies. The lower sideband lying between 60–64 kc/s is selected by means of the channel filter. Each remaining channel passes through a similar circuit, but with a different carrier frequency, and at the output of the channel filters the twelve selected sidebands are combined together and form the basic group of twelve channels in the frequency range 60–108 kc/s.

The filter used for selecting the required sideband in the system described above employs quartz crystals as resonant elements. Such crystals have a very high Q factor and enable the filters to have sharp cut-off points. In some twelve circuit carrier systems the filters do not use crystals but are constructed of normal coils and capacitors. These types of systems usually employ two stages of filter and after amplification is transmitted to the cable. At the receiving terminal the process takes place exactly opposite to that at the transmitting terminal. The signals first pass through the group demodulator where they are translated into the frequency range 60–108 kc/s. Each sideband is then separated from the others by the respective channel filters and then passes into the channel demodulator where it is converted to audio-frequency. The simplified circuit shown in Fig. 6.5 is for one direction of transmission only. Two such arrangements in opposite directions form one complete system.

Intermediate Repeater Stations. The cables carrying the twelve-circuit groups are amplified at distances of approximately 20 miles. At these intermediate repeater stations, as they are called, each cable pair is connected to an equalizer and then to an amplifier and out to the cable. It will be understood that the attenuation of a cable pair

at 12 kc/s is much less than it is at 60 kc/s. Thus at the end of a repeater section the level of the signal at 60 kc/s is much lower than at 12 kc/s. It is necessary to reduce all the frequencies to a uniform power level and this is done by the equalizer which has an attenuation-frequency characteristic exactly opposite to that of the cable.

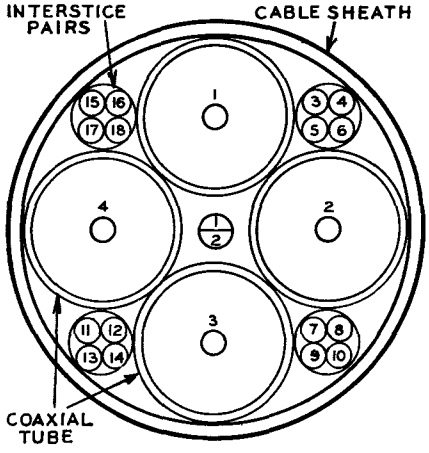


FIG. 6.6. 4-TUBE COAXIAL TELEPHONE CABLE WITH INTERSTICE PAIRS

Coaxial Cable Systems. The second type of wide band carrier system now in common use is the coaxial cable system. In this system only one pair of conductors is employed to carry all signals simultaneously. The conductors themselves are of a coaxial, or as is sometimes called, of concentric construction as illustrated in Fig. 6.6. This is a diagram of a four-tube type of cable now in common use. Each coaxial pair consists of a centre wire of 0·104 in. diameter. Over this centre conductor polythene discs are fitted at intervals, the outer conductor is a copper tape rolled around the polythene spacers to form a tube having a longitudinal seam and an inside diameter of 0·375 in. Wrappings of steel tape around the tube hold it rigid and reduce cross talk. Four such tubes are made up in quad formation and in the interstices between the tubes are a number of normal 20 lb paper insulated quads. A coaxial cable system requires one tube for one direction of transmission and a second tube for the return direction. Thus a four-tube cable will carry two completely separate coaxial transmission systems, each capable of carrying 600 circuits.

The reason for employing the coaxial type of conductor is that this form becomes self-screening at high frequencies. At these frequencies the current in the conductor tends to concentrate into the outer surface of the inner conductor and the inner surface of the outer conductor. At the frequencies normally used on such cables, between 60 kc/s and 2,500 kc/s and upwards, there is little external magnetic field; in consequence the cross talk between tubes and freedom from external interference is good. The balanced pair form of

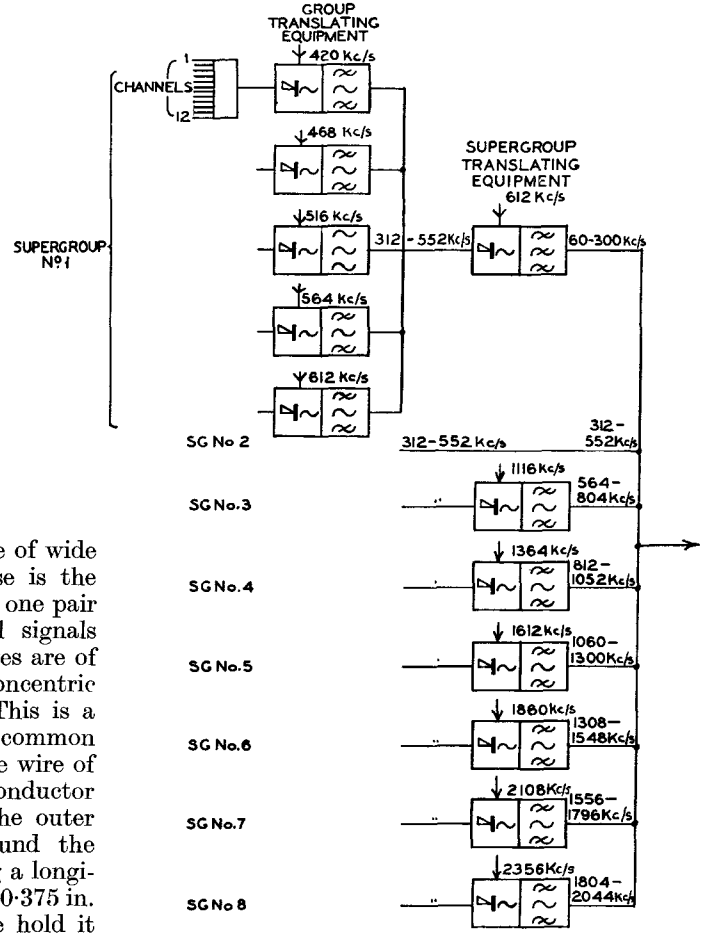


FIG. 6.7. TERMINAL MODULATION STAGES OF A COAXIAL SYSTEM SHOWING 8 SUPER-GROUPS EACH CARRYING 60 CHANNELS

construction apart from having a greater attenuation for the same overall diameter would require very accurate balancing of the capacitance of each wire to earth.

Terminal Equipment for Coaxial Cable Systems. The terminal modulation stages of a coaxial system are as shown in Fig. 6.7. Taking super-group No. 1 as an example, the output from five channel translating equipments in the frequency range of the

basic group 60–108 kc/s, pass into the group translating equipment. In this equipment, the first group is modulated with a carrier frequency of 420 kc/s and the lower sideband in the frequency range 312–360 kc/s is selected by a band pass filter. The other four groups are modulated as follows—

	Carrier Frequency	*Lower Sideband*
Group No. 2.	468 kc/s.	360–408 kc/s.
Group No. 3.	516 kc/s.	408–456 kc/s.
Group No. 4.	564 kc/s.	456–504 kc/s.
Group No. 5.	612 kc/s.	504–552 kc/s.

The five groups are then combined together to form one large group of 60 circuits, known as a super-group, of band width 240 kc/s in the frequency range 312–552 kc/s. This latter frequency range is known as the basic super-group frequency range. The same process takes place for the other super-groups. Each consists of five groups modulated and combined as shown above to form a super-group in the range 312–552 kc/s.

If we now examine super-group No. 1 a little further, we see that the output of the super-group passes into a further modulator known as the super-group translating equipment, with a carrier frequency of 612 kc/s. Here the whole super-group is modulated and the lower sideband of this modulation in the range 60–300 kc/s is selected by a band-pass filter. Super-group No. 2 passes through the super-group translating equipment without a change of frequency. Super-group No. 3 is modulated by a carrier of 1,116 kc/s and thus translates super-group No. 3 from the frequency range of the basic super-group into the frequency range of 564–804 kc/s. Similarly other super-groups are each modulated in the super-group translating equipment and are then all combined together for transmission on the coaxial cable. In Fig. 6.7 eight super-groups are shown but in many systems ten or more super-groups are transmitted on the line.

Line Equipment for Coaxial Cable Systems. At the high frequencies employed on a coaxial cable system the attenuation of the cable per mile is much greater than at audio-frequencies. Thus whereas on a loaded audio-cable repeaters are fitted at intervals of the order of 50 miles it is necessary to amplify a coaxial cable at much closer intervals. For a system carrying 400–600 circuits repeater stations are required every six miles along the cable route. As all the channels pass over the same coaxial pair only one amplifier is necessary for each direction of transmission at each of the repeater stations. Thus although amplifiers are required at more frequent intervals than on an audio-cable, there is a big saving in the number of amplifiers and furthermore the repeater stations for the coaxial cable repeaters are very small buildings.

It is common practice to provide spare amplifiers which may be brought into service by the operation of a relay when a fault occurs in a working amplifier. Only a few repeater stations are attended permanently by staff, most of the stations being operated normally without attention. From these unstaffed stations alarms are transmitted to one of the staffed stations in the event of a serious fault.

Close spacing of repeater stations would make it costly to provide for each of them a power-feed from the public mains and to provide at each station a stand-by engine-generator which would start up automatically in the event of a failure of the mains supply. To overcome this, the power for many of the stations, called dependent stations, is fed over the coaxial cable from one station, called a power-feeding station. Thus power need only be taken from the public mains supply every 30 miles or so and a standby engine generator is only required at the power-feeding stations.

CHAPTER 7

TELEGRAPH CIRCUITS

It has been explained in Chapter 1 how telegraph signals may be transmitted in the form of a code employing either direct or alternating currents. The circuits required to convey these signals may be made up in a number of different ways and the method adopted in any particular case is determined by considerations of technical efficiency and economy in the capital and maintenance costs of the plant used.

Circuits may be provided by means of separate wires carried overhead on insulators on poles or in underground or submarine cables or over radio links. At one time most telegraph circuits were on overhead wires but with the growth in the number of circuits required underground cables were used on many long distance routes. The cables used for telegraphy were originally kept separate from those used for telephony but for many years in most countries the line plant provided for telecommunications has been integrated and common cables are used for the provision of both telegraph and telephone circuits.

In most telecommunication networks there are considerably more telephone than telegraph circuits and the integration of cables for both telegraphy and telephony has enabled telegraph circuits to be provided much more cheaply. Also, it has enabled the telegraph service to grow on routes that would otherwise have been uneconomic if separate provision of telegraph wires or cables had been necessary. From a transmission point of view the integration of telegraph and telephone circuits into common cables and transmission systems is perfectly satisfactory, provided suitable precautions are taken to prevent interference between the telephone and telegraph circuits. In telegraph circuits using d.c. signalling the principal precaution taken is to insert low-pass (L.P.) filters between the telegraph transmitters and the lines, to prevent harmonics of the telegraph modulation from passing to line and causing cross talk to the telephone circuits. In both d.c. and a.c. telegraph signalling systems it is necessary to limit the current and voltage transmitted in order to keep the level of interference as low as practicable.

Metallic Telegraph Circuits. A metallic telegraph circuit is one composed of metallic conductors. In its most elementary form it consists of two conductors insulated throughout their length from each other and from earth and connected at each end to the transmitting and receiving apparatus. Such a circuit is suitable for the transmission of either direct or alternating telegraph signalling currents.

An Earth-return Telegraph Circuit—is a circuit which has a conductor (or number of conductors in parallel) between two points and which is completed through earth at these points. In such a circuit the resistance of the earth-return path is practically zero, provided the earth connexions at the two ends of the circuit are made efficiently. The manner in which such earth connexions are made is dealt with in Chapter 14.

Audio-frequency Circuits. Audio-frequency circuits will transmit alternating currents having frequencies within the range audible to the normal human ear. Two-wire circuits in underground cables are generally used when the distance is not great. For longer circuits valve amplifiers are provided at suitable intervals along the cable to compensate for the attenuation. These amplified audio-frequency circuits are usually composed of four wires, a separate pair being used for each direction of transmission and terminated at each end on a balanced four-wire to two-wire transformer, to which a two-wire telephone circuit can be connected (see Chapter 6). Unamplified audio-circuits may be used for either d.c. or a.c. signalling telegraph circuits.

Long audio-circuits having audio-amplifiers can be used as telegraph circuits, provided a.c. signalling is employed; d.c. telegraph signalling is prohibited by the presence of the line amplifiers which will not pass direct currents.

Amplified audio-circuits are often used for the provision of single-tone telegraph circuits. An oscillator is used to generate a voice frequency carrier which is modulated by the telegraph transmitter and transmitted over the line to the distant receiving apparatus. Permanent point-to-point telegraph circuits may be set up and operated in this manner. It is also possible to use this method as an alternative to speech on point-to-point telephone circuits and over switched telephone exchange connexions. In the latter case, the connexion must first be set up as a telephone call and the telegraph equipment then switched on to the line, the telephone being simultaneously disconnected. This method was used in the B.P.O. Telex service from 1932 until 1954 when it was

made obsolescent by the introduction of an independent telegraph switching network using telegraph channels and Telex teleprinter switchboards.

The use of long distance audio-circuits for single tone voice frequency telegraph circuits is uneconomic as a transmission method since only a small fraction of the available frequency range of the circuit is usually necessary for the transmission of the telegraph signals. For example, in single tone V.F. teleprinter working, 1,500 c/s is normally employed as the carrier frequency, the signalling speed is 50 bauds and the theoretical minimum band-width required for the transmission is thus from 1,475 to 1,525 c/s (i.e. 50 c/s band-width only). In practice, no limitation is placed on the sideband frequencies transmitted, as the whole band-width of the circuit is available for the transmission. Nevertheless, only a small fraction of the available band-width need be used to transmit the telegraph signals efficiently. The use of audio-circuits in this manner can therefore only be justified when there is no other method of providing a circuit, or when alternative telephone facilities are essential.

Telegraph circuits of this type form a very small percentage of the circuits operated in B.P.O. services. Their use is confined to a few hundred private wire circuits requiring alternative telephone and teleprinter facilities (see Chapter 16).

Superposed (i.e. By-product) Telegraph Circuits. Telegraph circuits may be derived from metallic conductors employed for telephone circuits by the process known as "superposing." A number of methods may be used as follow—

(*a*) *Phantom circuits.* A telegraph circuit may be derived from two metallic telephone pairs, by terminating each pair on a differentially wound transformer and connecting the telegraph sending and receiving instruments to the centre-points of the line windings of the two transformers. The metallic pairs are known as "side circuits" and the additional circuit superposed on the two side circuits is termed a "phantom circuit." Fig. 7.1 indicates the circuit arrangement adopted to obtain a telegraph phantom circuit and shows the phantom circuit connected for use as a two-way simplex circuit.

The current from the telegraph transmitter at station *A* divides equally between the two wires forming the telephone side circuit. The magneto-motive force (m.m.f.) produced by each of these currents flowing in the two halves of the line transformer secondary windings are therefore equal and opposite and so no resultant e.m.f. is induced in the telephone circuit. It is essential that the impedances of the two wires forming the side circuit are identical, otherwise the telegraph currents in each will not be equal and interference to the side circuits from telegraph signalling will occur. It will be noted that the direct current resistance of the phantom circuit is half that of the side-circuit since the two wires of the side-circuit are used in parallel. At station *B* the telegraph currents transmitted from *A* pass through the two halves of the differential line transformer to the centre point and thence to the receiving instrument.

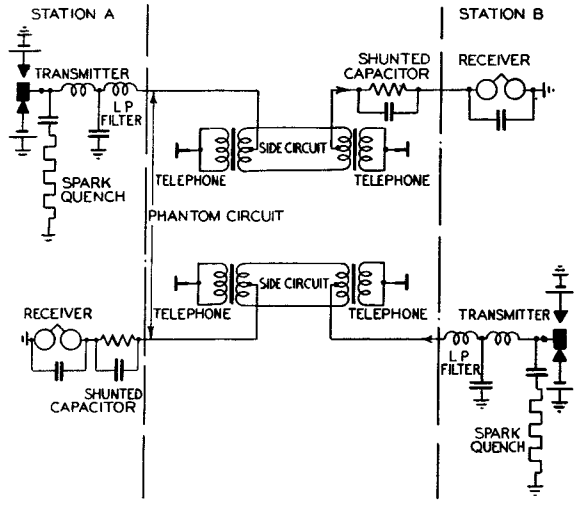


FIG. 7.1. PHANTOM CIRCUIT FOR 2-WAY SIMPLEX TELEGRAPH WORKING

Since the currents are equal there is no resultant m.m.f. produced by the telegraph signals in the line transformer to cause interference with the telephone side circuit.

The telephone speaking and signalling currents from the telephone sets on the side circuits produce alternating e.m.f.'s across the secondary windings of the line transformers and thus a.c. telephone currents flow around the respective side circuit loops. These have no effect upon the telegraph circuit since the latter is connected to the electrical centre-point of the transformers at each end of the side circuit.

Phantom circuits are suitable for the transmission of a.c. telegraph signals and may be used for either single-channel voice frequency signalling circuits or for multi-channel voice frequency (M.C.V.F.) telegraph systems, provided, in the latter case, the phantom circuit is suitably equalized over the frequency range employed for the telegraph signals. To improve the transmission efficiency (T.E.) for audio frequencies, the phantom circuit can be loaded by double-wound coils as

shown in Fig. 7.2 in which $S1$ and $S2$ indicate the side circuit coils, and P the phantom circuit coil. The side circuit currents flow differentially through the phantom coil and the latter therefore adds no inductance to the side circuits. Similarly, the phantom circuit currents flow differentially through

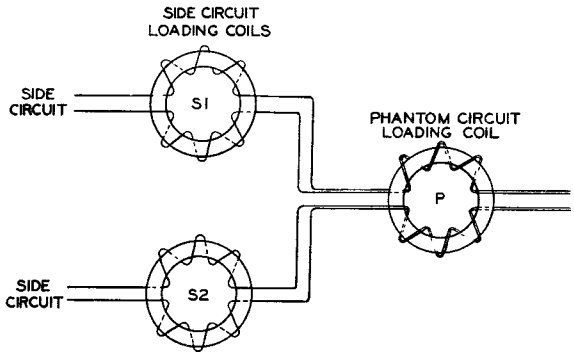


FIG. 7.2. INDUCTIVE LOADING IN A PHANTOM CIRCUIT

the side circuit coils and therefore the latter add no inductance to the phantom circuit.

(*b*) *Double-phantom circuits.* It is possible to derive a further circuit from two phantom circuits in a similar manner to that employed for deriving a phantom circuit from two side circuits. The circuit derived in this manner is known as a "Double-phantom circuit" and Fig. 7.3 shows the schematic circuit arrangement employed for the purpose.

The telegraph circuit is connected to the centre-point of the line side of the phantom circuit transformer. The telephone speaking and ringing currents on the side circuits circulate around their respective loops, whilst those on the phantom circuit divide at the centre-point of the line windings of the line transformer and the same considerations apply as in the telegraph phantom circuit. The telegraph currents transmitted divide at the centre-points of the line windings of the phantom transformer and provided the two halves of the winding, together with the side circuits with which they are associated, are equal as regards resistance, inductance and capacitance, there will be no resultant m.m.f. and therefore no e.m.f. will be induced into the telephone circuit. The path of the telegraph signals can be traced from Fig. 7.3. When phantom or double-phantom circuits are employed for d.c. telegraph circuits the telegraph signalling voltages and currents must be kept as low as practicable and low pass filters inserted in the transmitting circuits (see Figs. 7.1 and 7.3) to reduce interference to other circuits.

Where a telegraph circuit is superposed on a telephone circuit telephone battery signalling cannot be employed and it is necessary to use either 17 c/s generator, or voice frequency, signalling. Phantom and double-phantom circuits were used very extensively at one time in the B.P.O. for the provision of private wire teleprinter simplex circuits but the proportion of circuits provided in this manner is now very small since the standard method for providing long distance telegraph circuits is by means of channels in M.C.V.F. telegraph systems.

Time Division Multiplex Telegraph Systems. When the transmission characteristics of a line permit high-speed signalling, and it is required to make full use of its traffic-carrying capacity, it may be employed as a single high-speed telegraph circuit. This involves the use of high-speed transmitting and receiving instruments. Alternatively, it may be preferred to operate a number of low-speed telegraph circuits simultaneously over the same line.

Time Division Multiplex is one method of obtaining several low speed channels on one high-speed (H.S.) line. The line is connected in rapid

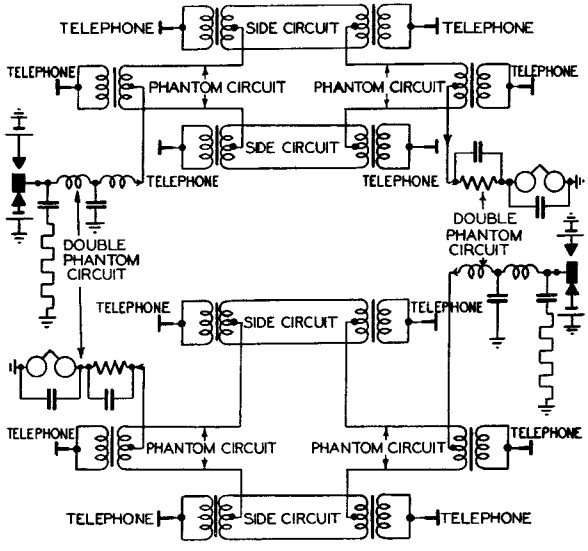


FIG. 7.3. A DOUBLE-PHANTOM CIRCUIT FOR 2-WAY SIMPLEX TELEGRAPH WORKING

succession to a number of transmitting and receiving instruments at each end, by means of synchronized distributors. Each channel is thus given the exclusive use of the line for a short period, hence the expression "Time Division," during which the elements of the signal combination can be sent sequentially at high-speed. The channel

transmitter can then be reset for the next character, at a lower speed, in readiness for the next period of connexion.

Time division systems of the foregoing type, in which a fixed number of signal elements is transmitted sequentially from each channel in turn, are only suitable for codes having a fixed number of elements, e.g. five-unit and seven-unit codes. For signalling codes having a variable number of elements for different characters, e.g. Morse code, it is necessary for time division working to interleave the signals of different channels element by element. At the receiving end the signals for each channel are received on a side-stable relay, so that when a pulse is received corresponding to the polarity of one element the receiving relay operates to that polarity and remains there until the next element for that channel is received, i.e. one unit interval later. Thus, in a Morse system the intervals between the successive connexions of a channel transmitter to the line, by the distributor, would correspond to the duration of one dot.

The outstanding difference between the interleaved and sequential systems of time division multiplex working is therefore that the fully interleaved system permits the use of different signalling codes on different channels at will, whereas the fully sequential system assigns a fixed number of signal elements to each channel in turn and only codes which utilize no more elements per character than the number provided can be used on such channels.

The distributors at each end of the line in time division multiplex systems must be accurately synchronized to ensure that the corresponding transmitting and receiving equipment for each channel are connected at each end of the line at the correct time. The aggregate signalling speed in the line of the derived telegraph channels is equal to that of the line if it were used as a single high-speed channel.

Typical systems of this type were the Delaney multiplex, used for Morse signalling and the better known Baudot multiplex system employing a five-unit code. The principles of the latter system are described in Chapter 2.

Time division multiplex systems were used extensively in the operation of direct current telegraph circuits until the introduction of the M.C.V.F. system of frequency division multiplex, which is described in the next section.

Although it has been obsolescent in the B.P.O. for land line circuits since about 1930, the Baudot system is still in service in some countries. Special forms of time division multiplex (T.D.M.) are also in use on many long submarine cables where the high attenuation prevents the use of a.c. signalling and the great depth of the oceans have until recent years made submerged repeaters impracticable. T.D.M. systems, particularly those of the error detection and/or correction type are also finding increasing application on radio links.

Multi-channel Voice-frequency Telegraph Systems

The most important and widely used method for providing telegraph circuits throughout the world on land lines and short submarine cables is undoubtedly the multi-channel voice frequency (M.C.V.F.) telegraph system, whereby as many as twenty-four two-way simplex telegraph circuits may be operated simultaneously over one telephone circuit. Special forms of M.C.V.F. telegraph systems are also operated in many cases over radio-telegraph links. The basic principle employed in M.C.V.F. telegraph systems is that a different audio-frequency carrier current is employed for each telegraph channel and the channels are separated at the sending and receiving ends by suitable band-pass filters. Thus the band-width of the telephone circuit is effectively divided into a number of smaller bands, each suitable for telegraph signalling.

The carrier frequencies used for M.C.V.F. systems are chosen to lie within the pass-band of a good quality telephone circuit. The telephone circuit used may be provided by open wire, underground cable or radio link or may itself be a channel in a telephone carrier group. In practice it is found more necessary to avoid short interruptions and certain types of interference for M.C.V.F. telegraph working than it is for telephone working. For this reason, special precautions need to be taken to avoid interruptions and interference on M.C.V.F. telegraph lines. Nevertheless, the M.C.V.F. telegraph systems employ essentially the same type of line plant, i.e. cables and amplifiers, as do normal telephone circuits. It is thus unnecessary to provide separate telephone and telegraph cable networks and the economic and practical advantages of this are enormous.

The overriding merits of M.C.V.F. working may be summarized as follows—

(*a*) The V.F. telegraph signals can be amplified by standard telephone amplifiers.

(*b*) The telephone line and amplifiers cause very little distortion to the telegraph signals and there is no limitation of the distance over which M.C.V.F. systems can be operated.

(*c*) The same line plant is used for M.C.V.F. telegraph circuits as for telephone circuits, so that no special telegraph cables are necessary and this

enables telephone and telegraph transmission systems to be completely integrated.

(*d*) The full band-width of the telephone circuit is utilized economically.

The band-width employed for each channel in a M.C.V.F. telegraph system is dependent upon the

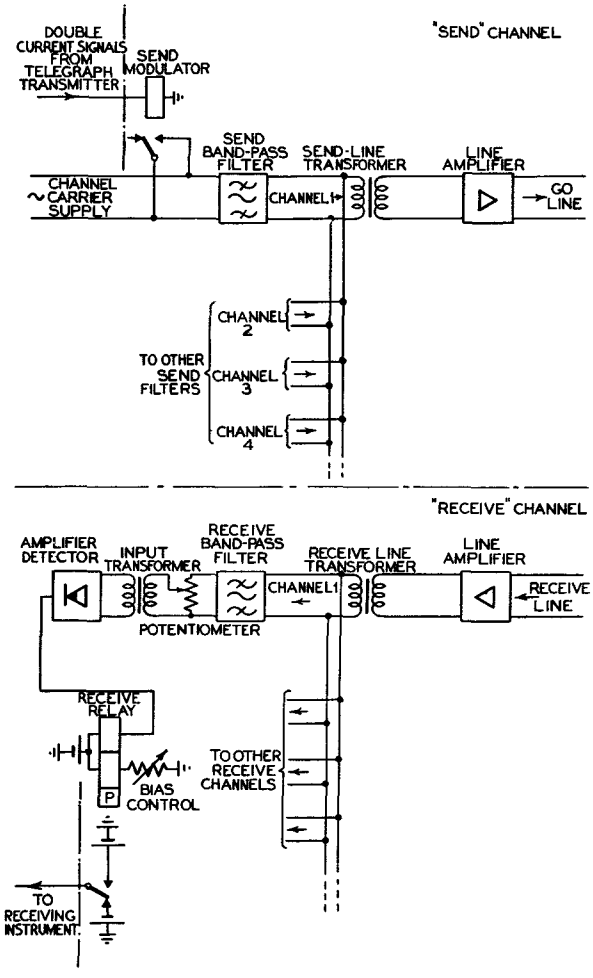


FIG. 7.4. BLOCK SCHEMATIC DIAGRAM OF A MULTI-CHANNEL VOICE-FREQUENCY TELEGRAPH SYSTEM

telegraph signalling speed. The great majority of standardized systems are used for teleprinter circuits and for this purpose the B.P.O., for example, has standardized the use of four, six, twelve, eighteen and twenty-four-circuit systems. The four-circuit system may be operated over either two-wire or four-wire lines, but the other systems require the use of a four-wire line. For four-wire working, each circuit uses the same carrier frequency in both directions of transmission, one pair of the four-wire circuit being used for "sending" and the other pair for "receiving." In two-wire working, different carrier frequencies must be used for the sending and receiving channel of each circuit.

Fig. 7.4 shows a block schematic of an amplitude-modulated telegraph system and the principle of its working is broadly as follows. The carrier-current is generated continuously and a different carrier-frequency is used for each channel. The transmission of the channel carrier-current is controlled by means of a modulator, operated by the d.c. signals received from the telegraph transmitter connected to the channel. The modulator is arranged to suppress the transmission of carrier-tone to the line during spacing signals and to pass tone during marking signals. The telegraph signals from the transmitter are thus converted into equivalent periods of either no-tone or tone, corresponding to the spacing and marking elements.

The modulated carrier signals from each channel pass to line through a channel band-pass filter, the mid-band frequency of which corresponds to the carrier-frequency of that particular channel. The purpose of the channel filter is two-fold, namely (*a*) it prevents alternating currents of frequencies which would cause interference with adjacent channels from being transmitted and (*b*) it presents a high impedance to the currents transmitted from the other channels, and so prevents any one channel from absorbing an appreciable amount of energy from the others.

At the receiving end the various channels are separated by similar filters. The current from each filter is passed to a separate amplifier-detector, the rectified output of which is used to control a telegraph relay. The receiving relay thus reproduces d.c. signals, corresponding to those from the distant transmitter which operates the receiving telegraph instrument connected to the channel. The amplifier-detector incorporates a gain control device to reduce the bias distortion of the telegraph signals which would otherwise occur due to variation in the attenuation of the transmission line.

When worked at signalling speeds not approaching the limit of frequency band-width of the channel, the distortion of the telegraph signals is normally quite small and is almost solely due to interference products from other channels. Provided the overall attenuation-frequency characteristic of the line is reasonably flat, the distortion is practically independent of the length of the line. This fact is of great importance and utility in routing circuits, particularly in the case of circuits composed of several V.F. channels connected in tandem and in

telegraph switching systems. Channels in the same system can be treated for practical purposes as having the same transmission qualities, independent of the channel used and its length. This feature of M.C.V.F. channels provides great flexibility and is also very useful under breakdown conditions where it is necessary to re-route a circuit rapidly to maintain service.

The standardization of M.C.V.F. telegraph systems in the B.P.O. as the method of provision of all long distance telegraph circuits has revolutionized the economics and ease of provision of circuits. Furthermore modern M.C.V.F. systems give a standard of transmission and stability of service over long distances much superior to that possible with the older d.c. methods of working which are now largely restricted to short distances. M.C.V.F. telegraphy in conjunction with the use of teleprinters has made possible the development of the many complex manual and automatic switching systems which are nowadays regarded as commonplace but which would have been impossible of attainment even 25 years ago.

The subject of amplitude-modulated (A.M.) and frequency-modulated (F.M.) M.C.V.F. telegraphy is treated in greater detail in Chapters 5 and 10.

Sub-audio Telegraph Circuits

Sub-audio telegraphy is a method of deriving a telegraph circuit from a telephone circuit, by using for the transmission of telegraph signals the portion of the frequency range of the circuit below that required to be employed for the transmission of speech.

The transmission of speech on commercial telephone circuits is possible with a frequency band of about 300 to 2,600 c/s. Thus, it is possible to use the frequency range 0 to 300 c/s of a telephone circuit for telegraph transmission provided that precautions are taken to avoid mutual interference between the working of the telegraph and telephone circuits and also to ensure that no degradation of the characteristics of the telephone circuit is caused by the telegraph circuit. This method of deriving a telegraph circuit is sometimes termed "compositing," particularly in the U.S.A.

The basic circuit arrangement for a sub-audio telegraph circuit is shown in Fig. 7.5. The connexion of the telephone set at each end of the line is made via a high-pass (H.P.) filter having a cut-off frequency of approximately 200 c/s. The telegraph set is connected at each end of the line via a low-pass (L.P.) filter which is also designed to have a cut-off frequency of 200 c/s, or less.

The cut-off frequency of the L.P. filter must be related to the speed of telegraph signalling to be employed. As already explained in Chapters 1 and 5, the modulation of telegraph signals produces component frequencies which are harmonics of the modulation speed. If all these harmonics were allowed to be transmitted those falling within the audio-range of the speech circuit would cause interference to the telephone circuit. For telegraph purposes it is theoretically possible to transmit the intelligence of the modulation, provided the fundamental frequency of the telegraph signals is

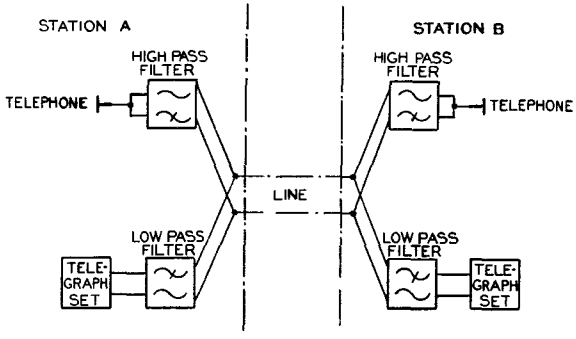


FIG. 7.5. SUB-AUDIO TELEGRAPH WORKING

transmitted. Thus for a speed of modulation of N bauds, the highest fundamental signalling frequency to be transmitted is $\frac{N}{2}$ c/s which corresponds to reversals transmitted at N bauds.

In practical designs of filters (see Chapter 5) it is not possible to obtain a sharp cut-off frequency. Furthermore, a sharp cut-off is not essential; it is necessary only to ensure that the filter causes a sufficiently high attenuation of the harmonic frequencies to reduce their power below the level at which they would cause interference to the telephone circuit. This form of characteristic is easily realized and in practical designs results in extremely high attenuation of harmonic frequencies of the telegraph signals in excess of the third or fifth. It will be realized that this action of the L.P. filter has the effect of rounding off the shape of the telegraph signals which are transmitted to line.

For teleprinter working at 50 bauds, a L.P. filter which cuts off at about 120 c/s would be quite suitable for sub-audio working. The L.P. filter must offer a high impedance to the telephone frequencies whatever the condition of the telegraph transmitting or receiving equipment, so as not to absorb power from the telephone circuit.

At the receiving end of the circuit the telegraph signals operate a relay and the resulting movements of the armature of the relay are very abrupt and this action causes sudden changes in the magnetic

flux distribution in the relay. A surge of e.m.f. is therefore induced in the relay coils by each transit of the relay armature. The surge voltage will contain harmonics of the fundamental signalling frequency which fall within the audible range. Similarly, if a vibrating receiving relay is used, currents are transmitted from the relay tongue to earth via the vibrating windings. These currents cause corresponding impulses to be induced into the receiving line due to transformer action in the

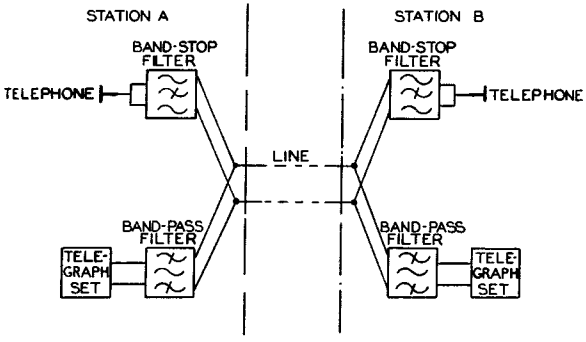


FIG. 7.6. SIMULTANEOUS SPEECH AND AUDIO TELEGRAPH WORKING

relay coils. The insertion of a L.P. filter between the line and the receiving telegraph set attenuates these audio-frequency telegraph currents and so prevents interference with the speech currents.

The H.P. filter connected in series with the telephone set at each end of the telephone circuit allows the passage of the speech frequency currents with little attenuation. The H.P. filter prevents, or at least severely limits, telegraph signals entering the telephone and so eliminates the low pitched noise which these signals would otherwise produce. Where telephone amplifiers are connected in a circuit it is necessary to provide arrangements for the telegraph signals to by-pass each amplifier, as the latter will not transmit d.c. signals. This involves the provision of H.P. and L.P. filters both sides of the amplifier.

Sub-audio telegraph circuits can be operated duplex but the duplex balances are complicated, as allowance has to be made in the balance network for the effect of the filters.

It has never been found necessary or economic to use sub-audio circuits in the B.P.O. telegraph system, except in the case of a few submarine cables where the provision of special equipment was justified. Typical cases were a duplex teleprinter circuit on a London–Jersey single core, unloaded submarine cable and two duplex teleprinter circuits worked between Blackpool and the Isle of Man on a continuously loaded submarine telephone cable. A special feature of the latter circuits was the low transmitting voltage used, i.e. 7 V, to avoid risk of affecting the characteristics of the loading and so causing cross-talk as a result of non-linear magnetization by the telegraph signalling currents. These circuits have since been replaced by teleprinter circuits operating in M.C.V.F. telegraph systems.

It will be clear that sub-audio telegraph circuits require a considerable amount of special filter equipment at both ends and at any amplifier stations on route. Circuits of this type are therefore costly and are only justified when circuits cannot be provided by cheaper means.

Simultaneous Speech and Audio Telegraph Working. By the use of suitable filters it is possible to allocate a small portion of the frequency bandwidth of an audio circuit for use as a single-tone voice frequency telegraph circuit whilst the remainder of the band-width is employed simultaneously for telephone purposes. Fig. 7.6 indicates the principle employed.

The telegraph set at each end of the circuit is connected to line via a band-pass filter, the mid-band frequency of which corresponds to the carrier frequency of the telegraph channel. This filter has a narrow pass range and so attenuates harmonic components of the telegraph signals at the transmitting end which would otherwise cause interference with the telephone circuit. The telegraph filter at the same time presents a high impedance to the telephone speech currents so as not to absorb any appreciable amount of speech energy. At the receiving end of the circuit the telegraph band-pass filter separates out the telegraph signalling currents received from the line and passes them on to an amplifier-detector for the operation of the telegraph receiving instrument. The band-stop filters in the telephone circuit are designed so as to stop the transmission to line of those speech frequencies which would fall within the frequency range of the telegraph signals and so cause interference with telegraph working. The band-stop filter presents a high impedance to telegraph signalling frequencies in the line so as to minimize the absorption of energy from the telegraph signals.

An arrangement of this sort may be used to provide simultaneously a speech circuit, together with either a simplex or a duplex telegraph circuit. For simplex telegraph working the same carrier frequency is used for telegraph transmission in each direction. Where a duplex telegraph circuit is required different carrier frequencies must be used for transmitting and receiving. In each case some degradation of speech occurs owing to the reduction of effective band-width of the telephone

circuit. This effect is worse where duplex telegraph facilities are provided since a wider band-width is necessary to cater for the two telegraph carrier frequencies. Simultaneous speech and telegraph equipment of this type is normally only used in exceptional circumstances where economies in line plant outweigh the consideration of high quality speech.

Super-audio Telegraph Circuits. Some telephone circuits are capable of transmitting a range of frequencies extending above the highest frequency necessary for the transmission of commercial speech. In such cases it is possible to employ the range above that employed for speech to provide one or more telegraph channels. The number of channels obtainable in this way depends upon the super-audio-frequency range available and the speed of signalling required in the telegraph channels. Telegraph channels derived in this manner are known as "Super-audio Telegraph Channels."

The principle of operation employed is indicated in Fig. 7.7 for the case in which only one sending and receiving telegraph channel is derived. The super-audio telegraph equipment is inserted between the four-wire termination of the telephone circuit and the terminal four-wire amplifier. On the sending side, the telegraph transmitter modulates a super-audio carrier frequency, which then passes to line via a high-pass filter having low attenuation for the transmission of the super-audio telegraph signalling currents. The H.P. filter, however, causes high attenuation of any audio-frequency signals in the telegraph modulation as these would cause interference with the speech circuit. Similarly, the L.P. filter in the speech path offers low attenuation to the transmission of speech currents in the audio range but severely attenuates any speech currents of super-audio-frequency as these would interfere with the telegraph signals.

At the receiving ends the function of the H.P. and L.P. filters is merely one of frequency discrimination, namely the L.P. filter passes only speech currents and the H.P. filter only passes the telegraph currents. The output from the L.P. filter brings the speech currents to the four-wire termination and thence to the receiving telephone, whilst the H.P. filter passes the telegraph currents to a suitable amplifier-detector for operation of the receiving telegraph instrument.

Where the super-audio range of the telephone circuit permits, it is possible to use it for the operation of a number of telegraph channels, in which case M.C.V.F. telegraph equipment operating on the principles already described on page 184 is connected to the H.P. filters shown in Fig. 7.7.

The carrier for each telegraph channel can either be generated at a super-audio frequency by individual oscillators or, alternatively, group modulation may be employed. In the latter case the individual telegraph channel carriers can be of audio-frequency and identical with those employed in a normal M.C.V.F. system. These carriers are modulated by the d.c. signals from the individual telegraph transmitters connected to the channels. The resulting modulation from the group of channels is then applied to a common modulator to modulate a super-audio carrier frequency. Only the lower side-band of this modulation is transmitted and thus the highest frequency channels of the V.F. system become the lowest frequency channels of the super-audio system. At the receiving end, the group of telegraph channels is first demodulated by means of a group demodulator

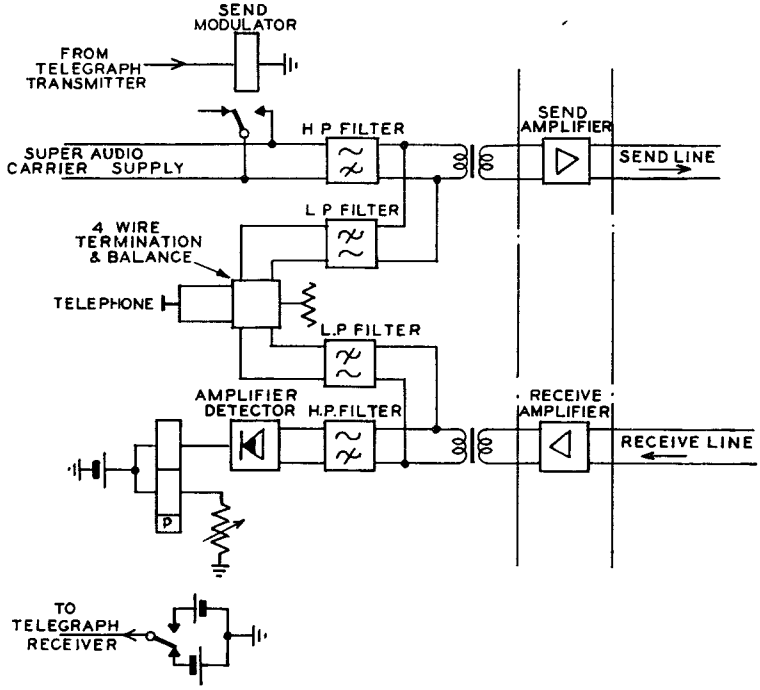
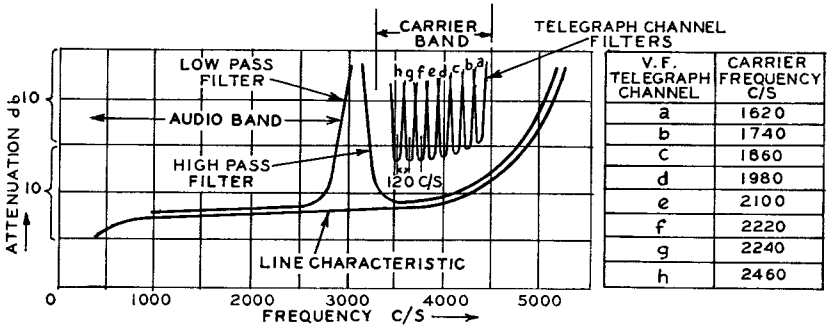


FIG. 7.7. SUPER-AUDIO TELEGRAPH WORKING

and the individual channels then derived by the normal channel filters, etc.

This method has the advantage that standard V.F. equipment can be employed both in the case of M.C.V.F. working on normal audio circuits and carrier channel is employed exclusively for telegraphy. This method of operation is not therefore normally referred to as a super-audio telegraph system, even although the telegraph currents in the line are of super-audio-frequency.



V.F. TELEGRAPH CHANNEL	CARRIER FREQUENCY C/S
a	1620
b	1740
c	1860
d	1980
e	2100
f	2220
g	2240
h	2460

FIG. 7.8. SIMULTANEOUS USE OF A TELEPHONE CIRCUIT FOR SPEECH AND 8 SUPER-AUDIO TELEGRAPH CHANNELS

for super-audio circuits. This use of standard channel equipment gives economies in both manufacture and maintenance.

Fig. 7.8 indicates in principle how the frequency range of a telephone circuit suitable for super-audio working is utilized for the provision of an audio speech circuit and eight super-audio telegraph channels.

In super-audio telegraph working (as in normal V.F. working) care must be taken to prevent overloading of any telephone amplifiers on route, otherwise cross modulation will occur and cause mutual interference between the telephone and telegraph circuits. Good quality H.P. and L.P. filters are necessary to reduce the mutual interference between the telegraph and telephone circuits. These factors, coupled with the fact that telephone engineers are constantly trying to improve the standard of speech and music transmission by increasing the audio-frequency range utilized, and by improvement of signal to noise ratios, leaves little opportunity or scope for the use of super-audio telegraph channels.

A few teleprinter super-audio channels were operated at one time by the B.P.O. on the Anglo-Dutch telephone cables and a six-circuit telegraph system employing group modulation was used between Newcastle and London. The B.P.O. no longer operates any systems of this type and super-audio telegraph systems are rarely employed in any modern telegraph network. The use of carrier telephone channels for the operation of M.C.V.F. telegraph systems is extensively employed in modern telecommunications networks but in this case the whole band-width of a telephone

Simplex Telegraph Circuits

Simplex Circuit Employing Loop Signalling. Fig. 7.9 illustrates a simple form of simplex telegraph circuit. The transmitter and receiver at each station are connected in series via the loop formed by the metallic line wires and a battery at one end. Normally, current flows around the loop, but when

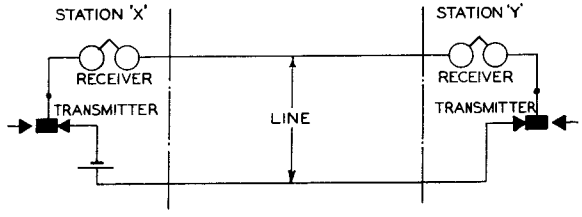


FIG. 7.9. SIMPLEX TELEGRAPH CIRCUIT (LOOP WORKING)

either transmitter is operated, single-current signals are produced which actuate the receiver at each end of the circuit. Thus the signals transmitted from one end of the circuit are received at the other and a local record of the signals is produced in the home receiver. The latter feature is often an essential requirement, e.g. in teleprinter private wire and telex services.

If both stations try to transmit simultaneously the signals are mutilated. The circuit is thus only capable of operating in one direction at a time.

A circuit in which the signals flow from the transmitter around a complete loop formed by the two line wires and the distant receiver is known as "loop working." In the case shown, the circuit is normally closed and only broken when signalling

occurs, this method of working is sometimes called "closed circuit working" and is extensively employed in American practice.

Single-wire Earth-return Simplex Circuit. Fig. 7.10 indicates a single-wire circuit arranged for transmission from a transmitter at station X to a receiver at station Y, in which the earth is employed as the return path. Fig. 7.10 (a) indicates the arrangement for closed-circuit working and Fig. 7.10 (b) for open-circuit working.

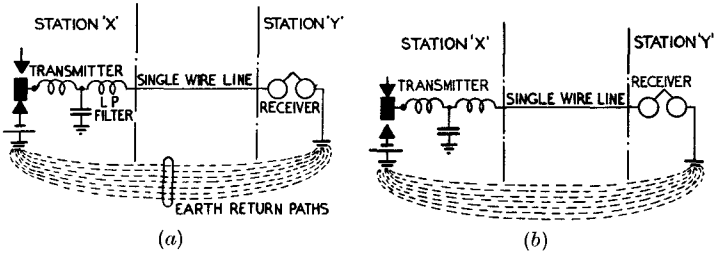


FIG. 7.10. SINGLE-WIRE EARTH-RETURN SIMPLEX TELEGRAPH CIRCUIT
(a) Closed-circuit working (b) Open-circuit working

In the case of Fig. 7.10 (a) it will be seen that when the circuit is idle current flows from the battery to the line via the transmitter at X and thence to the distant receiver at Y, whence it returns through the earth return path back to X. When the transmitter at X is operated, the flow of current is interrupted, thus single-current signals are produced which operate the receiver at Y. In the circuit shown in Fig. 7.10 (b) the operation of the transmitter also produces single-current signals but in this case no line current flows when the circuit is idle and the single-current pulses are produced when the transmitter is operated. This method has the advantage of reducing the current drain on the battery when the circuit is idle.

Fig. 7.11 shows a single-wire earth-return circuit employing double-current signalling and in this case current flows when the circuit is idle and operation of the transmitter causes the direction of current in the line and distant receiver to be reversed. Thus the receiver is actuated by double-current signal impulses.

Single-wire earth-return circuits suffer from the disadvantage that the circuit is electrically unbalanced, with the result that adjacent power or telecommunication circuits induce e.m.f.'s into the single-wire telegraph circuit. If these are of sufficient magnitude they will give rise to errors in the reception of the telegraph signals. Similar effects occur due to leakage and fault currents from neighbouring power and traction systems and in the case of long telegraph circuits the variations in earth potential which occur, particularly during magnetic storms, may be of sufficient magnitude to render telegraph working impossible. In the case of short circuits these effects are usually negligible.

The transmission of telegraph signals over a circuit will only be satisfactory if the distortion of the signals, which occurs in the circuit and equipment due to characteristic, bias and fortuitous effects, does not exceed the margin of the receiving apparatus.

Bias distortion can be eliminated by careful adjustments and the use of double-current signalling. Fortuitous distortion is mainly due to interference in the circuit and can be almost completely eliminated by using a balanced pair to form a loop circuit. The balanced pair can be either a twisted pair in a multiple-twin-cable, a pair in a star-quad cable, or a transposed pair on open wire lines. In each of these cases, the line is so constructed that any external source of interference induces, as nearly as practicable, equal e.m.f.'s in each wire forming the telegraph loop circuit. The effect of these induced e.m.f.'s in the loop very nearly cancel each other and the resultant interference is consequently greatly reduced. Loop circuits may therefore be operated satisfactory over much longer distances than normal one-wire circuits. A similar advantage can also be obtained by the use of single-screened (S.S.) conductors, in which the single-wire is enclosed by insulation over which a continuous earthed screen is wound. The latter form of construction was often used in the early days of long distance telegraphy for single-wire circuits.

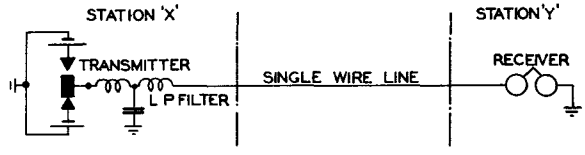


FIG. 7.11. SINGLE-WIRE EARTH-RETURN SIMPLEX TELEGRAPH CIRCUIT WITH DOUBLE-CURRENT SIGNALLING

In B.P.O. practice loop working is only necessary in a few cases since long distance circuits are provided principally by means of channels in M.C.V.F. telegraph systems. Single wire earth-return circuits are principally used for the short extension circuit connecting the voice-frequency channel to the transmitting and receiving apparatus at each end of the circuit, as indicated in Fig. 7.12 which shows

the connexions for one direction of transmission only.

Single-wire earth-return circuits also cause interference to adjacent telegraph and telephone circuits. To reduce the effect, a low-pass filter should always be inserted at the sending end of the circuit as indicated in the diagrams. Loop working considerably reduces these effects, since equal and

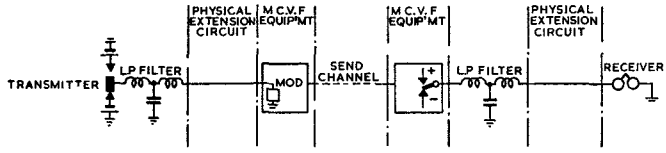


FIG. 7.12. CONNEXION OF A VOICE-FREQUENCY TELEGRAPH CHANNEL TO PHYSICAL ENDS

opposite currents flow in the two wires forming the telegraph circuit and these induce equal and opposite effects in neighbouring wires. This feature may be still further enhanced if a surge-transformer is employed in the telegraph circuit as indicated in Fig. 7.13.

The primary winding of a 1 : 1 transformer is connected at the transmitting end of the circuit in series with the *A* wire, and the secondary winding of the transformer is connected in the *B* wire as shown. The secondary connexions are made so that the voltage surge produced in the *B* wire is equal to and opposite to that flowing in the *A* wire, thus the surge conditions in the *A* and *B* wires are

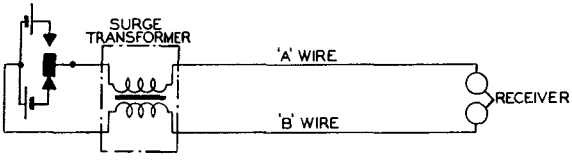


FIG. 7.13. USE OF A SURGE TRANSFORMER

identical in magnitude and phase but opposite in their effects on neighbouring circuits. The inductance of the surge-transformer also delays the build-up of the signalling currents and thus attenuates the higher harmonics which would cause most serious interference with neighbouring telephone circuits.

Single-wire Simplex Circuits Using Send-Receive Switch. In some cases a send-receive switch is employed in conjunction with single-wire earth-return circuits to enable either the transmitting or receiving equipment to be connected to line, according to whether the station requires to transmit or receive. In the rest position both stations have their switches set to receive, so that each is ready to receive messages instantly from the distant transmitter. In this condition no current flows. When either station requires to send, it operates its send-receive switch to the send position, thereby disconnecting the line from the receiver and connecting it to the transmitter. Operation of the transmitter then causes telegraph signals to be sent to the distant station. Fig. 7.14 (*a*) shows a single-current Morse key in which the back stop of the key is effectively used as a send-receive switch, whilst Fig. 7.14 (*b*) shows a double-current circuit in which the send-receive switch is separate from the transmitter, as for example in the case of the double-current Morse key and the send-receive switch of the Teleprinter No. 7.

Two-way Simplex Circuit. A two-way simplex circuit is a telegraph circuit consisting of two independent simplex telegraph circuits each arranged for operation in one direction only, one for transmission in one direction and the other for transmission in the reverse direction.

It will be clear that any of the single wire or loop

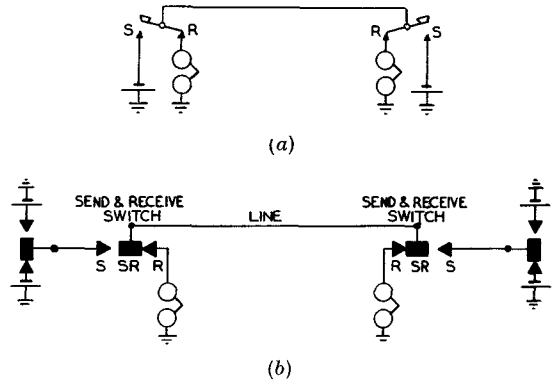


FIG. 7.14. SINGLE-WIRE SIMPLEX CIRCUIT USING SEND AND RECEIVE SWITCH

circuit arrangements already described for one-way simplex working can be adopted for two-way simplex working by providing a similar one-way circuit in each case for operation in the reverse direction. In two-way simplex working both channels can operate simultaneously, since from a signalling point of view they are independent of each other.

This method of working is employed extensively in the operation of point-to-point telegraph circuits. In recent years two-way simplex point-to-point circuits in the B.P.O. Public Telegraph Service have been steadily replaced, firstly by manually switched teleprinter circuits and now by automatically switched circuits in which connexions

are set up automatically by dialling. In both cases, however, the circuit condition when the switched connexion has been made is a two-way simplex circuit.

A two-way simplex circuit as employed by the B.P.O. on point-to-point public telegraph teleprinter circuits is shown in Fig. 7.15. In this case no local record of the message is required and the same teleprinter is used for sending and receiving at each end of the circuit.

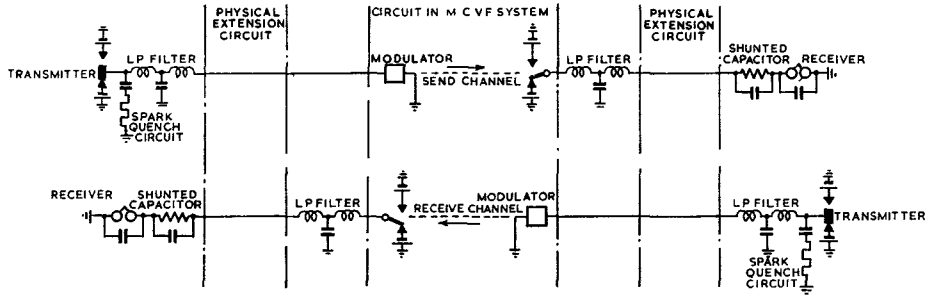


FIG. 7.15. 2-WAY SIMPLEX CIRCUIT USING V.F. TELEGRAPH CHANNELS AND PHYSICAL ENDS EMPLOYING DOUBLE-CURRENT D.C. SIGNALLING

Simplex Circuit with Local-record Facilities. It is often required that a local record should be taken of telegraph transmissions as a check that the message has been transmitted correctly and also to provide a permanent record at the transmitting end for filing purposes. This facility is almost invariably necessary when page teleprinters are employed. It is a standard arrangement on all B.P.O. teleprinter private wire and Telex installations.

A number of methods is available to provide local record facilities by connecting a local receiver or relay either in series with, or in leak from, the transmitter. One example of the series method has already been described and illustrated in Fig. 7.9 for closed loop working. Fig. 7.16 shows a number of other standardized methods. The circuits illustrated in Figs. 7.16 (*a*) and 7.16 (*b*) are similar in so far as the local record is obtained from a relay connected in the transmitting line. Fig. 7.16 (*a*) shows the arrangement in which a signalling battery is required only at one end of the circuit and is therefore suitable for central battery circuits. The transmitter at station X is connected for single-current signalling and operation of the transmitter causes single-current signals to flow through the line coil of the local record relay at station Y. The local record relay is biased for single-current operation by means of current flowing in the bias winding. The bias current is adjusted by means of the variable resistor $R.1$ to obtain optimum working conditions.

When the transmitter at X is idle no current flows in the A-wire, and the local record relay is therefore controlled by the current in the bias winding. The tongue of the relay is therefore actuated to its M contact. In this condition the transmitter at station Y, which is connected for double-current operation, extends negative battery via the M contact and tongue of the local record relay to the B wire of the line and thence, through the receiver at station X, to earth. When station X transmits, single-current impulses flow through the A wire of the line and actuate the local record relay, so causing double-current signals to be transmitted over the B wire to the receiving equipment at X. In addition, it will be noticed that the local record relay also repeats the signals transmitted from X as double-current signals to the receiver at station Y via resistor $R2$.

When station Y transmits, the double-current signals pass from the transmitting tongue via the M contact and tongue of the local record relay and then to the distant receiver via the B wire. In addition, a local record of these signals is obtained at station Y via the leak circuit from the tongue of the local record relay, through $R2$, to the receiving equipment at Y. Hence, the circuit provides simplex communication between X and Y, with local record facilities at each end of the circuit.

This circuit arrangement has been used extensively in the past in B.P.O. short distance teleprinter broadcast services. The circuit arrangement in Fig. 7.16 (*b*) has been similarly used for longer circuits, where double-current signalling was necessary to reduce the distortion of signals transmitted from the outstation, i.e. over the A wire. It will be noted that the only difference in the connexions and operation of this circuit, as compared with Fig. 7.16 (*a*), is that the transmitter

at station X is connected for double-current signalling, and therefore no bias winding is employed on the polarized local record relay at station Y.

Another variation of these two forms of obtaining a local record is the use of a local record relay at each end of a circuit instead of at one end only, and this method was employed on the early forms of B.P.O. Tariff "A" circuits, in which a phantom or a double-phantom circuit was used for the main line portion of the circuit between main terminal offices. This will be described later under "half duplex working."

When double-current signalling is used a simple leak circuit for a local record is possible using the send-receive switch as shown in Fig. 7.16 (*c*). This method is the present standard employed in the operation of the majority of B.P.O. teleprinter private wire circuits. It involves the use of double-current signalling at each end of the circuit and this is readily and cheaply provided by means of a small rectifier operated from a.c. mains or by a small rotary convertor operating from d.c. mains.

Double-current signalling is very worth while because of the improvements obtained in transmission characteristics, as compared with single-current signalling and also for the advantages derived from standardization of equipment. Referring to Fig. 7.16 (*c*), it will be seen that when the circuit is idle the transmitter at station X transmits a continuous negative voltage, via the A wire, to the distant receiving equipment via the send-receive switch at station Y. The transmitter at Y is similarly connected to the B wire and sends a continuous negative signal to the receiver at X. When X transmits, its send-receive switch is operated to "Send" during the signalling of each character and thus double-current signals are transmitted to the distant receiver at Y. At the same time, a local record of the signals is provided at X, since the receiver at X is connected to the transmitter via the leak resistor $R1$. Similar conditions occur at Y when the transmission is from Y to X. Hence, simplex communication between X and Y is available with local record facilities at each end of the circuit. This method of working is

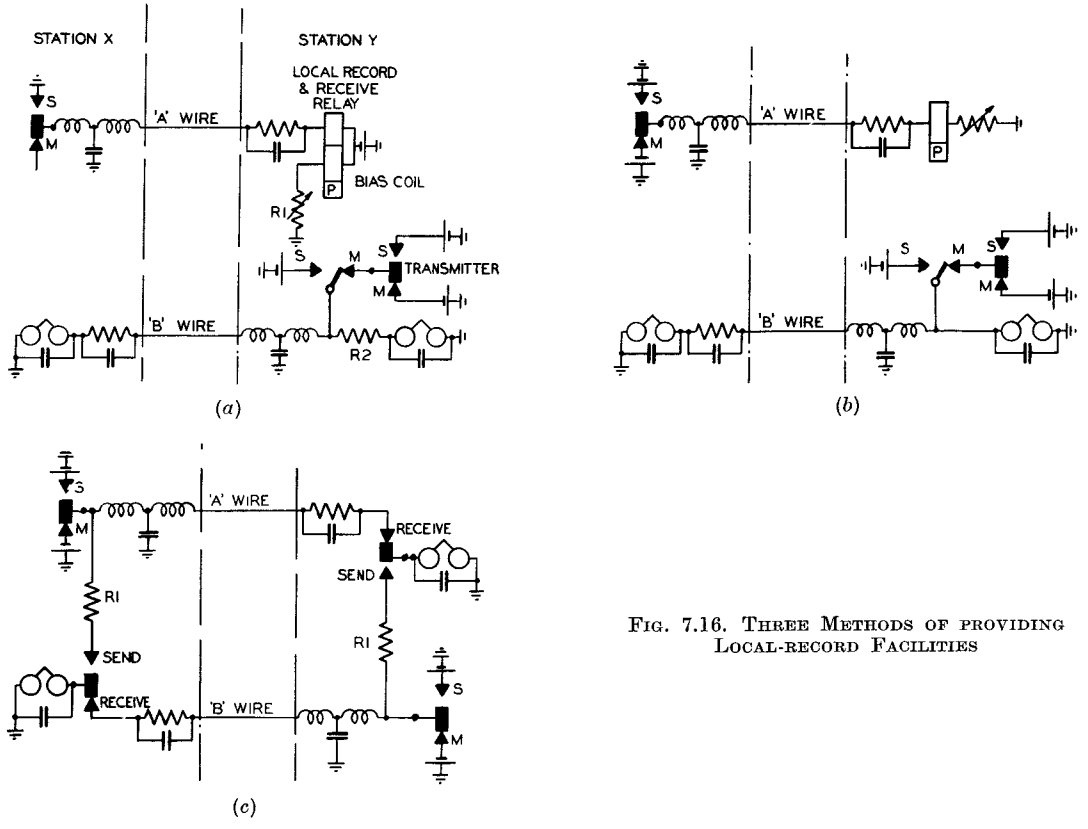


FIG. 7.16. THREE METHODS OF PROVIDING LOCAL-RECORD FACILITIES

very satisfactory and is cheaper in capital cost and maintenance than methods involving the use of a local record relay.

Duplex Working

Duplex working may be defined as "A multiple way system in which the circuit is arranged for

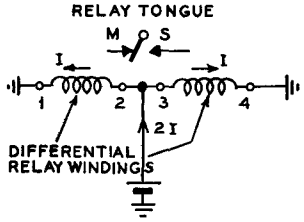


FIG. 7.17. DIFFERENTIAL RELAY ACTION

simultaneous operation in opposite directions over the same transmission path."

There are two basic methods of working duplex, namely—

(*a*) Differential Duplex and

(*b*) Bridge Duplex.

Single and double-current signalling can be employed in both systems and differential duplex can be operated in two ways, i.e.

(*a*) Combination Method and

(*b*) Opposition Method.

All these methods are equally applicable to Morse, synchronous and start-stop systems, and were at one time employed extensively in all parts of the world. The spread of M.C.V.F. methods of working has, however, largely superseded the need for increasing the traffic carrying capacity of circuits by duplexing. Differential duplex was mainly used for land-line circuits, and bridge duplex for submarine cable and very long land lines.

In order to work duplex it is necessary to fulfil the following transmission conditions—

(*a*) When the transmitting tongue at each end, *A* and *B*, of the circuit is resting on its marking contact the receiving relay at each end must be held to marking.

(*b*) When one transmitting tongue, say at *A*, is operated to spacing, the receiving relay tongue at *B* must move to spacing, whilst the receiving relay at *A* must remain at marking.

(*c*) When both transmitting tongues are moved to spacing, both receiving relays must also operate to spacing.

To understand the principle of operation of a duplex circuit, it is best to consider first the operation of a differential relay.

Consider Fig. 7.17, in which equal currents flow in opposite directions through two differential relay windings. Since the coils have identical characteristics, the currents will produce equal and opposite m.m.f.'s in the magnetic circuit of the relay. The resultant magnetic force on the armature due to these currents will thus be zero and so the armature will remain on the contact to which it was last operated, i.e. *M* in Fig. 7.17, provided the relay is side-stable. If a current were caused to flow through the relay coils in series, i.e. from tag 1 to 4, then the magnetic effect due to the two coils would be additive and the relay armature would move in one direction or the other, depending upon the direction of the current.

In the B.P.O. the standard convention for telegraph relays is that a current from a + battery, passing through the coils in the direction 2 to 1, or 4 to 3, causes the tongue of the relay to operate to its marking contact. Conversely, a current in the reverse direction will operate the tongue to its spacing contact.

Opposition Differential Duplex. Fig. 7.18 shows

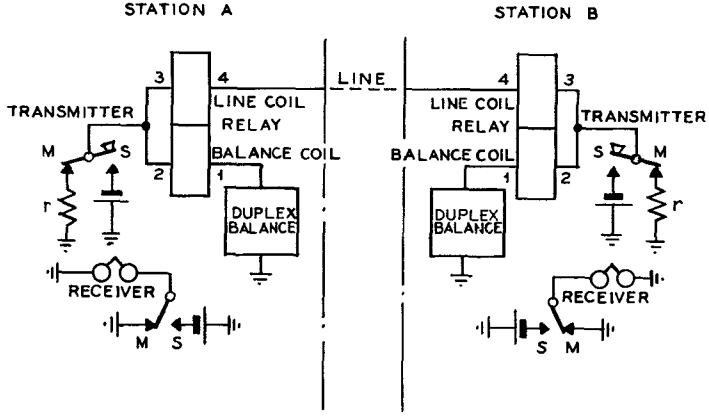


FIG. 7.18. SINGLE-CURRENT DIFFERENTIAL DUPLEX TELEGRAPH CIRCUIT—OPPOSITION METHOD

a simple form of opposition differential duplex circuit employing single-current signalling. The duplex balance is an electrical network made up of capacitors and resistors which simulate the electrical characteristics of the line and the distant receiving equipment. The resistors *r* are each equal to the internal resistance of the transmitting battery at each station.

When the transmitting key at *A* and *B* is at rest on its marking contact, no current flows in the

circuit and the receiving relay tongue rests on the marking contact M at both stations, under the control of a marking bias on each relay. When the key at A is operated to the spacing contact S, current flows from the transmitting battery at A to line and through the balance circuit at station A to earth. The electrical characteristics of the balance circuit at A are made equal to those of the series circuit formed by the transmitter and line coil at A, the line, relay line coil at B, resistor r and

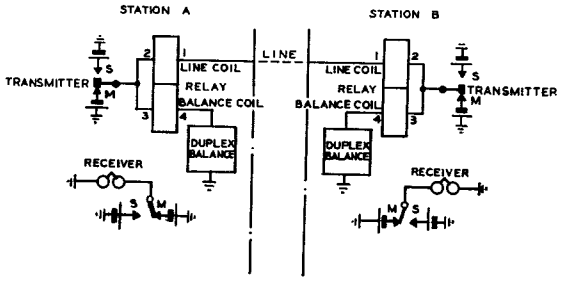


FIG. 7.19. DOUBLE-CURRENT DIFFERENTIAL DUPLEX TELEGRAPH CIRCUIT—OPPOSITION METHOD

earth return. The surges of current through the relay balance coil and the line coil of station A are therefore equal and opposite in effect. The receiving relay at A therefore does not operate. The relay at B, however, operates in response to the signal received from A through its line coil. Thus, signals transmitted from A are received at B. Conversely, signals transmitted from B are received at A.

When both keys are depressed no current flows in the line as the batteries at A and B, which are of equal voltage, are in opposition. Local currents do, however, flow in each balance circuit and cause the relay at A and B to operate to spacing. When the key at A is in transit, and therefore not making any contact, current from B flows through the two coils of relay A in series and then through the balance at A to earth. This current is half the normal value, but since it passes through the two coils of the relay at A, it will produce the normal magnetic effect and the response of the relay at A to the signal sent from station B will not be disturbed. The same considerations apply to the transmitter at station B.

It will thus be seen that when A and B transmit simultaneously the distant receiving relay is operated in accordance with the signals transmitted and so duplex working is possible with this circuit arrangement.

Single-current duplex working, in common with all single-current signalling systems, requires the receiving relay to be biased and this may necessitate meticulous adjustment of the relay, to counteract the effect of changes in battery voltage. Better performance is obtainable using double-current signalling, as there is less distortion and the circuit is less susceptible to false operation by interference currents.

Double-current Opposition Differential Duplex. Fig. 7.19 shows an opposition differential duplex circuit arranged for double-current signalling. Consider the case shown in Fig. 7.19 where both transmitters are in the marking position. The batteries at each station are of equal voltage. Thus, no current flows in the line or in the line coils of the relays. A marking current, however, flows in both balancing circuits, so the tongues of both relays are held in the marking position.

When the transmitting tongue at A moves to its spacing contact the current in the balance circuit at A is reversed, so tending to make the receiving relay at A space. Current is however now passing to the line, as the batteries at A and B are now placed in series-aiding through the line circuit. The line current is twice that flowing in the balance circuit, as the balance circuit has the same resistance as the line and distant receiving equipment. The effect of this line current on the line coil at A tends to make the receiving relay at A operate to marking. Since this force is twice that of the spacing force exerted by the current in the balance coil, the relay at A therefore remains operated to the marking contact. The current in the line windings of the relay at B is in the spacing direction and its value is twice that of the current in the balance circuit at B. The relay at B, therefore, moves over to its spacing contact. A similar action occurs when B sends a spacing signal to A.

When A and B both send a spacing signal to line, no line current flows but spacing current flows in each balance circuit and operates the receiving relays to their spacing contacts. When the transmitter at B is spacing and the transmitting tongue at A is in transit towards its marking contact, spacing current flows from B, through the line coil and balance coil of the relay at A, in series. Although the value of this current is half the normal balance current it now acts on two coils and therefore its effect is of the same value and sense as the normal balance current. The response of the receiving relay at A to the signal being sent from B is not therefore disturbed. At B, the current in the line coil under this condition is half that in the balance coil, so that the balance coil continues to maintain the relay in its spacing position until the transmitter at A reaches its marking contact. When this occurs, the relay at B operates to

marking, as already described. The reader will see from similar consideration of the other transit conditions that they do not upset the correct transmission of signals.

Differential Duplex Working: Combination Method. The combination method of differential duplex working is illustrated in Fig. 7.20. It will be observed that the transmitters at stations A and B

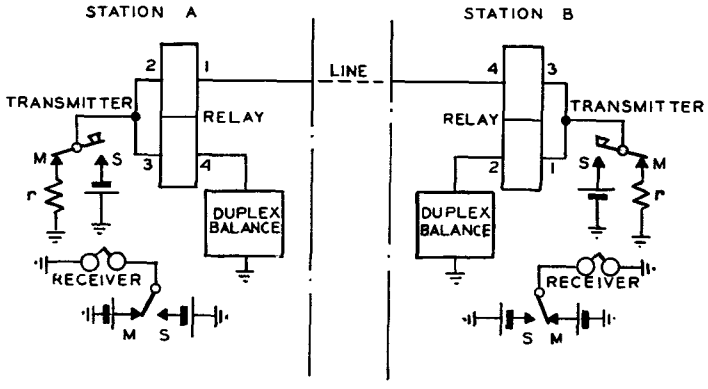


FIG. 7.20. DIFFERENTIAL DUPLEX TELEGRAPH CIRCUIT—COMBINATION METHOD

are connected for single-current operation but that at station A, negative battery is transmitted to line when the transmitting key is depressed; whereas at station B, positive battery is transmitted to line when the transmitting key is depressed.

When both transmitting keys are at rest, no current flows in the line or balance circuits and the receiving relay tongue rests on the marking contact M at each station under the control of the marking bias on the relay. When both transmitters are operated to spacing (i.e. S contact) the signalling batteries at A and B act in series-aiding, i.e. in combination in the line circuit. The value of the line current under this condition is therefore twice that which flows in the balance circuit. The effect of this current in the receiving relay line coil at each station preponderates over the effect of the marking bias and of the current flowing through the balance coil. Each relay, therefore, operates to the spacing contact S. When the transmitter at A is on its S contact, when that at B is on its M contact, then the current in the line and balance coil of the receiving relay at A will be equal and opposite in effect. The tongue of the relay at A will, therefore, be operated to its M contact by the marking bias on the relay. At station B, the line current will flow through the line coil and thence to earth through resistor r. The relay at B therefore operates to its spacing contact S.

Thus signals transmitted from A are received at B. Conversely, signals transmitted from B are received at A. When A and B transmit simultaneously it has been shown that the distant receiving relay is still operated in accordance with the signals transmitted, and duplex working is possible with this circuit arrangement.

The Balance Network. In all the foregoing duplex circuits the correct differential action of the receiving relay at each station, when it is transmitting, is dependent upon the balance circuit simulating the electrical characteristics of the line. It is not sufficient for the steady state current in the balance circuit to be equal to that in the line. The instantaneous values of the two currents must be equal, otherwise the receiving relay will be disturbed by the signals transmitted from the same station and duplex working would become difficult, if not impossible. If the line was very short it would be possible to use a resistance for the balance network but in long circuits, particularly long underground or submarine circuits, the effects of the capacitance of the line must be taken into account.

At the instant of connexion, or reversal, of a battery to such a line a current surge occurs due to the rush of current to charge the line capacitance. In a duplex circuit this surge flows through the line coil of the relay and would cause the relay to "kick" if a similar balancing surge were not also

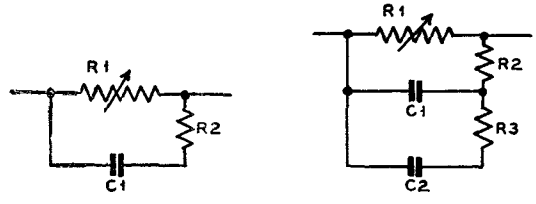


FIG. 7.21. DUPLEX BALANCE NETWORKS

allowed to pass through the relay balance coil and balancing network.

Fig. 7.21 (a) shows a basic network suitable for use as a balance circuit. The resistor $R1$ equals the resistance of the line circuit, whilst $C1$ simulates the distributed capacitance of the line and the distant receiving equipment. $R2$ delays the charge and discharge time of the capacitor $C1$. The longer the line, the longer the time taken for the current to reach its steady value, and therefore the longer must be the time taken to charge and discharge the capacitors in the balance network.

Fig. 7.21 (*b*) shows an enlargement of the basic network of Fig. 7.21 (*a*) by the addition of *R*3 and *C*2 to suit a longer line. It will be appreciated that *C*1 charges and discharges via *R*2, and *C*2 via *R*3 and *R*2. Thus *C*2, *R*3 increases the time constant of the circuit. This could be increased still more, if required, to suit any length of line by adding further arms to the network, e.g. *R*4, *C*3; *R*5, *C*4; etc.

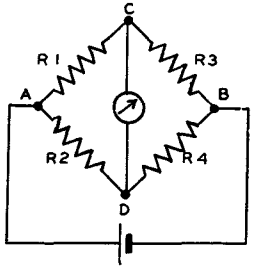


Fig. 7.22. Wheatstone Bridge Principle

In practical balance networks, some of the components are made variable to enable an accurate balance to be made and to adjust for small day-to-day variations in the line and equipment. The higher the speed of working a duplex circuit the more accurate the balance must be.

Bridge Duplex. The operation of a bridge duplex telegraph circuit is based upon the principle of the Wheatstone bridge.

Considering Fig. 7.22 which shows a simple Wheatstone bridge, it will be remembered that—

if $$R1 \times R4 = R3 \times R2$$

then the bridge will be balanced, and points *C* and *D* will be at the same potential so that no current will flow through the meter between *C* and *D*.

Fig. 7.23 shows the arrangement of a bridge duplex telegraph circuit in which the resistance arms *CE* and *CD*, and *FG* and *FH* are made equal.

The balance circuits, as in the case of differential duplex working, are adjusted to be equal in electrical characteristics to the line and distant receiving equipment. The receiving relay (or instrument) is connected, as shown, across points *E* and *D*, and *G* and *H* at station *A* and *B* respectively. When the transmitters are at rest on their marking contacts *M* no current flows. When the key at station *A* is operated to its spacing contact *S*, current from the battery divides equally at *C* between the resistance arms *CE* and *CD*. The potentials at points *E* and *D* are therefore equal, so that no current flows through the receiving instrument at *A*, which is therefore unaffected by the signals transmitted by *A*. The current through the resistance arm *CE* passes out to line to point *G* at station *B*. At *G* the line current divides; part flows through arm *GF* to earth and the remainder through the receiving relay and thence, via the balance and *HF* in parallel, to earth. The receiving relay at station *B* is therefore operated by a portion of the line current and thus signals transmitted from *A* successfully operate the receiving relay at *B*. Similarly, signalling currents transmitted from *B* operate the receiving relay at station *A* but, as the current divides equally at *F* through the equal resistance arms *FG* and *FH*, the receiving relay at *B* is not disturbed by signals transmitted by *B*.

Suppose that the transmitters at *A* and *B* are both operated to spacing then, as the voltage of the signalling battery is the same at each station, no current flows in the line as points *E* and *G* are at the same potential. The current at station *A* divides unequally at *C*, part flowing through *CED* to operate the receiving relay and part via *C* to *D*. At point *D* the currents unite and flow via the balance network to earth and thus back to the transmitting battery. The operation of the receiving relay at *B* is similar to that at *A*.

Thus, it will be seen that when *A* and *B* transmit simultaneously the distant receiving relay is operated in accordance with the signals transmitted and therefore duplex working is possible with this circuit arrangement.

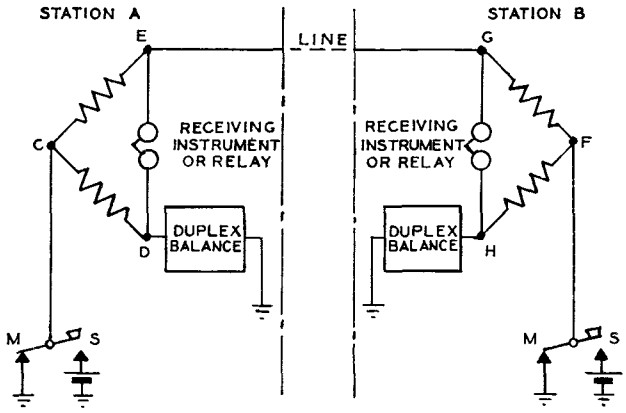


Fig. 7.23. Bridge Duplex Telegraph Circuit

When the key at *A* is in transit between its contacts, and assuming that *B* is transmitting a spacing signal, current from *B* divides at *E*, part flows through the arm *ED* to operate the receiving relay to spacing and the remainder flows through *EC* and *CD* in series. At *D* these currents unite and flow, via the duplex balance circuit, to earth, and thus back to the transmitting battery at *B*. The relay at *A* thus remains operated in accordance with the signalling condition transmitted from *B*,

despite the transit condition of the transmitter at A.

The reader will see from consideration of other transit conditions that they do not upset the correct operation of the circuit.

In the foregoing consideration of bridge duplex working, it has been assumed that the ratio arms of the bridge are equal. It will be appreciated, however, that this is not essential, because in a Wheatstone bridge a balance can be obtained provided $R1 \times R4 = R2 \times R3$ (see Fig. 7.22),

$$\text{i.e.} \qquad \frac{R1}{R2} = \frac{R3}{R4}$$

By analogy, therefore, the ratio of the arms CE and CD and FG and FH may also be varied, so long as the ratio of the line and balance circuits are suitably adjusted.

Alteration of the ratio of the resistance arms of the bridge circuit affects the value of the current transmitted to line and also the portion of the line current which flows through the receiving instrument. Thus in Fig. 7.23 if CE is reduced in proportion to CD, the portion of the line current which would flow through the receiving relay at A would be reduced.

In practical bridge duplex circuits it is usual to employ signalling capacitors in the resistance ratio arms of the bridge and a shunted capacitor in series with the receiving relay, as shown in Fig. 7.24. The signalling capacitors enable the line to be charged more rapidly during signalling and the shunted capacitor acts as a distortion correcting device.

Bridge duplex working is mainly used for long submarine cable circuits, etc., where the capacitance of the circuit is high. In such cases greater speeds of working can be attained with bridge duplex than is possible with differential duplex.

This advantage is mainly due to—

(*a*) The use of signalling capacitors.

(*b*) The use of a shunted capacitor in series with the receiving relay.

(*c*) In bridge duplex working the signals transmitted pass to line through ratio arms which are only resistors, whereas in differential duplex, the transmitted signals have to pass through the coils of the receiving relay which are inductive and thus increase the build up time of the signals.

Double-current Bridge Duplex. Bridge duplex circuits are normally worked with double-current or three condition cable code signalling. The basic circuit arrangement is identical to that already described, except that the transmitters are connected for double-current or three condition code signalling and the receiving relays are not biased.

Operation of Duplex Circuits in Telephone Cables. With the exception of long submarine telegraph cables the majority of telegraph circuits are provided by means of wires in telephone cables. When direct current signalling is employed over such circuits it is essential that a L.P. filter is inserted between the telegraph transmitter and the line to prevent the higher frequencies present in

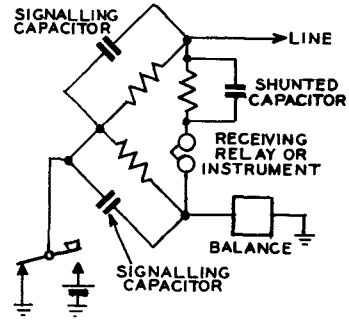


FIG. 7.24. BRIDGE DUPLEX TELEGRAPH CIRCUIT SHOWING USE OF SIGNALLING CAPACITORS AND SHUNTED CAPACITORS

the telegraph modulation from passing out to line and causing interference with adjacent speech circuits. The telegraph signalling voltages and currents must also be kept as low as practicable to reduce the interference.

Telegraph circuits which use an earth-return signalling circuit are particularly liable to produce interference and are themselves more subject to interference. In the latter case the interference has the effect of increasing the distortion of the telegraph signals and thus reduces the working margin.

These troubles can be largely eliminated in duplex working by operating the circuit on a loop basis. Both differential and bridge duplex circuits may be operated in this manner and the descriptions and diagrams already given in this chapter apply for loop working except that a wire is used in place of the earth return paths.

In loop working the circuit is insulated from earth and thus its operation is not affected by varying earth resistances or currents. Furthermore, as equal and opposite currents flow in the A and B wires of the line loop, interference to other circuits is practically eliminated and interference voltages induced into the wires of the loop cancel each other out.

An alternative method having similar advantages is that shown in Fig. 7.25, in which the B wire of the line is earthed at each end and thus acts as an earthed screen to the signalling A wire. In addition, a surge transformer is fitted at each station as

shown. Thus, when a surge current flows into the A wire the surge transformer produces an equal and opposite surge in the B wire, thus neutralizing the effect of the surge on other circuits.

It should be noted that unlike the previous differential duplex circuits so far described, which employed a two coil receiving relay, a relay having four coils is used in this case. In practice, on long circuits, two auxiliary coils on the relay are also often used in a Gulstad circuit to increase the sensitivity of the relay. For simplicity the G circuit is not included in Fig. 7.25. The four coils of the receiving relay are wound so as to be very accurately balanced in their electrical and magnetic characteristics.

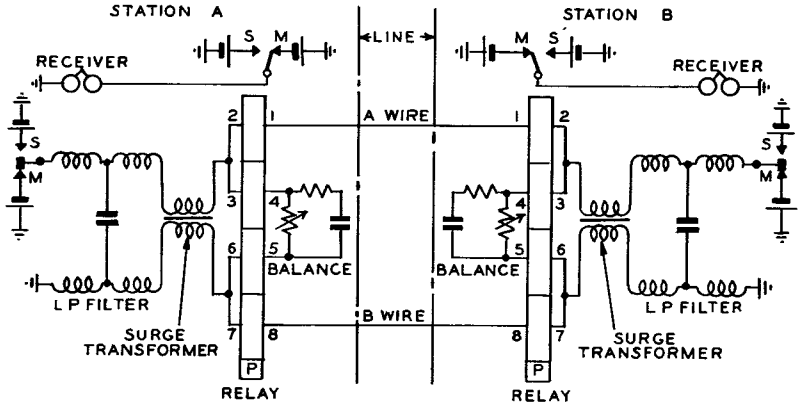


FIG. 7.25. DIFFERENTIAL DUPLEX TELEGRAPH CIRCUIT IN A TELEPHONE CABLE SHOWING USE OF LOW-PASS FILTERS AND SURGE TRANSFORMERS

Referring to Fig. 7.25 it will be seen that two coils of the receiving relay are connected in the duplex balance circuit and one coil is connected in series with the A and B wire of the line. The resistance of the balance is adjusted to be twice that of the A wire. When the transmitter at A and B is on the marking contact M, no current flows in the A wire, as the transmitting batteries act in opposition to each other. Both receiving relays are therefore operated to marking by the effect of the current in the balance circuit flowing in the relay coils 3–4, 5–6. Similarly, when both transmitters operate to space no line current flows and the receiving relays are both caused to space by their balance circuit current. If now the transmitter at station A is restored to its marking contact, then as the batteries at stations A and B are now in series-aiding in the A wire, line current flows. If we ignore for the moment the transient currents which flow and only consider the steady state current conditions on the relay, the position is as follows. The line current flowing in the A wire is four times that in the balance, because the voltage operating in the line is twice that in the balance, and the line resistance is half that of the balance circuit. At station A the effect of the line current acting on coil 1–2 therefore preponderates over the balance current acting on the two coils 3–4 and 5–6. The relay at A, which was previously spacing, therefore continues to space. Similarly, at station B the effect of the line current acting on coil 1–2 preponderates over the current in the balance acting on coils 3–4 and 5–6. In this case, however, the line current is in a direction which causes the relay to operate to marking, whereas previously it was spacing.

Thus, the receiving relay at B is operated in accordance with the signals transmitted from A and, conversely, the receiving relay at A operates in accordance with the signals transmitted from B. The circuit is therefore capable of duplex transmission. Reverting now to consideration of the transient conditions which occurred when the transmitter at B was spacing and A was operated from spacing to marking, the following action occurs. At the instant the transmitter at A operated to its marking contact, a surge of current flows from the transmitter at A through the primary winding of the surge transformer to the A wire and balance circuit. This transient current induces equal and opposite transients in the secondary winding of the surge transformer, and the resultant transient current, which flows in the B wire, and its associated line coils at stations A and B are in a direction which assists the correct action of the receiving relays at these stations. Furthermore, the transient currents caused to flow in the B wire neutralize the interference effect on other adjacent circuits of the transient line signals in the A wire. It should be noted with this circuit arrangement, that interference from earth currents or from circuits in the same cable will cause currents to flow over both the A and B wires in the same direction. Provided these currents are equal, and in practice they are, the effect on the receiving relay will be nullified, as the currents flow in the receiving relay coils 1–2 and 7–8 in opposite directions.

Half-duplex Circuit. The foregoing circuit arrangement was extensively used at one time in the operation of B.P.O. private wire teleprinter circuits. Phantom and double-phantom circuits

were employed for the main-line portion of the circuit. This method of operation was however abandoned in favour of the circuit arrangement shown in Fig. 7.26. The latter circuit does not require such an accurate duplex balance and was found to have greater working margin. It will be

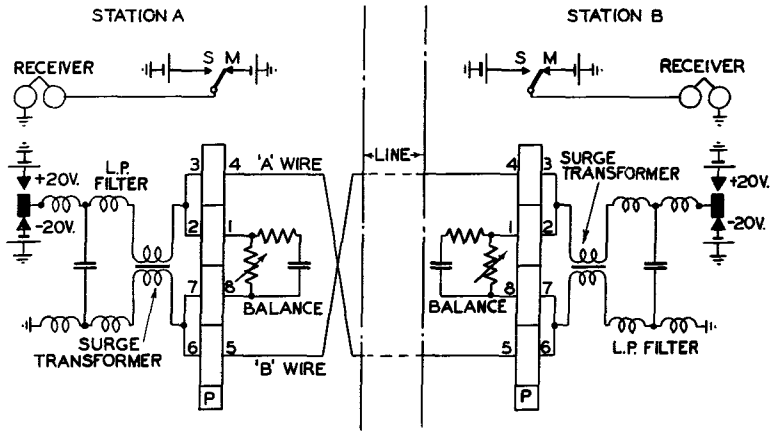


FIG. 7.26. HALF-DUPLEX TELEGRAPH CIRCUIT

observed that this circuit is similar to that of Fig. 7.25 except that at station A the A and B wires are crossed. Thus station A transmits to station B over the A wire and thence to earth via the receiving relay coil 5–6 at station B. Similarly, station B transmits to station A over the B wire and thence to earth through the receiving relay coil 5–6 at station A. The receiving relay at each station operates differentially, in so far as the effects of the signals from the transmitters of that station are concerned. Thus from a transmission

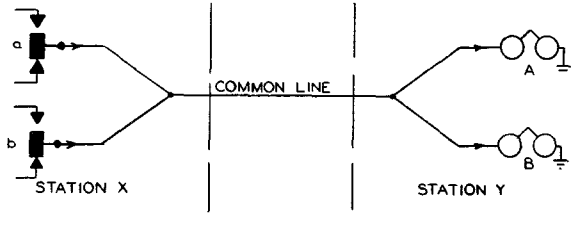


FIG. 7.27. DIPLEX TELEGRAPH CIRCUIT

point of view the operation of the receiving relay is controlled by the double-current signals received through its line coil 5–6. In effect the circuit is a two-wire simplex circuit.

The use of this circuit for private wire simplex teleprinter circuits having local record facilities is referred to in Chapter 16. The circuit is often called a "half-duplex circuit."

Diplex Working. Diplex working may be defined as a method of working in which common equipment is used for the simultaneous transmission of two messages in the same direction over a circuit. In diplex operation a common circuit is used to connect two stations X and Y as shown in Fig. 7.27 and, by the use of suitable circuit arrangements at each end, two transmitters a and b at X may transmit messages simultaneously to receiving equipments A and B respectively at Y. The basic circuit employed for a diplex circuit is shown in Fig. 7.28.

The receiving apparatus at Y consists of a polarized and a non-polarized relay connected in series with the line and earth. The polarized relay operates to marking or spacing, depending upon the direction of the line current received, i.e. it operates from double-current signals of a given magnitude determined by the sensitivity of the relay. The non-polarized relay requires a much greater current for its operation than that required by the polarized relay and thus, the double-current signals which normally operate the polarized relay are insufficient in magnitude to operate the non-polarized relay. The latter is only operated when the

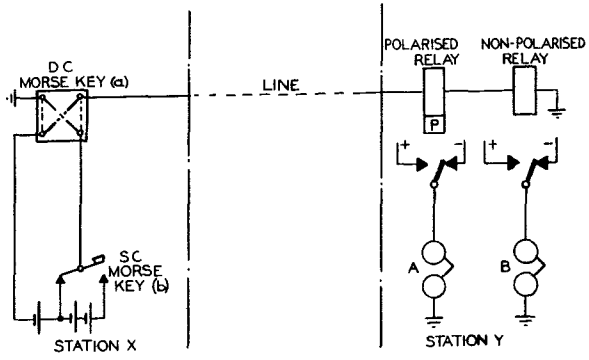


FIG. 7.28. PRINCIPLE OF OPERATION OF A DIPLEX CIRCUIT

magnitude of the line current is increased and when this occurs the operation of the non-polarized relay is independent of the direction of the current. At the same time, the operation of the polarized relay is not disturbed by the increased current. At the sending end of the circuit there are two transmitters, one of which reverses the current, so producing double-current signals, the other

increases the magnitude of the current. The principle of operation will be clear from a study of Fig. 7.28.

Quadruplex System. A quadruplex system is a multiple-way system in which the circuit is arranged for the simultaneous transmission of two messages in each direction over a single circuit. Quadruplex working is in effect a duplexed diplex system.

evident from the earlier description of diplex and differential duplex working.

In this method of working, the portion of the circuit employing double-current signals was known as the A-side, and the portion of the circuit operating with increased current (i.e. current increments) was known as the B-side. It will be observed from Fig. 7.29 (*b*) that when a

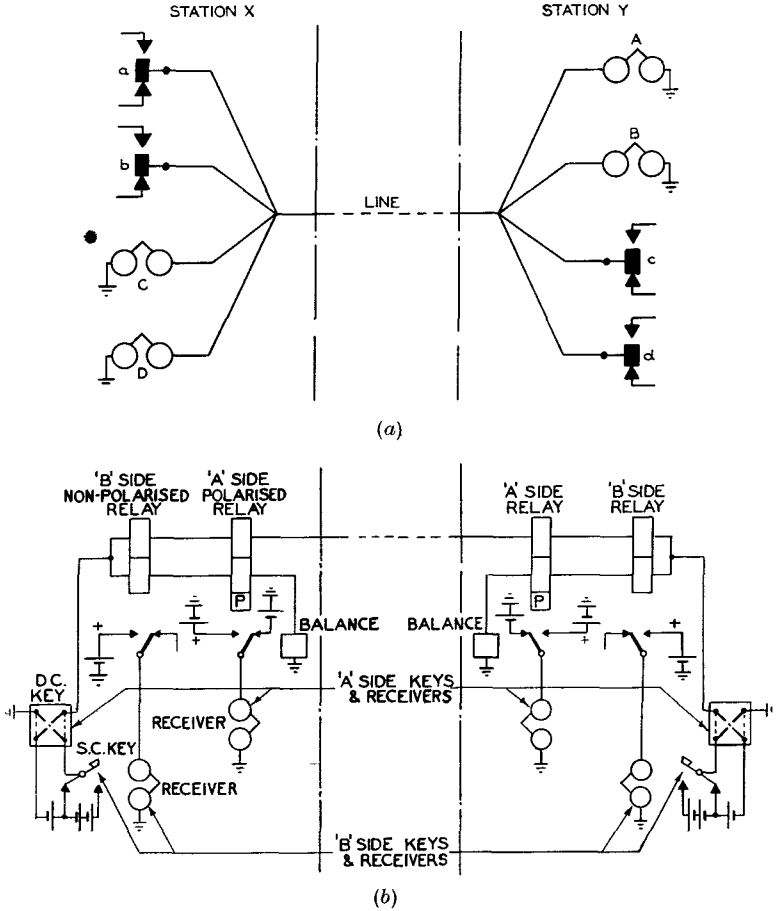


FIG. 7.29. PRINCIPLE OF QUADRUPLEX SYSTEM

In quadruplex operation, a common circuit is used to connect two station X and Y as shown in Fig. 7.29 (*a*), and the circuit arrangements enable two transmitters a and b at X to transmit simultaneously to two receivers A and B respectively at Y, whilst two transmitters c and d at Y transmit simultaneously to two receivers C and D at X. Fig. 7.29 (*b*) indicates the schematic circuit arrangement employed, from which it will be seen that the circuit is arranged as for differential duplex operation. The operation is therefore self-

transmitting key is passing from the back to the front stop that its signalling battery is entirely disconnected from the circuit. To avoid this a special key, having a make-before-break feature, was used to ensure that the front contact was made before the back contact was broken.

Another difficulty found in the operation of diplex and quadruplex circuits was known as the B-kick which occurred when the B-side relay was operated by a marking current and the current was then reversed by operation of the A-side key. The

reversal of current in the line cannot occur instantaneously owing to capacity effects and thus a short interval of time occurs during which the current in the non-polarized relay is insufficient to hold it operated to marking. The bias therefore pulls the tongue momentarily off the marking stop, so causing the received signal to be split. To overcome this difficulty the arrangement shown in

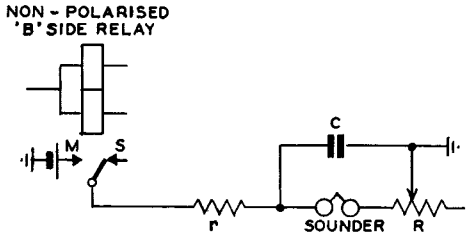


FIG. 7.30. USE OF CAPACITOR TO OVERCOME "B" KICK IN DIPLEX AND QUADRUPLEX WORKING

principle in Fig. 7.30 was adopted, in which during the time the non-polarized relay is operated, i.e. to the marking contact, the capacitor C is charged. When the relay is released the capacitor discharges through the receiving instrument, e.g. a sounder, and thus maintains the armature of the instrument in its operated position. The time constant of the circuit can be adjusted by suitable choice of the values of C and R to ensure that the sounder remains operated during the momentary breaks in the operation of the B-side relay during the period of reversal of the current in the line.

The resistor r reduces the value of the surge current and so reduces sparking and wear at the relay contacts.

Telegraph Repeaters. Due to the effects of line capacitance and inductance and in some cases leakance, e.g. in long overhead circuits, the strength of telegraph signalling currents is attenuated during transmission. The effect on the shape of the telegraph signal has already been explained in Chapter 5. It has been shown that whereas at the transmitter the nature of the current changes for each signal transit is abrupt, at the receiver these current changes occur more slowly. There is a finite build-up time for the current and the longer the circuit the longer it takes for the current to reach its steady-state value of $\frac{E}{R}$. If the line is sufficiently long and the signal elements short, then the steady state value may never be reached during successive signal elements. When this occurs the response of the receiver to the received signals is no longer uniform and the received signal is therefore distorted. If the distortion of any signal element is greater than the margin of the receiver, the signals will fail to be received correctly. In the limit, the received current may fail to reach a value which is great enough to operate the receiver for every element and this effect puts a limit to the speed, or length of line over which signals can be transmitted satisfactorily.

The function of a repeater is to overcome the effects of attenuation of the line signalling current. A repeater receives the attenuated signals at the end of a section of a line and re-transmits them at their original, or other desired current value, to the next section of the line. The repeater thus restores the abrupt nature of the signalling changes present in the original signal. It will be realized, however, that the repeater cannot correct for any time distortion which may be present in the received signals. If signals received by a repeater are distorted then the re-transmitted signals, although restored to full amplitude square modulations, will nevertheless, even with a perfect relay, have the same amount of time distortion as in the received signal.

Considering a line having negligible inductance and leakance, the maximum speed of signalling can be shown to be approximately proportional to $\frac{1}{CRl^2}$ where C and R are the capacitance and resistance per mile respectively and l the length of the circuit in miles. If the length of the line is halved, the maximum speed of signalling may be quadrupled. Thus, the maximum speed of operating a long circuit may be improved by inserting a repeater at its mid-point or a number of intermediate points.

In practice, lines have inductance and leakance and the receiving equipment is also inductive; fortuitous distortion is also present in the received signals. The simple relationship shown above therefore does not apply. Nevertheless, the maximum speed can be increased, or alternatively the line distortion reduced, by breaking the circuit into repeatered sections.

Figs. 7.31 and 7.32 show the arrangement of repeaters suitable for use respectively in two-way simplex and duplex circuits. From the diagrams it will be seen that the lines from the terminal stations terminate upon relays at the repeater station. These relays function as re-transmitting relays to the next section of the circuit. The attenuated signals are sufficiently strong to operate the relays and these in turn re-transmit the same, or any other required, battery power to the next section of line. Ample current strength to operate the relays at the terminal stations is thus maintained in the circuit. In practice the repeater is

often operated with a G circuit to increase its sensitivity.

Long distance d.c. telegraph circuits are rarely used nowadays except for submarine cables. In B.P.O. practice, d.c. repeaters were employed fairly extensively until recent years in phantom

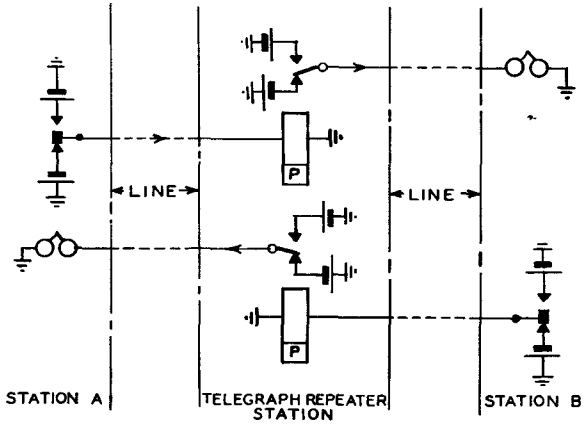


FIG. 7.31. USE OF TELEGRAPH REPEATERS IN A 2-WAY SIMPLEX CIRCUIT

and double-phantom circuits used for private wires but long distance land-line circuits and many short distance submarine circuits are now operated over M.C.V.F. telegraph systems and do not require telegraph repeaters.

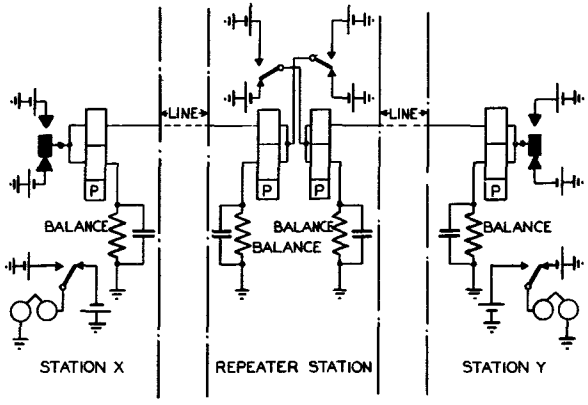


FIG. 7.32. USE OF TELEGRAPH REPEATERS IN A DUPLEX CIRCUIT

An application which is still common is a relay termination at the end of a long line to repeat the received signals to a teleprinter. In the latter case the repeater is fitted because its relay has much greater sensitivity than the teleprinter electromagnet.

Telegraph Broadcasting Systems. There is a considerable commercial demand for systems of communication which permit rapid distribution of messages from a central office to a number of outstations. Police administration frequently require to circulate quickly particulars of stolen cars, wanted persons, etc., as well as information of an administrative character. Other organizations, e.g. the Meteorological service, Ministry of Labour and News Agencies, where a community of interests exists between a central office and a number of subsidiary offices, have a considerable volume of broadcast traffic. A variety of teleprinter broadcast systems have been designed to meet the special requirements of such organizations and, while a wide range of facilities is provided in the various systems, the basic principle of the broadcast relay circuit is similar in all cases.

The basic broadcasting circuit—is shown in Fig. 7.33. The telegraph transmitter is connected in series with the coils of one or more telegraph relays, depending upon the number of lines to be included in the broadcast. Signals transmitted from the broadcasting transmitter therefore operate each of the broadcast relays simultaneously and the tongues of these relays repeat the signals to the receiving lines of the stations connected to the broadcast. The number of lines which can be connected to one

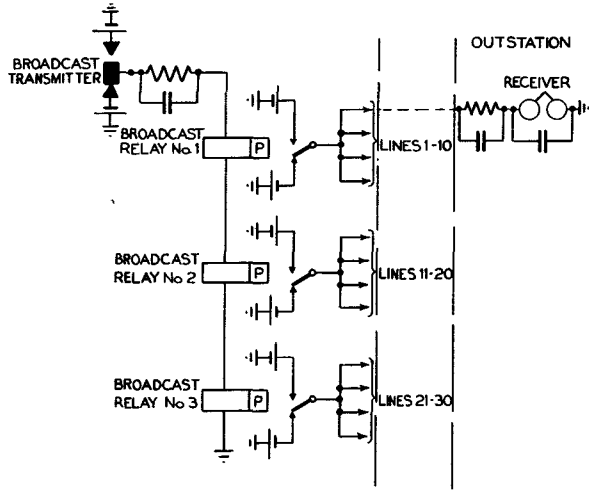


FIG. 7.33. PRINCIPLE OF TELEGRAPH BROADCAST SYSTEM

broadcast relay is dependent upon the current which can be safely carried by the contacts of the broadcast relay. Sparking at the relay contacts during signalling must be kept to a minimum, otherwise contact build-up and pitting will rapidly occur and lead to short-circuiting and destruction of the contacts, due to welding of the contacts and the tongue. The amount of sparking can obviously

be reduced by limiting the number of lines connected to each broadcast relay tongue and thus reducing the broadcasting current to be supplied. This, however, increases the number of relays to be employed when a large number of lines is to be connected in the broadcast system and therefore leads to an increase in the size of equipment as well as capital and maintenance costs.

Another consideration in this matter is the necessity to minimize the voltage drop which occurs in the signalling supplies to the relay contacts, otherwise this will give rise to an increase in the distortion of the signals. In practice, the best compromise is sought and each broadcasting relay is loaded with the maximum number of lines possible without causing undue sparking.

One arrangement standardized for teleprinter circuits is shown in Fig. 7.34. Each relay will supply a maximum of ten lines which may be physical circuits or V.F. channels. The more onerous condition is when physical circuits are connected, as in this case each line must be fitted with a low pass filter to prevent interference to adjacent telephone circuits in the cables. In this case the capacitance of the line and filter is high, thus leading to high surge currents through the relay contacts during signalling.

The battery feed to each contact is connected from a fuse through a protective resistor, PR of 40 Ω; this limits the surge current to a safe value and protects the contacts from welding if a short circuit of the tongue and contacts occurs in service. Sparking at the contacts during signalling is limited by the spark-quench circuits shown connected in Fig. 7.34 between the relay tongue and contacts.

Another important feature in the design of the broadcasting circuit is the inclusion of a special resistor bulb in series with each broadcasting receiving line. Its resistance when carrying the normal signalling current is low but this increases rapidly if the current rises due to fault conditions. Thus, in the event of a full earth occurring on a receive line the resistance of the bulb limits the fault current to a safe value which enables the other lines to continue to receive the signals without much increase in distortion. The bulb in the faulty line glows brightly, so indicating the fault condition immediately.

In some broadcasting systems the lines are set up permanently for broadcast reception and for this type of network a broadcast relay unit is fitted at conveniently situated points throughout the network with lines radiating from each. Transmission from the broadcasting office is then repeated via the other broadcast units to each receiving point. Any number of receiving points may be so connected in a broadcast so long as the number of lines in tandem from the broadcasting office to any receiving point does not exceed the transmission limit.

Supervisory signalling is usually required in a broadcasting network to enable acknowledgment of reception to be given. In addition it is usually necessary to provide facilities to enable outstations to transmit to the Head Office both for inward traffic and for the purpose of asking any

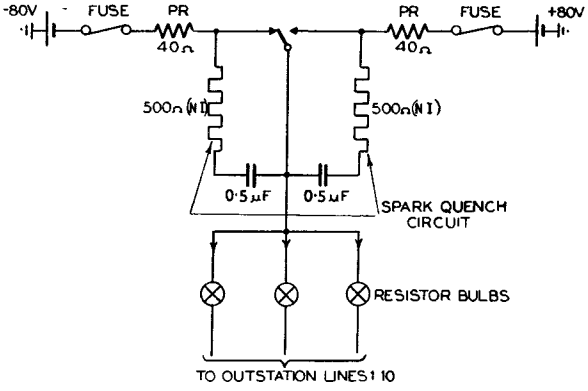


FIG. 7.34. PROTECTIVE ARRANGEMENTS FOR TELEGRAPH BROADCAST RELAYS AND LINES

questions arising from broadcast messages received. In these cases a broadcasting switchboard is used. Various types of switchboards are employed for this purpose depending upon the number of lines, supervisory arrangements and the flexibility required for selective broadcasting to certain outstations. The types of switchboard provided to meet various requirements in B.P.O. services are more fully described in Chapters 8 and 16.

Omnibus (or Conference) Systems. An omnibus system, or conference system as it is sometimes called, is one in which several subscribers are connected together so that any one subscriber can transmit signals simultaneously to all the remaining subscribers. Only one subscriber must transmit at a time otherwise the different signals would mutilate each other. It is therefore usual to arrange a precise order in which the subscribers should acknowledge signals, to reduce the possibility of two subscribers transmitting at the same time.

The basic circuit arrangement employed in an omnibus system is shown in Fig. 7.35 which illustrates an omnibus system interconnecting four subscribers. The current in the subscribers' sending lines is made equal by adjustment of the resistors $R1$, $R2$, $R3$ and $R4$. The current in the bias coils of the relay is spacing and its value is adjusted so

that its effect is just balanced by a marking signal flowing in any three line coils. When the circuits are all idle a continuous marking signal is transmitted from each subscriber and this flows through one coil of the conference relay to earth. The marking current in three line coils balances the spacing bias and therefore the relay is operated to its marking contact due to the preponderating marking effect of one coil. When one subscriber transmits a spacing signal the relay operates to

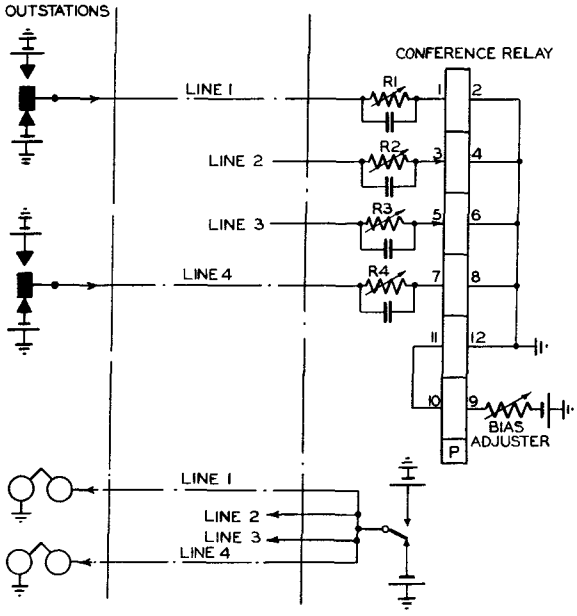


FIG. 7.35. PRINCIPLE OF TELEGRAPH CONFERENCE (OMNIBUS) SYSTEM

$T2$ of relay 2 to all receiving lines. Similarly, if any subscriber on lines 5–8 transmits then relay 2 repeats double-current signals to all the receiving lines. As before, only one subscriber can transmit at a time otherwise the signals will be mutilated.

If less than eight lines are required, the spare line coils of the relays are connected to negative battery, i.e. they have a permanent marking signal in them.

The protective arrangements for the contacts of

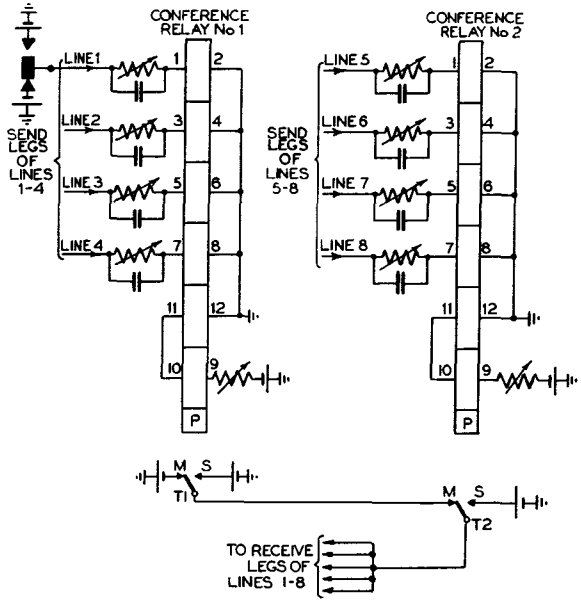


FIG. 7.36. METHOD OF COUPLING TWO TELEGRAPH CONFERENCE RELAYS

spacing due to the preponderating spacing effect of one coil.

The relay tongue is connected to all the subscribers' receiving lines in parallel. Hence when all circuits are idle a continuous marking signal is transmitted to each subscriber's receiver. When signals are transmitted from one subscriber the conference relay repeats the signals to all the other subscribers connected to the relay and also gives a local record back to the transmitting subscriber.

If more than four subscribers are required, then another conference relay is added as shown in Fig. 7.36. It will be seen that when all the circuits are idle both relays are operated to marking and relay tongue $T2$ extends a continuous marking signal to all receiving lines from the marking contact and relay tongue $T1$. If only one of the subscribers on lines 1–4 transmits, relay 1 repeats double-current signals via contact M and tongue

a conference relay have not been shown in Figs. 7.35 and 7.36 but they are generally similar to those already described for a broadcast relay and are needed for the same reasons.

Spark Quench Circuits. When an inductive circuit carrying current is suddenly broken a back e.m.f. is generated, due to the stored electromagnetic energy, which tends to maintain the current flow. If the inductance in the circuit is high then the back e.m.f. may be considerable and this is commonly the case in telegraph circuits due to the presence of electromagnets of the receiving instruments, line filters and relays. If special precautions are not taken the back e.m.f. produced will cause a severe spark, or arc, at the point at which the circuit is broken. This will cause contact wear and transfer of contact material tending to produce a crater in one contact and a pip on the other. The irregularities so produced on the

contact faces increase the contact resistance and, if the working gap is small, the effective gap is progressively reduced and may cause the contacts to bridge and so become inoperative. In extreme cases on double-current contacts this effect may lead to short-circuit and welding between the marking and spacing contacts through the tongue. When make contacts are operated, "bounce" is

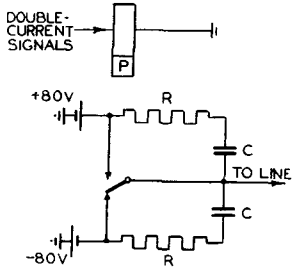


FIG. 7.37. SPARK QUENCH CIRCUIT FOR RELAY CONTACTS

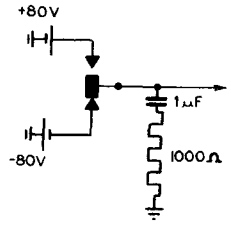


FIG. 7.38. SPARK QUENCH CIRCUIT FOR TELEPRINTER TRANSMITTER CONTACTS

very undesirable because the successive breaks of the circuit which occur during the bouncing are accompanied by sparking.

To reduce the harmful effects of sparking a spark quench circuit is always provided on relay and transmitter contacts in telegraph circuits and other contacts breaking inductive loads, e.g. teleprinter governor contacts. The basic method employed is to provide a relatively low impedance local circuit across the contact gap by means of a capacitor and resistor.

Fig. 7.37 shows a typical arrangement for a $\pm$ 80 volt signalling relay. At the instant of break, the back e.m.f. produced in the circuit, causes the capacitor across the breaking contacts to be charged up through its series resistor. This limits the instantaneous voltage which appears across the contact gap and thus reduces the tendency to spark. A damped oscillation occurs and the energy in the line and equipment is dissipated harmlessly in the resistance of the circuit and spark quench. It will be seen from Fig. 7.37, that the spark quench capacitor across the contacts which are open is fully charged. Thus, if a resistor were not provided in series with the spark quench capacitor, then due to the discharge of the capacitor, there would be a heavy current flow at the instant the contacts "made" which would tend to weld the contacts. The resistor connected in the spark quench capacitor circuit limits this discharge current to a safe value.

The values of C and R vary for different circuit conditions. Furthermore, if the signalling supply is of low impedance, the arrangement shown in Fig. 7.37 may be replaced on earth-return circuits by a single spark quench circuit, serving both contacts and connected between the transmitting tongue and earth. The latter arrangement is the standard employed on B.P.O. teleprinter transmitters. See Fig. 7.38.

Radio Interference Suppression

It can be shown mathematically that any waveform, other than a sine wave, is composed of two or more sine waves added together. In this way a square wave may be shown to consist of a fundamental sine wave having a frequency equal to that of the square wave, plus a series of harmonics up to *infinity*, the amplitude of the harmonics being inversely proportional to their order. Similar analyses can be made of other non-sinusoidal waveforms. Thus any current which is caused to change very rapidly, e.g. due to telegraph signalling or the commutator, or governor, of an electric motor, contains frequencies which extend throughout the spectrum used for radio and television services and is thus a potential source of interference to these services. The amplitudes of any particular frequencies in the current flowing in the interfering source will depend to a large extent upon the radio frequency characteristics of the device, i.e. distributed inductance and capacitance, rather than upon the order of the harmonics concerned.

Propagation of Interference. Nearly all devices that cause radio interference are connected to a power or signalling supply by two or more wires in which, therefore, radio-frequency currents will flow. Taking the simple case of an electric motor

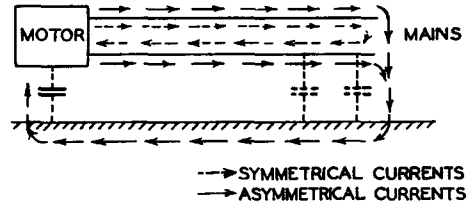


FIG. 7.39. RADIO-FREQUENCY CURRENTS IN AN ELECTRIC MOTOR CIRCUIT

connected by two wires to a mains supply, then during operation the radio-frequency currents produced may flow symmetrically and asymmetrically as shown in Fig. 7.39. It will be seen that the asymmetrical currents flow outwards along both wires in parallel, the return circuit being via earth and the capacitance of the motor to earth. It should be noted that the connexion of an earth wire to the motor frame materially reduces the impedance of the asymmetrical current path and

hence increases the current. The symmetrical currents flow along one wire and return via the other and will not, therefore, produce any appreciable external field if the two leads are correctly balanced and terminated. This condition however does not obtain in practice and consequently an asymmetrical component is developed.

The interference currents may either be radiated by the wiring in the vicinity of the source ("direct radiation") or be conveyed some distance along the supply wires ("mains borne") and radiated near to the receiving aerial. In general, the low radio-frequency currents, i.e. those in the long and medium wave-bands, can be conveyed considerable distances along the mains whereas the higher television-band frequencies suffer considerable attenuation. On the other hand, the radiating efficiency of comparatively short lengths of cable is high at television frequencies and correspondingly poor at low frequencies. As a result, low-frequency interference is primarily mains borne and high-frequency interference is primarily directly radiated by wiring close to the source.

Principles of Suppression. The object of suppression is to reduce the radio-frequency (R.F.) currents flowing externally to the interfering device and is achieved by providing a low impedance shunt-path back to the source or a high impedance series-path in wiring leading away from the source.

The physical and electrical dimensions of the inductors and capacitors used and their position in the circuit depend on the frequency concerned, the mechanical construction of the interfering device and its associated wiring. Detailed discussion of all these features is beyond the scope of this book but the following points should be noted—

(*a*) Shunt capacitors are most effective when the impedance of the source and the impedance of the supply circuit is high, whereas inductors are most effective where impedances are low.

(*b*) The maximum value of capacitor used may have to be restricted by safety considerations, particularly where connexion between a.c. mains and exposed metal frames are concerned.

(*c*) Inductors are only practicable for comparatively small currents; they become very bulky and expensive when currents in excess of 5 amps are involved.

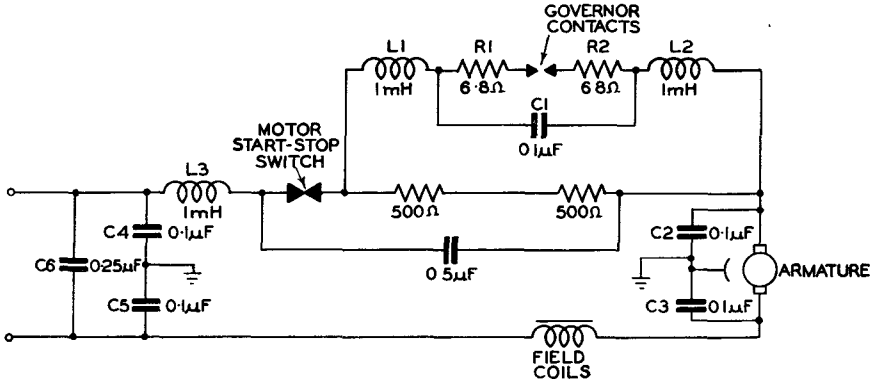


FIG. 7.40. RADIO INTERFERENCE SUPPRESSION OF TELEPRINTER MOTOR AND GOVERNOR CIRCUITS

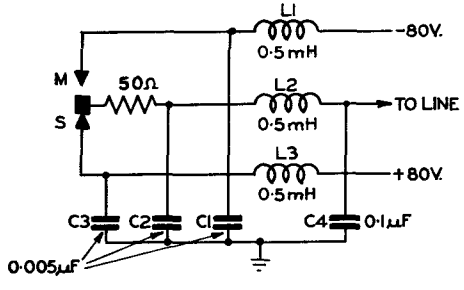


FIG. 7.41. RADIO INTERFERENCE SUPPRESSION OF TELEPRINTER TRANSMITTER CONTACTS

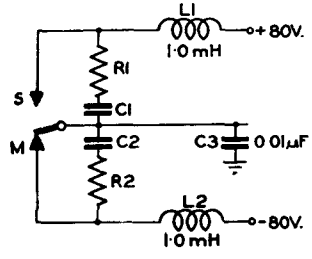


FIG. 7.42. RADIO INTERFERENCE SUPPRESSION OF A TELEGRAPH RELAY

(*d*) Capacitors should be placed so that the large circulating R.F. currents flowing through them are not coupled closely with other wiring.

(*e*) Inductors should be placed so that input and output wires are well separated.

(*f*) The value of capacitance used varies from 1 μF (where safety permits), to about 100 pF for suppression of frequencies between 150 kc/s to 100 Mc/s. The values of inductance used for similar frequencies range from 2–3 mH to 10 μH.

Two important practical examples of the application of the foregoing principles will now be examined in some detail to illustrate typical methods adopted in B.P.O. practice for telegraph transmitters, motors, governors and relays.

Radio-interference Suppression of a Teleprinter No. 7.

(*a*) *Suppression of the Motor and Governor* (Fig. 7.40 refers). Since some suppression components are common to both the governor and motor the motor circuit will be considered as a whole. Interference from the motor governor circuit is of considerable amplitude, as comparatively large changes of current are involved. The low impedance shunt path is provided by $C1$ connected across the governor contacts and the high impedance series path is provided by 1 mH, 1 A inductors $L1$ and $L2$. These components are fitted above the teleprinter base-plate and as close to the governor as possible. The function of resistors $R1$ and $R2$ is to reduce the surge current which flows when the contacts remake and discharge capacitor $C1$.

Capacitors $C2$ and $C3$ provide a low impedance shunt path for interference currents generated by the motor commutator and are fitted on the brush mountings inside the motor. Some series impedance is provided by the field coils of the motor in one lead and by the 1 mH inductor, $L3$, in the other lead. Both these components are also in the series circuit of the governor.

Capacitors $C4$, $C5$ and $C6$ are fitted to the supply leads at the tag block, beneath the base-plate, where $L3$ is also mounted.

(*b*) *Suppression of the Transmitter Contacts* (Fig. 7.41 refers). A similar arrangement to that used in the motor circuit is adopted for the transmitter contacts, though in this case the shunt capacitors are connected to the machine frame. Both shunt and series elements have smaller values than those used in the motor circuit and are fitted beneath the base-plate, immediately below the transmitter contacts.

(*c*) *Suppression of the Send-Receive Switch Contacts.* The suppression arrangements used in the send-receive switch circuit are identical with those used for the transmitter contacts and are mounted similarly beneath the base-plate.

The complete suppression arrangements for a Teleprinter No. 7, as described above, provide adequate suppression over the range 200 kc/s to 70 Mc/s, although no components designed specifically for high frequencies are fitted.

Radio-interference Suppression of a Telegraph Relay (Fig. 7.42 refers). The suppression of a telegraph relay follows the same general lines as already described. The arrangements used in a typical case are as follows. $R1$, $C1$ and $R2$, $C2$, shown in Fig. 7.42, form the normal spark-quench circuits. For radio-interference suppression, high series impedance in the mark and space contact leads is provided by $L1$ and $L2$, with low shunt impedance $C3$ providing adequate suppression in the tongue circuit. The whole relay is enclosed in an earthed metal screen and the suppressor components are fitted inside this screened enclosure.

The foregoing arrangements provide adequate suppression over the range 200 kc/s to 70 Mc/s.

With the increasing use of higher frequencies for radio services there is a possibility that the suppression arrangements at present employed on telegraph equipment will be inadequate at frequencies above the present television band. For this purpose additional suppression in the form of miniature non-dust cored inductors, fitted very close to the sources of interference, will be required.

CHAPTER 8

MANUAL SWITCHING TELEGRAPH SYSTEMS

In its simplest form a telegraph circuit provides the means for transmitting written information from one fixed point to another and such a circuit is known as a point-to-point circuit. If we consider two towns A and B, to facilitate the interchange of business and social messages between them there will be a demand for telegraph service. The service provided must be quick and reliable

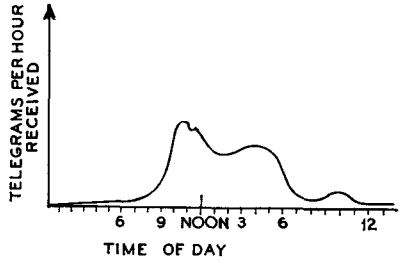


Fig. 8.1. Typical Daily Traffic Graph

and as cheap as possible and so account must be taken of a number of factors which will now be discussed. In the simple case being considered, the needs of the Public Telegraph Service could be met by the provision of one or more point-to-point telegraph circuits between the two towns—the number of circuits required being dependent upon the amount and incidence of the traffic. Messages will of course have to be sent in both directions but for the purpose of the present discussion only the traffic from A to B need be considered as similar considerations apply to the traffic from B to A.

Traffic Flow. Clearly during the night few telegrams will be received for transmission from A to B whereas during the morning there will probably be many and a peak load will occur. During the lunch period a lull is to be expected and in the afternoon there will be another peak in the traffic, although usually this will be smaller than the morning one. This is illustrated in Fig. 8.1 which shows a typical graph of the telegrams received per hour plotted against the time of day. It is found in practice that this rise and fall in the traffic flow is remarkably regular from day to day, though sporting events or local and national crises of various kinds will at times cause irregularities.

Number of Circuits Required. If the average time required for the transmission of a telegram be taken as one minute, then a single circuit could theoretically dispose of $60 \times 24 = 1{,}440$ telegrams per day. If the daily average of telegrams from A to B is 1,000 then it is clear from Fig. 8.1 that the great majority of them will be originated between 9 a.m. and 6 p.m. and hence if only one circuit from A to B were used there would be a large accumulation of telegrams during the peak period. Thus although all the messages would be transmitted within 24 hours the great majority would be subject to considerable delay. To avoid this more circuits have to be provided and the number chosen has to be an economic compromise between the peak load delay and the increased cost in lines, equipment and operating staff which the extra circuits would entail. It may be that as many as twenty circuits would be required between A and B.

Need for Flexibility. During the peak period adequate staff must be available at B to dispose of the traffic received over these twenty circuits, whereas at night a single telegraphist would probably be able to attend to all traffic on these circuits and that from other centres as well. In doing this she would have to move about from instrument to instrument as the calls came in. This could be avoided if only a few of the lines from each place

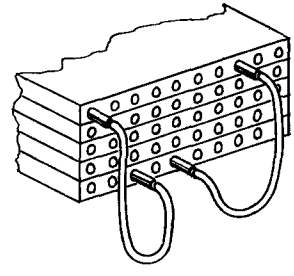


Fig. 8.2. Simple Concentrator

were used during the slack periods and if the instruments for these few could be restricted to a few positions in the same section of the operating room. This is done in practice by means of a "concentrator" which is a device on which incoming lines and terminal instruments are terminated and by means of which the terminal instruments are connected to the lines as required.

Simple Concentrator. Fig. 8.2 shows a possible arrangement of such a concentrator. Both the lines and the instruments are terminated on jacks and

by means of double-ended cords any line may be connected to any instrument. Thus during peak traffic periods all the lines may be provided with instruments and during the slack periods the few lines that are required may be allocated instruments which are in the most convenient places for staffing. Another incidental advantage of a concentrator is that if a terminal instrument becomes faulty the line may readily be switched to another instrument.

This form of concentrator is limited in its scope as the changes have to be carried out to a fixed time-table or by special co-operation between the supervisors of the offices concerned.

More about Traffic Flow. The graph in Fig. 8.1 shows the general trend of traffic flow but, if we were to consider the actual number of telegrams received from minute to minute during the peak period, we should find it to be very variable. Fig. 8.3 shows a curve typical of what might be expected. The point to notice is that although the average rate of flow is relatively large the actual flow at any particular time may be large or small and is constantly changing. Thus we shall see that it is only for relatively short periods that all the lines will be simultaneously using their terminal instruments. This means that if instruments and telegraphists are permanently allocated to these lines they will not be fully occupied and such use of staff and equipment is wasteful.

If the traffic curves for all the groups of circuits

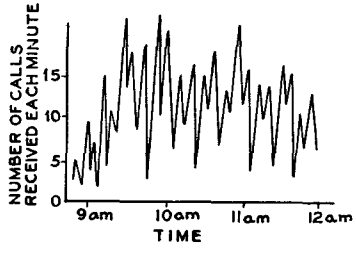


FIG. 8.3. GRAPH SHOWING NUMBER OF CALLS IN HAND DURING PEAK PERIOD

terminating in one office are considered together, the traffic peaks of all the groups are most unlikely to occur simultaneously and may be assumed not to do so. Thus if the total number of circuits entering a particular office from a number of towns is say, 150, we should find in practice that not more than perhaps 80 were ever simultaneously engaged even during the peak hour. If it can be arranged that an incoming line is provided with an instrument only when it actually needs one the total number of instruments required will be substantially less than the total number of lines and so a saving is made in instruments and telegraphists. Moreover there is a consequential saving in accommodation space which is an important economic consideration.

This type of concentrator, which will now be described, possesses the further advantage that the operator is able to distribute the traffic evenly between the telegraphists who are on duty, thus improving the overall traffic efficiency.

Concentrator with Calling Facilities. So that the concentrator operator may know when a line

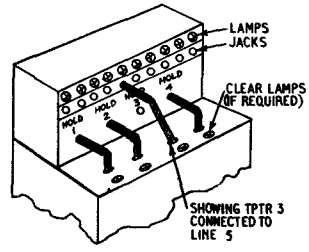


FIG. 8.4. LAYOUT OF SMALL CONCENTRATOR WITH CALLING FACILITIES

requires an instrument each line is provided with a calling device and the lighting of a lamp in association with the line jack is the device usually adopted. Fig. 8.4 shows the layout of a small concentrator of this type. The incoming lines are terminated on jacks arranged in rows and each jack has immediately above it a calling lamp. The receiving teleprinters (or other instruments) are terminated on cords and plugs which are normally inserted in "hold" jacks when the teleprinters are not in use.

The circuit principles of the concentrator are shown in Fig. 8.5. Negative battery from resistor $R1$ passes to line via $L3$ and the tip conductor springs of the jack and holds the distant teleprinter in its normal rest condition. This teleprinter in turn sends negative battery to line to pass via the ring conductor springs of the incoming jack, rectifier $MR1$ and $L2$ to earth. The rectifier shunts the coil of relay L sufficiently to prevent its operation. The receiving teleprinters are held marking by the negative battery from their own transmitting contacts, this being returned via the hold jack.

Telegraphist Calls. To call the concentrator operator, the distant telegraphist sends a series of space-bar (or other character) signals and during the positive elements of these signals the rectifier $MR1$ is no longer an effective shunt of relay L. Hence relay L operates to the first positive element and locks via its $L1$ contact and the auxiliary springs of the line jack. $L2$ and $L3$ cause the signals to be returned to the calling teleprinter which is here assumed to be of a type which has no local record via the send-receive switch. On seeing

the signals returned the caller knows that as yet the call is unanswered. *L4* lights the calling lamp* associated with the line jack and *L5* sounds the "night-alarm" buzzer if the night-alarm key is operated, as it is only when the concentrator is left unattended.

Operator Answers. The concentrator operator now takes the plug and cord of a disengaged instrument position from the hold jack where it has been accommodated and inserts it into the jack of the calling line. The breaking of the inner springs of the line jack releases the relay *L* and the line is now connected directly to the instrument. *L4* puts out the calling lamp and the night-alarm buzzer is stopped by *L5*. Thus the necessary transmission conditions are established.

Where the number of terminal instruments is small and they are located near to the concentrator the receiving telegraphist will be able to advise the concentrator operator to break down the connexion or will do this herself. When the plug is removed from the line jack it is replaced into the hold jack to maintain holding conditions on the local instrument, which is then available for use on any other line.

Use of Clearing Signals. When there is a large number of receiving instruments or where for some reason they cannot be located near to the concentrator, it is necessary to have a clearing signal so that the concentrator operator may know when to break a connexion. To provide this facility the dotted connexions shown in Fig. 8.5 will be required in addition. When the plug is inserted into the line jack in answer to a call, relay *X* operates from the earth on the sleeve of the jack. *X1* lights the "call and engaged" lamp at the teleprinter table thus informing the telegraphist there is a message to receive. On completion of the message, the telegraphist momentarily presses the "clear" button so operating relay *Y* which locks via *Y2* and *X2*. *Y1* puts out the call and engaged lamp and also lights the clear lamp which is associated with the cord. *Y3* sounds the night-alarm buzzer if required. The concentrator operator then knows that the call is completed and replaces the cord in the hold jack. Thus relay *X* is released and *X2* in turn releases relay *Y*. *Y3* stops the night-alarm buzzer.

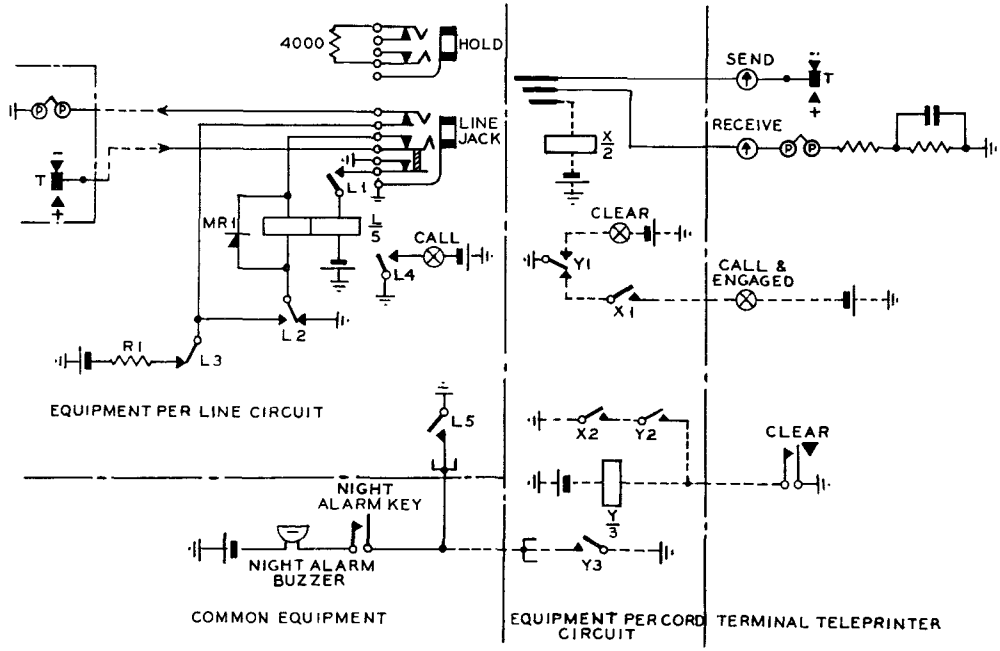


FIG. 8.5. CONCENTRATOR WITH CALLING AND CLEARING FACILITIES

Teleprinter Ancillary Concentrator System

With the concentrator just described every incoming call was distributed to its particular termination by means of the concentrator operator. At large offices more than one operator would be

* As 6 V lamps are, in general, used for all calling and supervisory lamp circuits a 6 V supply is required. Otherwise all the batteries used in this chapter may be assumed to be ± 80 V. For details of power supplies see Chapter 14.

necessary, though some relief could be obtained by switching the busiest lines to instruments for long periods. In the Teleprinter Ancillary Concentrator System the need for concentrator operators is avoided by making each telegraphist act as operator as well. The tendency of the earlier concentrators to create a bottleneck on the incoming traffic is thus avoided and the system was much used in the B.P.O. for the public telegram service prior to the introduction of manual and automatic teleprinter switching.

Circuit Operation. The circuit principles of the Teleprinter Ancillary Concentrator System will now be described. Fig. 8.6 shows the equipment associated with the line, whilst Fig. 8.7 shows that associated with a telegraphist's position. As soon as a telegraphist sits at a position, the position staffed key (*KPS*) is operated and *KPS*1 lights the green position staffed lamp so bringing to the

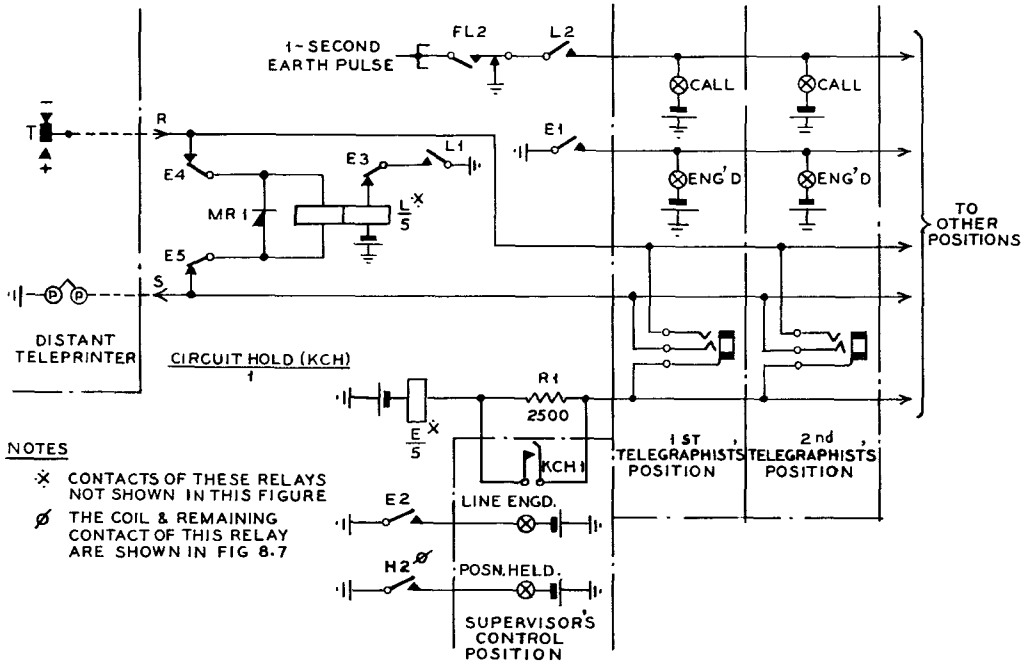


FIG. 8.6. LINE CIRCUIT (TELEPRINTER ANCILLARY SYSTEM)

Each telegraphist's position is provided with a panel of jacks on which all the incoming and outgoing lines in that office are terminated. Associated with each jack are two lamps, one to show when the line is engaged and the other to give a calling signal. Each position also has a cord circuit by means of which the teleprinter is associated with the lines as required. To enable a supervisor to obtain a ready indication of the adequacy of staffing, each position is also provided with two large indicating lamps, a green one which lights when the position is staffed and a red one which lights when the position is engaged with a call.

To make an outgoing call the telegraphist simply plugs into the circuit required, having noted that the engaged lamp is not lit, and sends space-bar calling signals. When a call is received, a calling lamp lights at every position in the receiving office and the first telegraphist to plug-in will take the call.

Call Received. When the distant end calls by sending space-bar signals, relay *L* operates (as was described for the previous concentrator). *L*1 locks relay *L* via *E*3. *L*2 extends an earth from *FL*2 to light each of the calling lamps associated with that line.

Telegraphist Answers. When a telegraphist picks up her plug and puts it into the calling jack, relays *PE* and *H* are placed in series with the resistor *R*1 and relay *E*. Relays *PE* and *E* operate but the current is too small to operate the relay *H* (the use of relay *H* will be explained later). *E*1 notice of the supervisor that the position is available for traffic. Normally in each line negative battery from the distant teleprinter is returned via *E*4, *MR*1 and *E*5 to hold that teleprinter. Relay *L* is unaffected owing to the shunting action of the rectifier *MR*1.

lights all the engaged lamps, so that no other telegraphist will answer the circuit nor try to use it for an outgoing call. *E*2 lights the engaged lamp on the supervisor's control panel. *E*3, *E*4 and *E*5 ensure that relay *L* releases, so putting out all the calling lamps. At the same time the return of the calling signals is stopped and the caller knows the call has been answered. *PE*1 causes the red position engaged lamp to be lit in place of the position staffed lamp and the supervisor is made 6 sec. If we assume for the moment that the uniselector wipers were resting on contact No. 1 when relay *L* operated, then *L*4 will also have operated relay *FA* from the earth on contact 1 of the uniselector arc No. 1. *FA*1 locks relay *FA* to earth via *L*5, and *FA*2 prepares a circuit for relay *FL*. When the uniselector wipers reach contact No. 6 (i.e. in 30 sec time), an earth from arc No. 2 is extended via *FA*2 to operate the relay *FL*, which locks via *FL*1 and *L*5. *FL*2 (see Fig. 8.6)

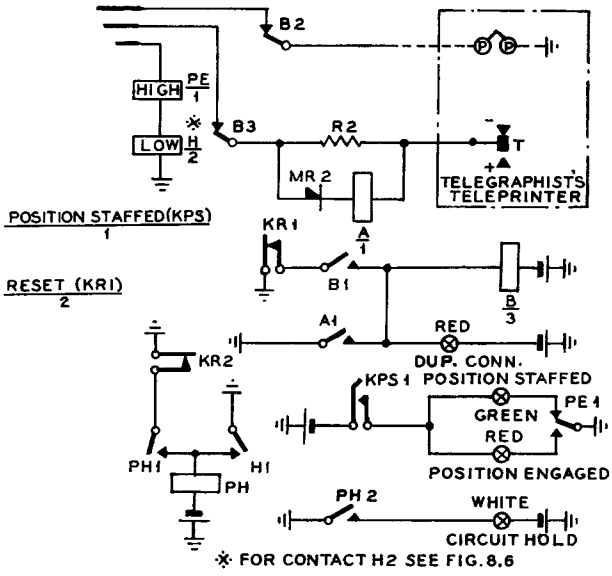


FIG. 8.7. TELEGRAPHIST'S CORD CIRCUIT (TELEPRINTER ANCILLARY SYSTEM)

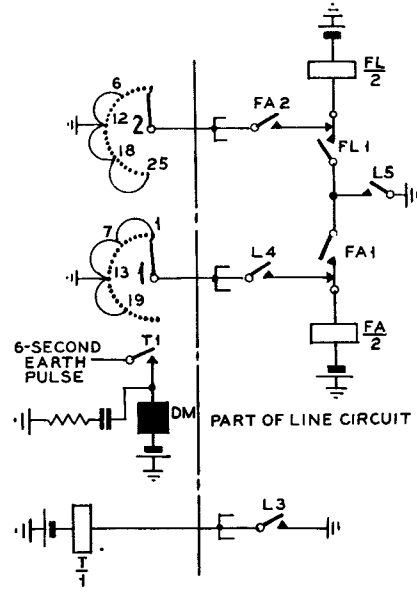


FIG. 8.8. CONTROL CIRCUIT FOR CALL LAMP FLASHING (TELEPRINTER ANCILLARY SYSTEM)

aware that that position is taking traffic. The tip and ring of the plug are connected respectively to the telegraphist's teleprinter receiver and transmitter and hence signalling conditions are established.

Delayed Answering. To guard against a calling signal being left unanswered at busy periods when several calling lamps may be glowing simultaneously, the calling lamp is arranged to flash intermittently if it is still unanswered after a period of from 30 to 60 sec and the telegraphists are instructed to give priority of answer to flashing lamps. The circuit of this facility is shown in Fig. 8.8 which is supplementary to Fig. 8.6.

When a call originates, besides the operations already described, *L*3 operates relay *T* and *T*1 extends a six-second intermittent earth pulse to the drive magnet of a uniselector. This causes the wipers of the uniselector to rotate one step each replaces the normal earth for the calling lamps by a one-sec interrupted earth pulse which therefore causes the lamps to flash. 30 sec is the minimum time delay before the lamps are made to flash; had the uniselector been resting on contact No. 2 when the line first called, then relay *FA* would not have operated until contact 7 was reached. This would mean that relay *FL* would not have operated until contact 12; hence the total delay would be 60 sec. Thus the exact time before flashing begins varies according to the position of the uniselector at the instant of calling, but will not be less than 30 sec nor more than 60. It should be noted that the uniselector is common equipment and serves all the line circuits.

Duplicate Connexion Circuit. Normally the engaged lamp prevents another operator from plugging into a circuit that is already engaged. Since, however, each circuit calls at all positions

simultaneously there is a considerable chance, especially during slack periods, of two operators plugging into the same calling circuit simultaneously. When this occurs it is arranged that the first operator to transmit causes the lighting of the "duplicate connexion" lamp in the position of the other.

The conditions that arise when two cords are in the same line are illustrated in Fig. 8.9 which shows a portion of two telegraphists' circuits plugged into the same line. If it be assumed that the telegraphist in the first position transmits first, then during the positive element of the first teleprinter signal a current will flow as indicated by the arrows in Fig. 8.9. In the first position $MR2$ prevents this current from operating the relay A, but in the second position the rectifier has the opposite effect and relay A operates. Thus, referring back to Fig. 8.7, $A1$ operates relay B and lights the duplicate connexion lamp. $B1$ locks relay B under control of the springs $KR1$ of the "reset" key, and $B2$ and $B3$ prevent the telegraphist (who did not transmit first) from interfering with the other telegraphist's signals. On seeing the duplicate connexion lamp, the plug is withdrawn and the reset key (KR) is operated momentarily to release relay B and restore the position to normal.

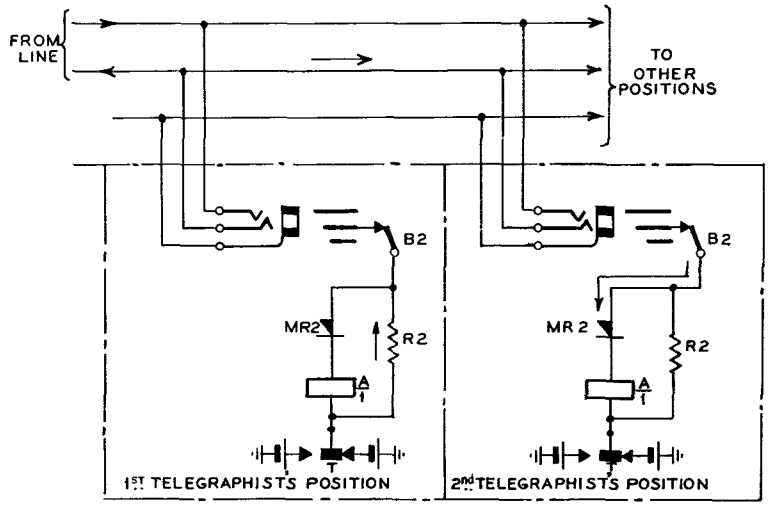


FIG. 8.9. DUPLICATE CONNEXION CIRCUIT (TELEPRINTER ANCILLARY SYSTEM)

Circuit Hold Facility. When during busy periods the supervisor finds there is an accumulation of traffic for one particular distant office, it is more efficient to hold a circuit to that office and appoint one operator to dispose of all traffic that has accumulated. To advise the operator using that circuit not to clear, the supervisor operates the "circuit hold" key (KCH)—Fig. 8.6—associated with that line. This short-circuits the 2,500 Ω resistor $R1$ in the sleeve circuit of that line and so increases the current flow, with the result that relay H operates. $H1$ operates relay PH which locks via $PH1$ and the reset key. $H2$ lights the "position held" lamp in the supervisor's control panel. $PH2$ lights the circuit hold lamp, so advising the telegraphist not to clear. The subsequent release of the circuit hold key by the supervisor and the momentary operation of the reset key (KR) by the telegraphist, releases relays H and PH and restores the cord circuit to normal. Clearing then takes place as usual.

Small Concentrator for Subscribers. To satisfy the needs of commercial users who may rent a small number of private lines radiating from a central office but who do not wish for economical reasons to rent more than one or two teleprinters at that central point, a concentrator can again be used. A typical small concentrator suitable for terminating up to five lines and one or two teleprinters will now be described. Interconnexion is effected by means of keys and the circuit is shown in Fig. 8.10.

In the rest condition of the circuit the local teleprinter A sends negative battery via the $KA1$ and the $KA3$ springs of each line, to hold its own electro-magnet to marking. Local teleprinter B is similarly held via KB springs. In each line circuit, negative battery passes from resistor $R1$ via $KB2$ and $KA2$ to the various send lines and so holds the distant teleprinters to marking. In each line also the marking current normally received on the R wires, passes to earth via $R2$ and the rectifier which shunts the relay L.

When the telegraphist at the distant end of, say, line No. 1 calls by sending space-bar signals the relay L operates and $L1$ lights the calling lamp. It should be noted that in this circuit the calling relay L is not locked. The rectifier, which shunts relay L, renders it slow to release and, although it receives current only during the start and third signal elements, it holds until the end of the stop signal before releasing. Thus the calling lamp does not give a steady glow as in the circuits described earlier but flashes intermittently. From an operating viewpoint this is a disadvantage as a steady lamp is more easily seen. Owing, however, to the complexity of the equipment required in M.C.V.F. lines they are more prone to short, transient

interruptions than direct current metallic lines. Where calling relays are provided with locking circuits, such transient conditions will cause false calls and consequent inconvenience. For this reason non-locking calling signals are generally to be preferred for circuits provided by means of V.F.

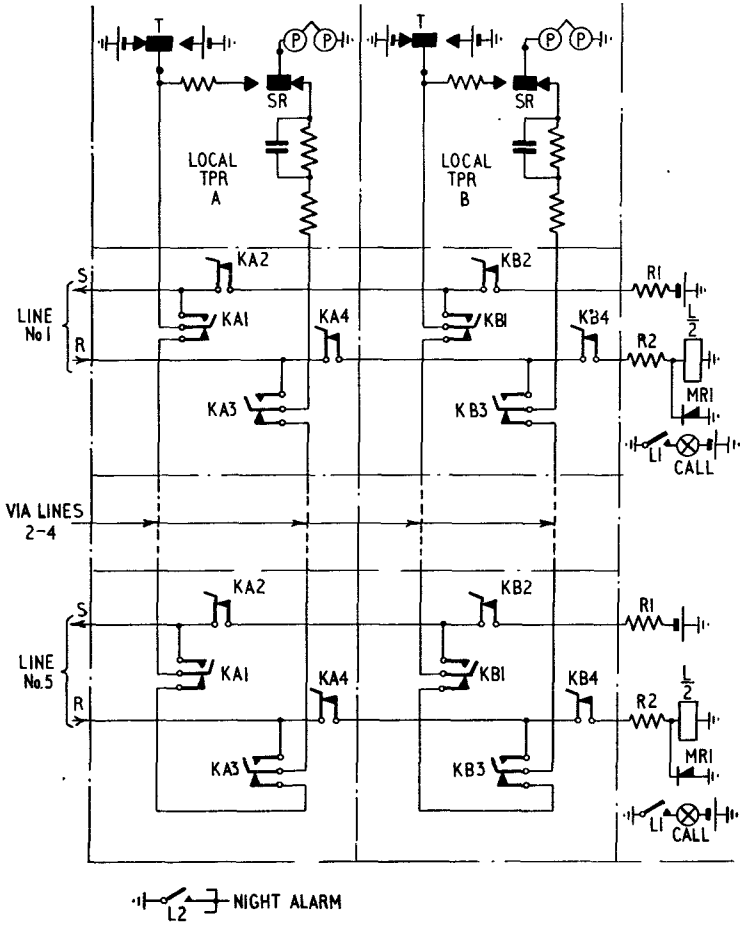


FIG. 8.10. SMALL CONCENTRATOR FOR SUBSCRIBERS

telegraph channels and locking circuits for the metallic lines.

Referring again to Fig. 8.10 we see that an operator at the concentrator may now associate the calling line with the local teleprinter *A* by operating the connecting key *KA* associated with the first line. *KA*1 connects the local teleprinter transmitting springs to the send wire of line No. 1, and *KA*2 disconnects the normal holding current. *KA*3 connects the local teleprinter receiving electro-magnet circuit to the receive wire of line No. 1, and *KA*4 disconnects the calling relay *L*. Thus the lamp flashing is stopped and transmission conditions are set up. Similarly, had the key *KB* been operated the line would have been switched to the local teleprinter *B*. When the message is completed the key *KA* or *KB* of the line in question is restored to give the original conditions again. No clearing signals are necessary as the local teleprinters are located near the concentrator. For slack periods a night alarm buzzer is available.

Retransmission and the Need for Through Switching. All the switching devices so far described have been of the concentrator type which enable a number of point-to-point circuits from one main office to be selectively connected to any one of a number of local instruments. Using systems of this type it is necessary for any message from one out-office to another to be retransmitted at the Head Office. Similarly, in more complex networks of point-to-point circuits, any message which has to be sent from one office to another with which it is not directly connected must be transmitted to an intermediate office for retransmission to its destination. Depending upon the configuration of the network this process may involve retransmission of the same message at several intermediate offices before it reaches its destination. For example in Fig. 8.11 several towns in the U.K. are shown connected in a hypothetical network of point-to-point circuits. In this case the volume of traffic is such as to justify point-to-point circuits only as shown, with the result that messages between Dundee and London have to be retransmitted at Edinburgh, whilst messages between Plymouth and Dundee have to be retransmitted at both London and Edinburgh.

Retransmissions not only lead to delay in getting the message through but are also wasteful of operating time and message forms, whilst the liability to errors in transmission is increased owing to the use of additional operators and instruments.

Another important point to observe is that any question concerning a received message has to be retransmitted back through as many offices as were involved in forwarding the original message. This laborious and costly process is often quite intolerable

when quick question and answer communication is vital.

The need for retransmissions can, of course, be avoided by the provision of a point-to-point circuit from each office to every other office in a network but such provision can rarely be justified economically when the network is large. Point-to-point circuits in a network are provided only between those offices which have a sufficient volume of traffic between them, whether this be originating or terminating or retransmitted.

Where retransmitted traffic would otherwise be appreciable it is desirable to be able to interconnect remote offices by a simple switching operation at an intermediate office, or offices, and thus, for the duration of the message, to give direct communication facilities between the originating and destination offices. This avoids retransmissions and so reduces the overall transmission time and the possibility of loss or error and enables instant acknowledgment of receipt to be given which is a great advantage in many cases.

When one office is connected to another by two or more circuits in tandem it is essential that the cumulative distortion of the switched connexion should be within the margin of the receiving machine. Furthermore, the instruments at the various offices must be capable of inter-working instantly without the need for special or meticulous adjustments.

Both these requirements are readily satisfied by modern telegraph circuits and instruments. The introduction of M.C.V.F. telegraph systems as the standard method of providing long telegraph circuits, enables circuits to be provided over almost any distance with low signal distortion and great stability. This allows switching networks to be built up permitting as many as five channels to be interconnected to establish a call between any two offices. An even greater number of channels can be interconnected if regenerative repeaters are inserted at suitable points. Similarly, the teleprinter, with its typewriter keyboard, high receiving margin and absence of difficulties in speed control and synchronizing, is ideally suited as an operating instrument in switching networks.

These two prime factors have had a decisive effect in the development of the many diverse forms of switching networks which exist today. In fact it was not until these devices had been widely introduced that switching systems permitting connexion of one long telegraph circuit to another on national and international networks could be developed on any appreciable scale.

The circuit principles of a number of well-known and typical types of manual teleprinter switchboards will now be described.

Single Position Manual Switchboard

The type of teleprinter circuit mainly used commercially is the simplex circuit. This permits

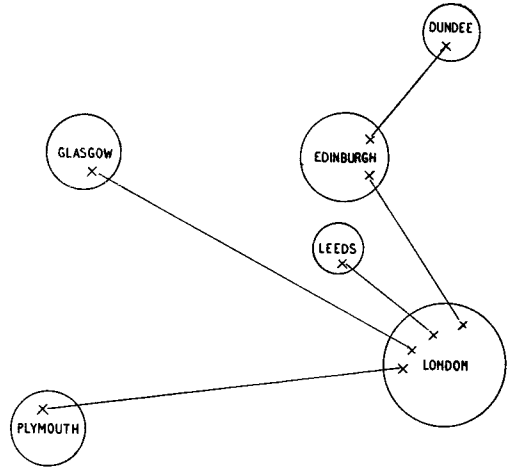


FIG. 8.11. TYPICAL NETWORK OF POINT-TO-POINT CIRCUITS

transmission in either direction, but not simultaneously. Further, a local record of the message is generally provided by the sending teleprinter and besides being of assistance to the operator during sending, the local record is usually required as a file copy.

A typical single position manual switchboard is shown in Fig. 8.12, and its basic requirements are that—

1. It shall provide a means of terminating the station lines which are to be switched. The most common arrangement is to terminate them on jacks and in Fig. 8.12 these may be seen in three horizontal rows of ten in the left hand panel.

2. The station telegraphist shall have a means of calling the switchboard operator when a connexion is required. This necessitates that the telegraphist shall send a calling signal and that this shall cause a calling lamp to light above the appropriate jack at the switchboard.

3. The switchboard operator shall have the means of communicating with the calling station by teleprinter, so that the call may be answered and the line required ascertained. Connexion to the subscriber is made by a cord and plug.

4. The calling line may then be connected to the called line. This is done with a second cord, the two cords and the associated equipment being termed a "cord circuit." Ten such cord circuits

may be seen on the shelf in Fig. 8.12 whilst Fig. 8.13 shows a typical layout.

5. When the call is completed, a clearing signal sent by the station telegraphists shall light clearing lamps in the cord circuit, so that the switchboard operator may know when to break down the

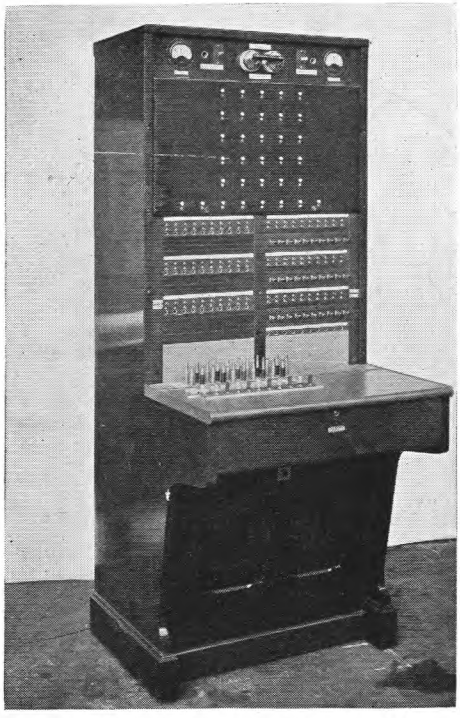


FIG. 8.12. TYPICAL SINGLE POSITION MANUAL TELEPRINTER SWITCHBOARD
(By courtesy of H.M. Postmaster-General)

connexion. The other features to be seen in Fig. 8.12 will be explained later.

The switchboard operator's teleprinter is accommodated on a separate table not shown in Fig. 8.12.

The Calling Circuit. The circuit elements of a typical single position switchboard will now be described beginning with the calling circuit. The equipment associated with the line jack of the station is shown in Fig. 8.14. It will be seen that the station teleprinter is normally held to marking by the negative battery applied to the send line via the resistor $R1$ and the ring springs of the break type jack. The negative battery from the station on the receive line does not operate relay L, owing to the shunting effect of the rectifier $MR1$. The station telegraphist calls the switchboard with space-bar signals and the relay L operates and releases intermittently. $L1$ flashes the calling lamp, whilst $L2$ flashes a common pilot lamp and when required sounds a night alarm buzzer also.

Switchboard Operator Answers. The operator's position circuit and an associated cord circuit are shown in Fig. 8.15. To answer the call, the switchboard operator then takes an answering cord,

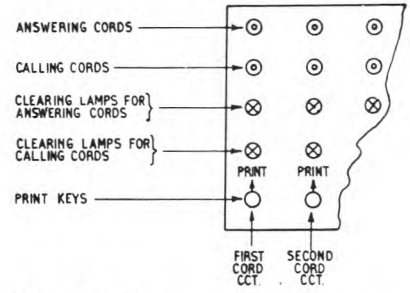


FIG. 8.13. TYPICAL KEYSHELF LAYOUT

operates the position "answer" key (KA) and the "print and monitor" key (KPM) of the cord circuit chosen, and places the answering cord of that circuit into the jack of the calling line. The breaking of the ring springs of the jack releases relay L, which puts out the calling and pilot lamps and stops the night alarm buzzer. At the same time, the auxiliary

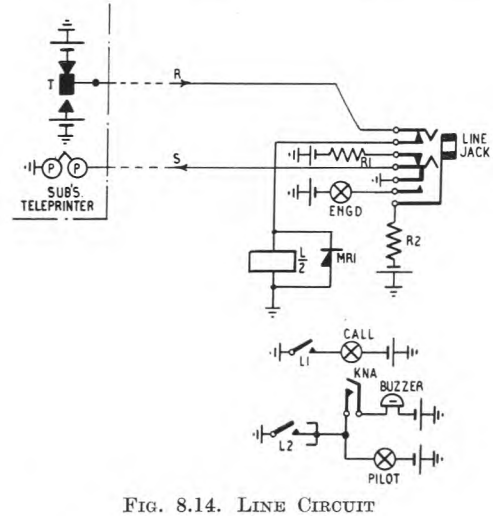


FIG. 8.14. LINE CIRCUIT

springs of the jack light the engaged lamp (the engaged lamps are mounted immediately above the calling lamps and their use will be described later).

$KPM1$ causes the cord connecting relay CC in that cord circuit to operate to battery obtained via the resistor $R3$ which is shared by all the cord circuits. $CC1$ locks relay CC via the low resistance winding only and so brings the potential of the

common point almost to earth potential. Hence, if the print and monitor key of another cord circuit were now operated then the potential available at the common point would be too small to operate the second relay *CC*. This is a safeguard against the faulty connecting together of two subscribers

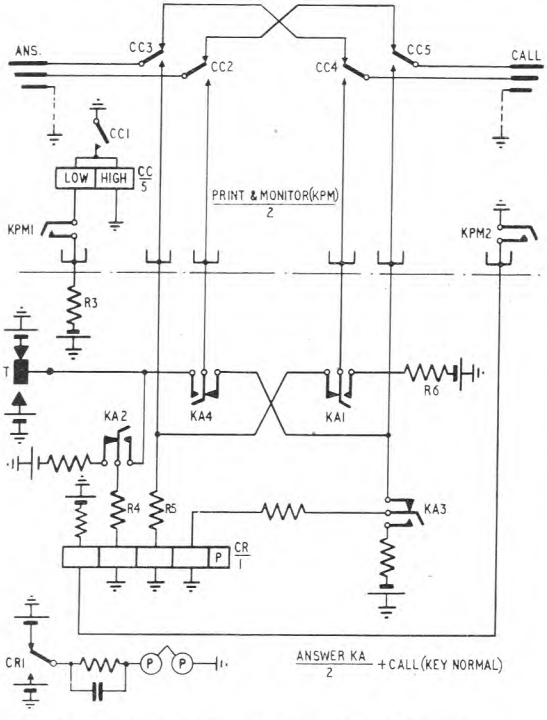


FIG. 8.15. PART OF CORD AND POSITION CIRCUITS

by the inadvertent operation of two print and monitor keys.

The transmission conditions between the calling subscriber and the switchboard operator should now be noted. The switchboard operator's teleprinter sends a marking signal via springs *KA*4, *CC*2 and the send line, to the subscriber's teleprinter receiving electromagnet. At the same time, a marking signal is also connected via springs *KA*2 and resistor *R*4 to a winding of the polarized controlling relay *CR*. The subscriber's teleprinter transmitter sends a marking signal via *CC*3 and resistor *R*5 to a second winding of relay *CR*. *KA*3 produces a further marking signal in a third winding, whilst *KPM*2 gives a spacing signal in the fourth winding. Now this spacing current produces twice the ampere turns in the relay as do each of the other three windings individually, so that there are two spacing units of magnetic flux and three marking units. The net effect, therefore, is one marking unit. Thus, whenever the switchboard operator, or the distant telegraphist, transmits (provided they do not try simultaneously) one of the three marking coils is made to space during positive elements of the signals. The relay, therefore, responds to the signals of both the subscriber and the operator and at *CR*1 provides a record for the operator. (The subscriber's local record is provided by the send-receive switch of her teleprinter.)

Operator Connects Called Line. To extend the call to the wanted line, the operator takes the calling plug of the cord circuit she is using, puts it into the jack of the wanted line and sends a "go ahead" signal to the calling subscriber. On inserting the calling cord, the called subscriber's teleprinter is held by a marking battery via resistor *R*6, *KA*1, *CC*4 and the ring of the plug and jack, whilst the receive line from that subscriber is left disconnected at *KA*3 and *KA*4. The operator now retires from the circuit by restoring the print and monitor key. This releases relay *CC* whose contacts disconnect the operator's circuit from the cords and leave them connected through. The operator is now free to deal with other calls.

Clearing Circuit. In order that the operator may know when to clear the circuit each teleprinter

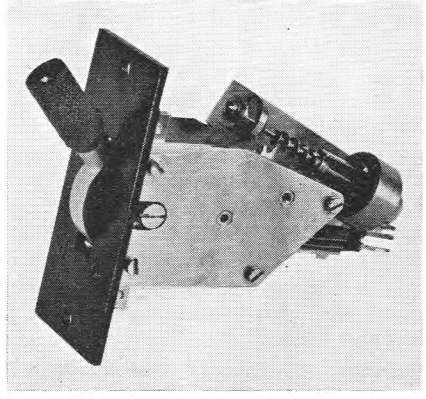


FIG. 8.16. AUTOMATIC CLEARING KEY
(By courtesy of H.M. Postmaster-General)

station is provided with a clearing key which is operated for five seconds when the message is finished. Originally the estimation of this time period was left to the judgment of the subscriber using an ordinary non-locking key but later automatic keys incorporating a clockwork delay feature were used (see Fig. 8.16). The operation of the clearing key applies a spacing current to the

send line and after the five seconds the normal marking current is restored. The circuit designed to test for this clearing signal must have some form of a delay feature, so that it will not operate to the spacing elements of teleprinter signals. It must, however, respond to the long space of the clearing

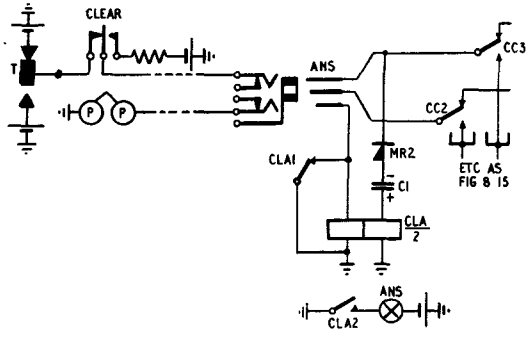


FIG. 8.17. CLEARING CIRCUIT

signal. The principle of the clearing circuit is shown in Fig. 8.17. An exactly similar circuit using a relay *CLC* is associated with the calling cord.

While the call is in progress the normal marking condition of the line charges capacitor *C*1 via the rectifier *MR*2, so that the plate next to the rectifier is negative. During the transmission of the positive elements of the telegraph signals the polarity tends to be reversed but owing to the high backward resistance of the rectifier and the short duration of the positive elements, the charge on *C*1 is substantially unaltered. When a clearing signal is received, however, the positive polarity is maintained for 5 sec and this allows adequate time for the charge on *C*1 to be completely reversed. At the end of the 5 sec, therefore, the potential across the capacitor is equal to the full 80 V of the signalling supply and this is effectively in series with the — 80 V from the teleprinter. Hence on release of the clearing key there is a very rapid reversal of charge on the capacitor and the consequent surge current operates relay *CLA*. *CLA*1 locks relay *CLA* by allowing current to flow in its other winding and *CLA*2 lights the clearing lamp of the answering cord. Similarly the clearing signal sent out by the called subscriber will light the clearing lamp associated with the calling cord. On seeing the two lamps alight the operator withdraws the cords so restoring each line and the cord circuit to its original condition.

The operation of the clearing circuit depends to some extent on the resistance of the lines. If the resistance of the line from which the clearing signal is sent is high, the operating current for relay *CLA* is restricted and further, the potential available at the capacitor *C*1 is limited, particularly if the resistance of the other line to which the first is connected is low. If, therefore, the line resistance exceeds a certain definite limit, failure of the clearing signal may result. By suitable choice of circuit components this limit can be made no worse than that for signalling distortion. (In some early versions of this circuit, however, the clearing circuit imposed the greater restriction.)

Broadcast Facilities. Another facility that the switchboard provides is broadcasting, by which is meant the transmission of a message from one station to a number of other stations simultaneously. The basic circuit that enables this to be done is shown in Fig. 8.18. This is in effect simply the connexion of ten lines in parallel to the transmitting contact of a relay which repeats the signals from the broadcasting teleprinter.

For the reasons now to be given special safeguards are necessary to protect the transmitting contacts. Owing to the line capacitance, together

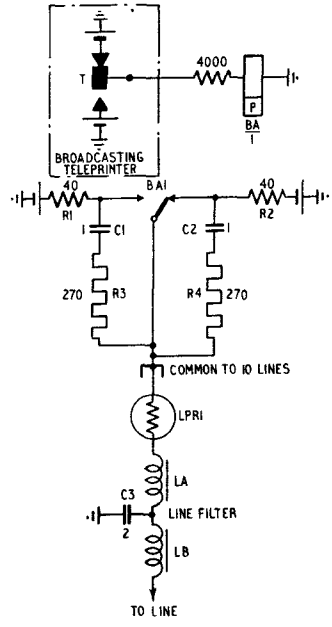


FIG. 8.18. BASIC BROADCAST CIRCUIT

with that of the line filters, the initial current surge from the closing of the broadcasting relay contact is of the order of 3 A. Thus if there is any contact bounce severe sparking occurs. This causes the contact points to build-up, so reducing the contact gap and finally resulting in short-circuiting of the contacts. A heavy fault current now flows and if this is allowed to exceed 2 A, the

contacts become welded together causing serious damage to the relay. The 40 Ω resistors $R1$ and $R2$ are therefore provided to prevent such welding by limiting the fault current to 2 A. At the same time the 80 + 80 V battery supply is fed via 1·5 A fuses so causing this fault current to be disconnected. The 40 Ω resistors must be capable of dissipating 160 W under fault conditions and hence they are large and of the vitreous enamelled type.

Sparking at the contacts is prevented by the spark quenches $C1$, $R3$ and $C2$, $R4$ but this does not entirely stop the building-up of the contact points. In practice it has been found that although the spark quenches suppress the visible sparking they are not effective against arcing at radio frequencies. The fitting of radio-interference suppressors in addition to the above spark quenches, has been found to treble the working life of the contacts, hence radio-interference suppressors are now fitted for this purpose alone.

Fig. 8.19 shows the contacts of a broadcast relay fitted with its spark quenches and radio frequency suppressors. The ballast resistors $LPR1$ have a cold resistance of 100 Ω and are substantially

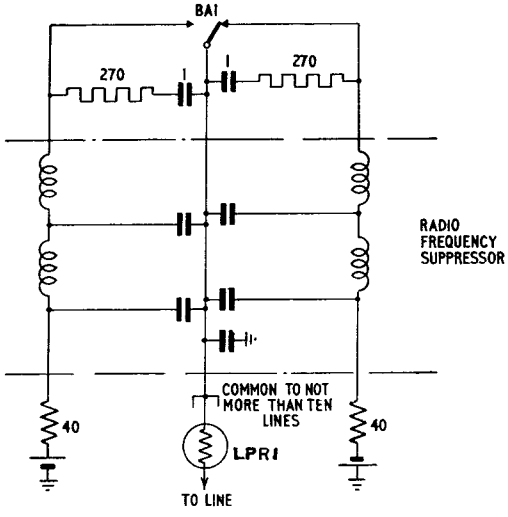


Fig. 8.19. Radio Suppression Filters and Spark Quenches associated with Basic Broadcast Circuit

unaltered by the normal transmitting current of about 20 mA. Without these ballast resistors an earth fault on one of the lines would cause excessive current to flow in the faulty line at the expense of the others which might also be rendered ineffective. This serious effect is prevented by the ballast resistor in each line which will not pass more than about 100 mA and so restricts the fault current and prevents the other lines from being robbed of their current.

The use of this basic broadcasting circuit in the single position switchboard is shown in Fig. 8.20. Having answered a calling station and received a request for a broadcast, the operator

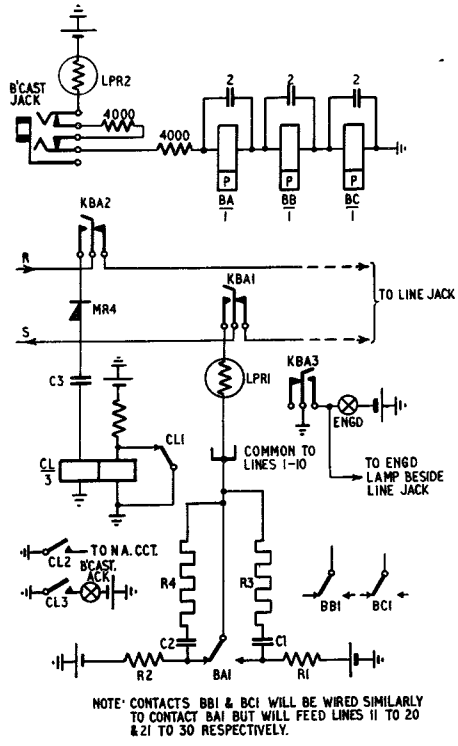


Fig. 8.20. Broadcast Circuit

places the calling cord into the broadcast jack so placing the calling station in control of the broadcast relays. The "broadcast" keys (KBA) of each line that is to receive the broadcast are now operated. $KBA1$ connects the send line to its appropriate broadcast relay contact and $KBA2$ connects the broadcast clearing circuit to the receive line. $KBA3$ lights the engaged lamps.

The caller is now instructed to proceed with the broadcast. When the broadcast is completed each receiving station should send a clearing signal and relay CL, which functions exactly like the relays CLA and CLB in the cord circuit, operates in response. $CL1$ locks relay CL, and $CL2$ operates the night alarm if required. $CL3$ lights the "broadcast acknowledgment" lamp and when all the acknowledgment lamps have been noted, the operator clears the connexion. The broadcast jack is placed at the bottom of the right-hand panel

of the switchboard; also in this panel are the thirty broadcast keys arranged in three rows of ten and associated with each of these is a white broadcast acknowledgment lamp and a red engaged lamp. The purpose of the two engaged lamps, one beside the line jack and another beside the broadcast key, will now be apparent, as a line must not

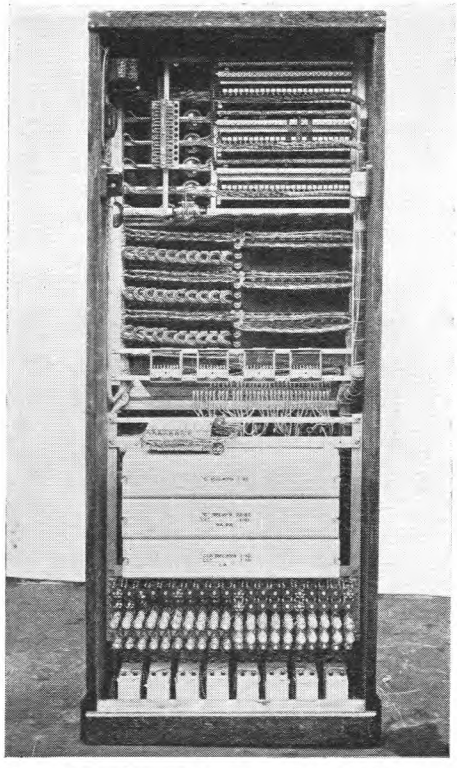


FIG. 8.21. REAR VIEW OF SINGLE POSITION TELEPRINTER SWITCHBOARD
(By courtesy of H.M. Postmaster-General)

be connected to a broadcast if it is already engaged on an ordinary call nor must an ordinary call be connected if the line is engaged on a broadcast.

All the equipment required in conjunction with the cord circuits and the operator's position is mounted in the rear of the switchboard, a view of which is shown in Fig. 8.21.

Multiple-type Switchboard

The number of lines that can be connected to a single position switchboard is limited by two factors—

1. The physical limit to the number of jacks that can be placed within an operator's reach, and
2. The rate at which a single operator is able to dispose of the calls that originate.

The second condition is much more restrictive than the first. Thus although several hundred lines can readily be accommodated in the jack field of a position one operator may not be able to deal with the busy hour traffic of more than perhaps forty or fifty subscribers, the actual number being dependent upon the average calling rate. A large switchboard will, therefore, require many operators' positions and as each operator will require to have access to all the lines, these are "multipled," i.e. repeated, along the line of switchboards in such a way that all the lines appear within the reach of

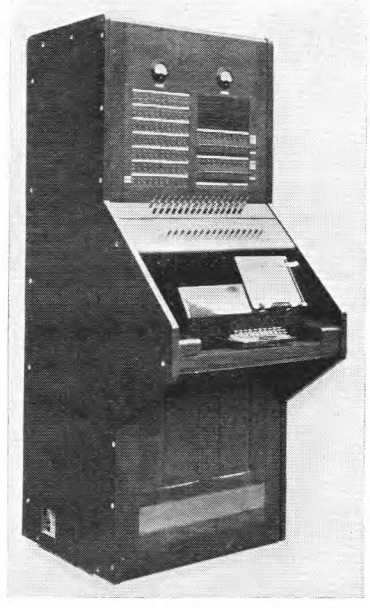


FIG. 8.22. OPERATOR'S POSITION OF MULTIPLE-TYPE TELEPRINTER SWITCHBOARD
(By courtesy of H.M. Postmaster-General)

each operator. Such a switchboard is called a "multiple type switchboard."

An operator's position of a multiple type switchboard is shown in Fig. 8.22 whilst a suite of such positions is shown in Fig. 8.23. It will be seen that the operator's teleprinter is housed within the switchboard, separate tables being inconvenient where a line of positions is concerned. The key-shelf is above the teleprinter and is sloping to give easier operation and the face of the switchboard is divided into two panels as with the single position switchboard. The circuit principles of a multiple type switchboard are very similar to those of the single position switchboard already considered and only the points of difference will therefore be described.

Multiple Type Line Circuit. Series connected break type jacks are unsuitable for providing access to a line at a number of switchboard operators' positions, because if an operator inadvertently inserted a plug into the jack of a line that was already engaged the connexion might be cut off. Hence three-point jacks wired in parallel are used and a sleeve relay is provided to disconnect the calling equipment when the operator answers and also to indicate that the circuit is engaged. Such a line circuit is shown in Fig. 8.24 and it will be seen that, so long as a cord is inserted in one of the jacks, the relay E is held operated. Contacts $E1$ and $E2$ perform the same function as the break springs of the jack in the line circuit of the single position switchboard. Contact $E3$ may be used either to light an engaged lamp at each multiple appearance of the line or to operate Free Line Signalling lamps. The latter is the more usual arrangement for multiple switchboards and will now be described.

Free Line Signalling. In the single position switchboard each engaged line was marked by the lighting of a lamp over the line jack. This system of marking engaged lines is sometimes called "visual engaged signalling" (V.E.S.). When a group of lines all go to the same place as for example the junction circuits between two switchboards or a number of lines all terminating in the same office, V.E.S. has the following disadvantages—

1. At busy periods the large number of engaged lamps causes glare to the operators and a fair amount of heat is dissipated.

2. Owing to the repetitions of the multiple, the current consumption of the lamps is large.

In the multiple type switchboard, therefore, where there are many such groups of lines, the system known as "free line signalling" (F.L.S.) is preferable. In this system lamps are lit only over the first free circuit in the group and both the above disadvantages are overcome.

The circuit principles of F.L.S. are shown in Fig. 8.25. Associated with the $E3$ contact of the sleeve relay in the line circuit are three tags A, B and C. In the first line of a group of circuits A is strapped to B so that when $E3$ is normal the F.L.S. lamps of that circuit are lit, so marking it free. Tag C of the first line is strapped to tag B of the second line in the group whilst tag C of the second is strapped to tag B of the third and so on. Thus if the first circuit is engaged $E3$ diverts the battery from the F.L.S. lamps of the first circuit to those of the second. Similarly if the second circuit is engaged then the $E3$ contact of the second circuit will switch the battery to the third circuit. As the C tag of the last line of a group is not strapped, no lamps will be showing if all the circuits in the group are engaged.

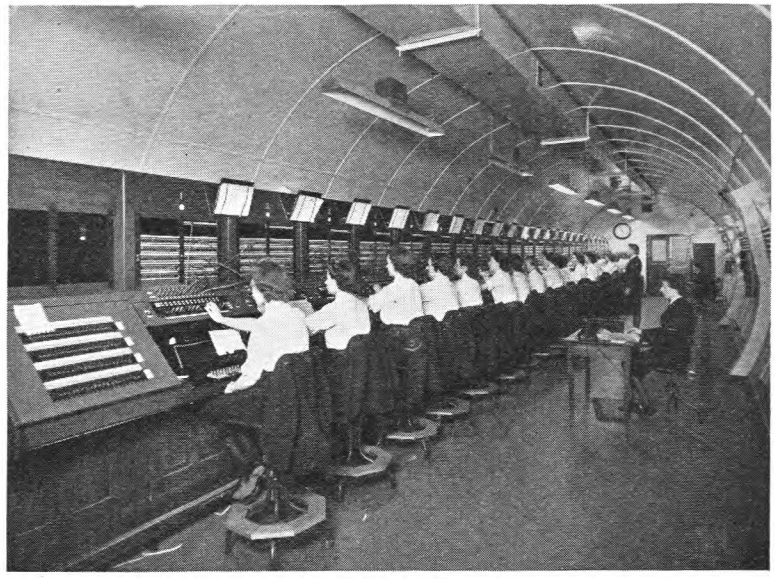


FIG. 8.23. SUITE OF MULTIPLE-TYPE TELEPRINTER SWITCHBOARDS
(By courtesy of H.M. Postmaster-General)

Duplicate Connexion Facility. A duplicate connexion circuit exactly similar to that described for the Teleprinter Ancillary Concentrator System (see Fig. 8.9) is used in the multiple type switchboard and is required for exactly the same reasons.

Broadcast Facilities. Broadcast facilities can be provided in the multiple type switchboard if required but the facility is restricted to a predetermined selection of lines as this has been found to be adequate in practice. Two distinct broadcast circuits (known as A and B) are often provided so enabling two different broadcasts to take place simultaneously. (Of course any one line can be connected only to one broadcast at a time.) To do this a duplicate set of broadcast relays is required and two-way keys are provided; A broadcast facilities are given with one movement and B broadcast facilities with the other movement of the key. The circuit is illustrated in Fig. 8.26 which should be compared with Fig. 8.20. When a

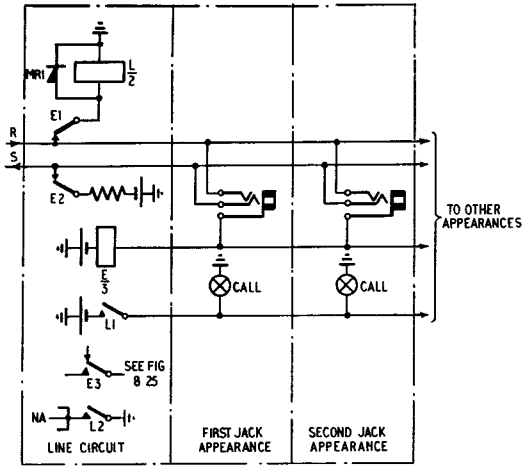


FIG. 8.24. LINE CIRCUIT OF MULTIPLE-TYPE TELEPRINTER SWITCHBOARD

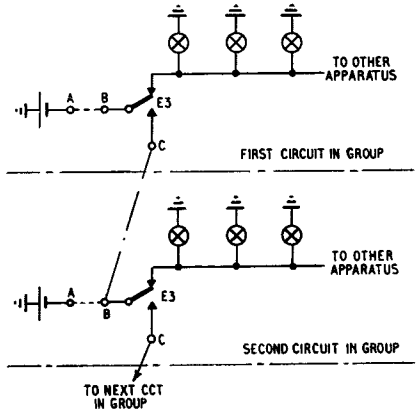


FIG. 8.25. FREE LINE SIGNALLING

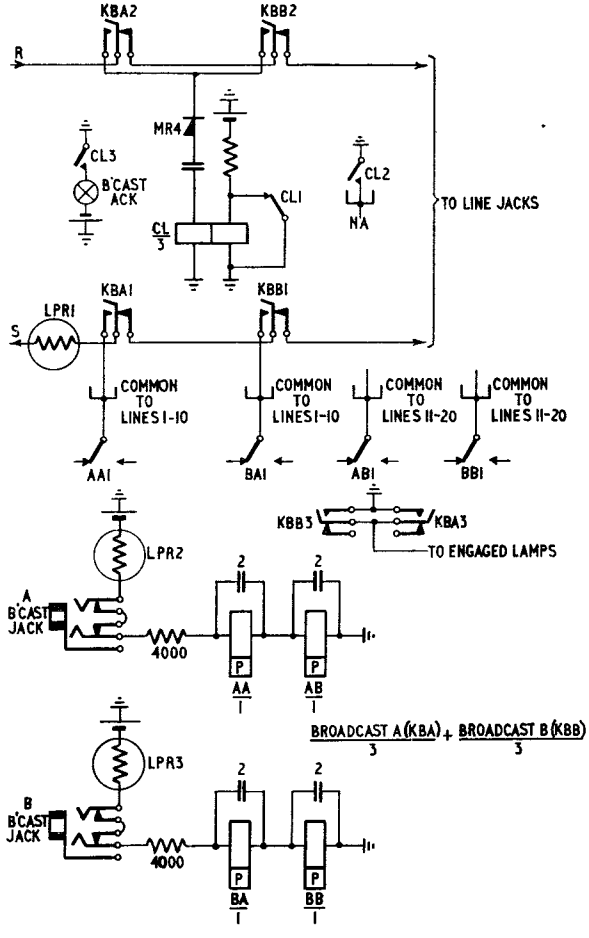


FIG. 8.26. METHOD OF PROVIDING TWO DISTINCT BROADCAST CIRCUITS

to be provided and the switching keys for this circuit would be coded KB. In practice, keys KA and KB are arranged to be the opposite movements of a two-way key. Further, since the total number of key contacts required is more than can be accommodated on a single key, two mechanically coupled keys are used. Owing to the large number of keys that would be required, key switching is not suitable for large switchboards.

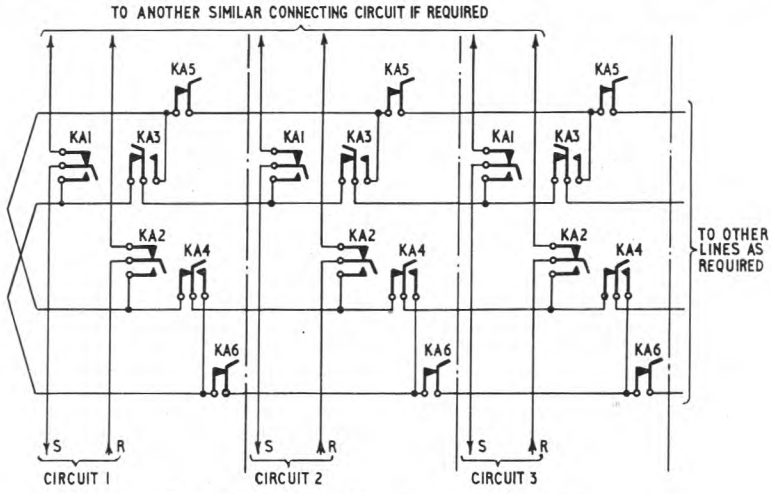


FIG. 8.29. BASIC KEY SWITCHING CIRCUIT

A cordless switchboard with a capacity for five lines is shown in Fig. 8.30. In a horizontal line across the middle of the panel are the five mechanically coupled pairs of "line connect" keys numbered from left to right. An upward movement of two of these coupled pairs gives an A connexion, whilst a downward movement gives a B connexion. Above each of these keys is a clear lamp and above each of these again, a call lamp. The print keys which enable the operator to associate her teleprinter with a calling line are in a row at the bottom of the panel and are operated downwards. The upward movement of these keys provides the "receive broadcast" condition and above each of these keys is a "broadcast acknowledgment" lamp. To the right of the five "line connect" keys is a "broadcast" key which is used in conjunction with a "line connect" key to connect a line to the broadcast relay, and a "monitoring" key.

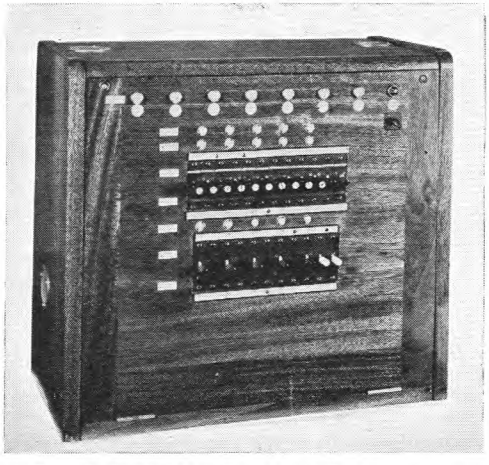


FIG. 8.30. SMALL CORDLESS TELEPRINTER SWITCHBOARD
(By courtesy of H.M. Postmaster-General)

The basic calling, clearing and broadcasting circuits follow the same lines as the earlier switchboards already described and a study of Fig. 8.31 should enable the working of the board to be followed. A rear view of the cordless switchboard showing the equipment is given in Fig. 8.32.

Two-line Switchboard. Private wire users frequently require the facility of switching their private wire circuit from a central office to a subsidiary office, or factory, usually not very far away. For this purpose a simple two-line switchboard is used and key switching is again adopted. The elements of the circuit are shown in Fig. 8.33.

Normal Conditions. If line 1 be regarded as the more important line of the two, the switchboard teleprinter is normally placed in connexion with this line by the operation of key KLA. The operator's teleprinter and the teleprinter terminating line 1 are therefore in contact and signalling can take place as required. If line 1 sends a clearing

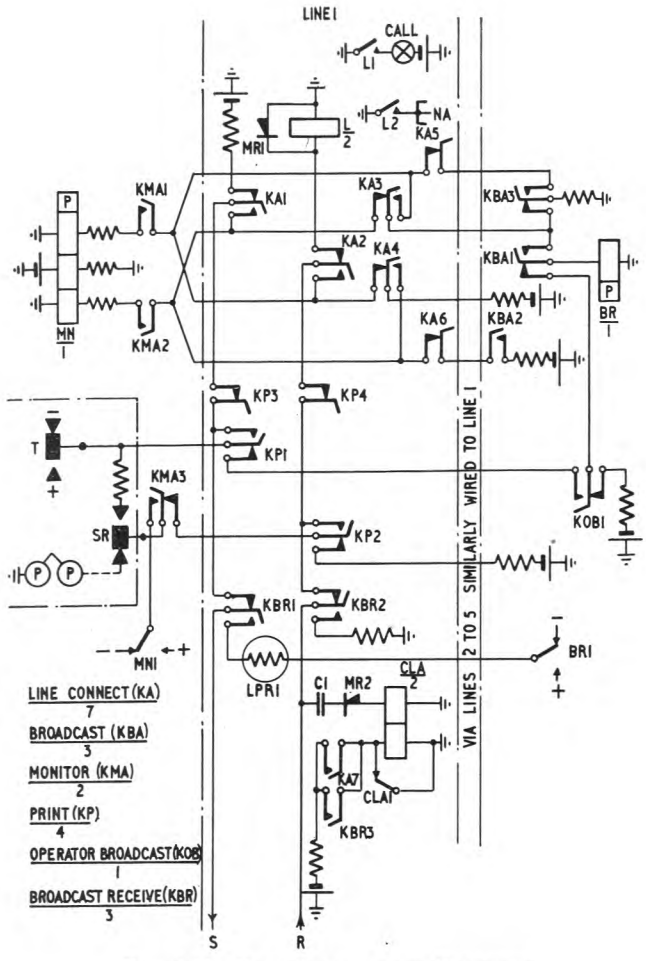


FIG. 8.31. CIRCUIT OF 5-LINE CORDLESS TELEPRINTER SWITCHBOARD

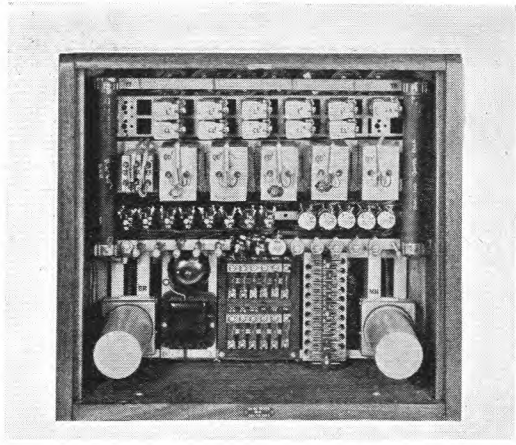


FIG. 8.32. SMALL CORDLESS TELEPRINTER SWITCHBOARD (REAR VIEW)
(By courtesy of H.M. Postmaster-General)

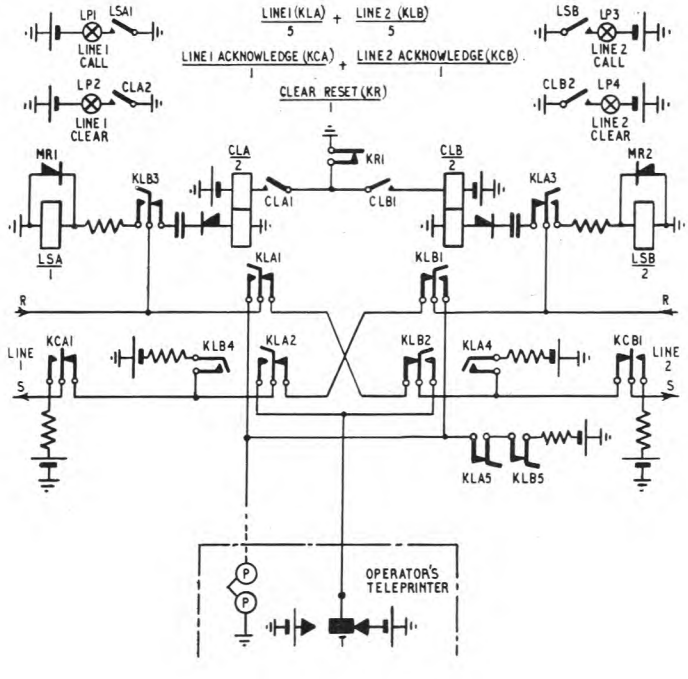


FIG. 8.33. TWO-LINE TELEPRINTER SWITCHBOARD

signal, relay *CLA* operates (as described above) and lights the clear lamp. This is subsequently put out when the operator momentarily presses the "clear reset" key (*KR*).

Connexion to Line 2. If the operator wishes to communicate with line 2 then key *KLB* is operated

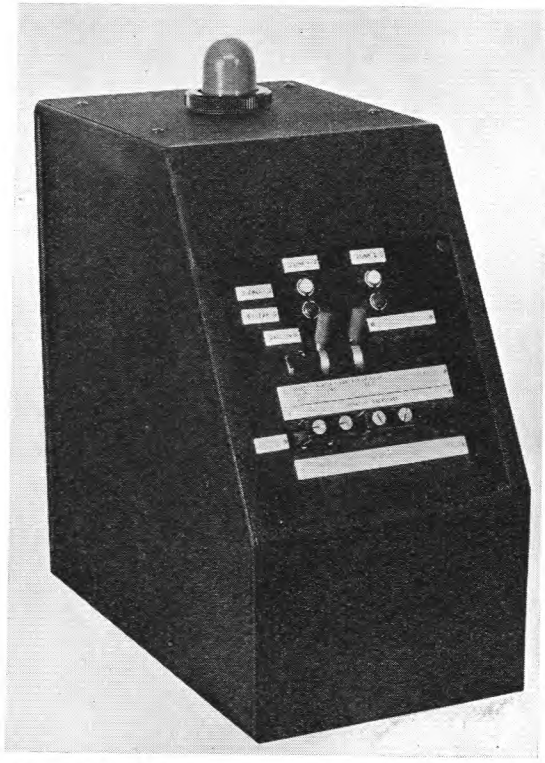


FIG. 8.34. TWO-LINE TELEPRINTER SWITCHBOARD
(*By courtesy of H.M. Postmaster-General*)

and exactly similar conditions are set up. When the clearing signal is received the operator restores key *KLB* and reoperates key *KLA*.

Connecting Line 1 *to Line* 2. If line 1 wants to communicate with line 2 then after calling the operator the key *KLA* is restored so leaving the lines directly through. Afterwards, when the clearing signals are sent, the operator breaks the connexion by reoperating key *KLA* and puts out the clearing lamps by operating the key *KR*.

Line 2 *Calls.* If while *KLA* is operated line 2 wants to make a call, space bar calling signals are sent and these operate relay *LSB* which lights the calling lamp. The operator therefore switches to line 2 and either takes the call or switches it to line 1 if so required. If the operator happened to be engaged with line 1 when line 2 called, then the "line 2 acknowledge" key is operated once or twice. This applies an intermittent spacing condition to line 2 and causes the teleprinter to race intermittently. This is interpreted as an engaged signal. A similar condition is available if line 1 calls while the operator is engaged with line 2.

Fig. 8.34 shows a switchboard of this type which, as it is quite small, is table mounted.

Switchboards for Two-way Simplex Circuits. In certain specialized fields, e.g. in the public telegraph network, where heavy traffic in both directions simultaneously is liable to arise, the ability to use two-way simplex working has distinct advantages. With this form of working a local record of the messages sent cannot be provided except by duplicating the teleprinters at each end of the circuit. In the B.P.O. public telegraph service, however, local records are neither provided nor needed because—

1. A written original of the message to be sent is available for reference.

2. Highly trained telegraphists using tape printing machines, are able to transmit accurately without consulting a local record.

It follows that some differences in circuit detail and in operating procedure are necessary with switchboards for two-way simplex and these will now be described. A general view of the switchboard is given in Fig. 8.35 and it may be noted here that the lines are, in general, set up on a one-way basis. The jacks of the incoming lines are accommodated in the lower portion of the switchboard multiple, whilst the jacks of the outgoing lines are in the upper portion. F.L.S. lamps are provided for the outgoing lines and ancillaried calling lamps for the incoming lines.

The Line Circuit. Fig. 8.36 shows the circuit principles of an incoming line circuit. It will be seen that the line is looped via *E*1 and *MR*1 and hence the transmitting battery of the station teleprinter is normally returned to hold its own teleprinter.

Telegraphist Calls. When a number is required, the calling station telegraphist transmits continuously the telegraph code of the station she requires, e.g. GW GW GW, etc., for Glasgow. These signals are returned via the *E*1 loop and hence the calling telegraphist receives a local record on her machine of the calling signals. At the same time, the relay *L* operates in response to the positive elements of the signals and *L*1 gives a flashing calling signal at each appearance on the switchboard.

Operator Answers. The switchboard operator's cord and position circuits are shown in Fig. 8.37. The operator picks up an answering cord, checks that the common splitting key (*KC*) is in the "answer"

position (i.e. normal), operates the appropriate "print" key (KP) and inserts the cord into the calling jack. As with earlier switchboards $KP1$ operates the relay CC which locks to a common battery, obtained in this case from the relay H which also operates. $KP2$ with $CC2$ operates relay A. $H1$ removes the marking current from one coil of the polarized relay CR but the other coil is now made to mark via $KC2$, $CC4$, $SA3$ from a negative battery via $R1$. When the cord is in the jack, earth from relay P is extended via $SA2$, both coils of relay SA in series, sleeve of cord and jack, to the negative battery of relay E in the line circuit (Fig. 8.36). Relays P and SA operate in series and $SA1$ locks relay SA via its low resistance winding,

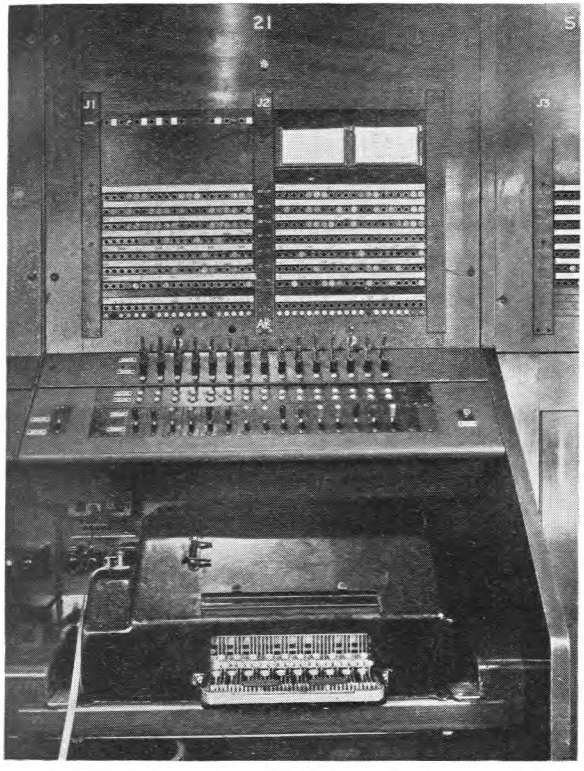


FIG. 8.35. FRONT VIEW OF TELEPRINTER SWITCHBOARD FOR 2-WAY SIMPLEX CIRCUITS
(By courtesy of H.M. Postmaster-General)

so operating relay E. $SA1$ and $SA2$ also cause the relay P to release again. (This momentary operation of relay P serves no useful purpose at this stage and its use will be described later.) $SA3$ and $SA4$ switch the lines of the answering cord. In the line circuit, $E1$ cuts off the calling telegraphist's local record circuit so that she now knows the switchboard operator has answered. The telegraphist transmits the code of the called station two or three times more, so that the switchboard operator may receive a record of the request. These signals are received via the tip of the jack and cord, $SA3$, $CC4$, $KC2$, to a coil of relay CR. $CR1$ controls the operator's teleprinter. Similarly the switchboard

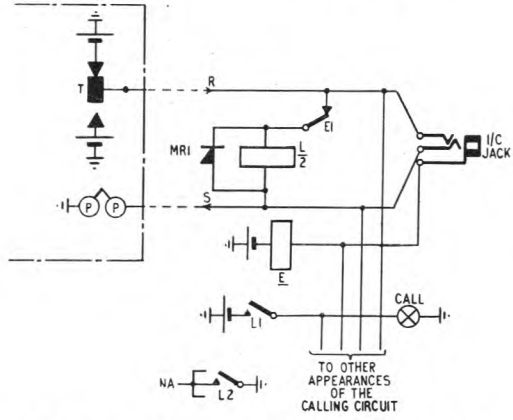


FIG. 8.36. INCOMING LINE CIRCUIT (2-WAY SIMPLEX WORKING)

operator may, if necessary, transmit to the calling telegraphist from the transmitting tongue T of her teleprinter via $A2$, $CC3$, $SA4$, ring of cord and jack to the send line and so to the caller's teleprinter receiving electromagnet.

Operator Selects Calling Line. The operator now takes up the calling cord and places it into the jack of an outgoing line which is similar to that of the incoming circuit in Fig. 8.36 except that in place of a calling lamp an F.L.S. lamp is provided.

On insertion of the calling cord, relays P and SC function exactly as did relays P and SA for the answering cord. As $E1$ in the called line circuit disconnects the hold circuit for the teleprinter electromagnet an alternative loop is maintained temporarily via $SC3$, $CC5$, $A3$, $CC6$ and $SC4$. The operator then transmits the "you are through" signal (DF) to the caller and restores the print key (KP) thus releasing relays CC and H. Contacts $CC3$, 4, 5 and 6 provide a direct path between the cords, whilst $CC2$ releases relay A. $H1$ once again holds relay CR and hence the operator's teleprinter to mark.

Signalling to Called Line. Should the operator wish to transmit to the telegraphist at the called line, the print (KP) and call (KC) keys must be operated. Relay CL then provides the same conditions for the calling cord as did relay A for the answering cord.

Monitoring. If the operator wishes to monitor a

connexion the monitor key (*KM*) is operated. This operates relays *CC* and *H* as before but *CC*2 is not now able to operate relay *A* or *CL*. The path between the cords is thus maintained via the operated contacts *CC*3, *CC*4, *CC*5, *CC*6, *CL*3 and *A*3 and relay *CR* is teed on to one line or the other as required according to the position of *KC*2.

Engaged Conditions. When *P* operates *P*1*x* the answering and calling cords, were too brief to cause any operation of relay *DD*.

If, however, the calling cord had been put into an engaged line, the potential encountered on the sleeve of the jack would have been low owing to the earth via the low resistance winding of the relay *SA* in the engaged cord. This lowered potential is too small to operate the relay *SA* of the newly

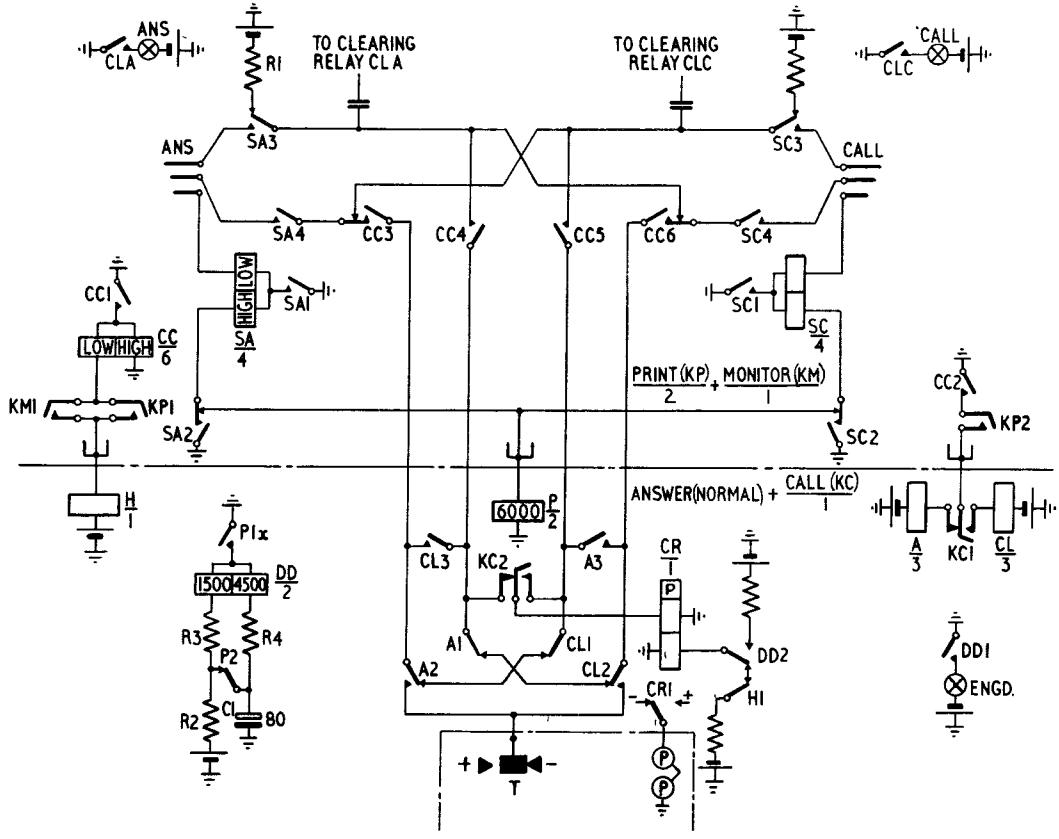


FIG. 8.37. CORD AND POSITION CIRCUIT (2-WAY SIMPLEX WORKING)

causes currents to flow in both windings of relay *DD* to the battery via the resistor *R*2. The magnetic effects of these currents are roughly equal and opposite and relay *DD* does not operate. As *P*2 breaks, the current for the 4,500 Ω winding of *DD* is maintained for a time by the accumulated charge on the 80 μF capacitor *C*1. As this charge becomes dissipated so the current in the 4,500 Ω winding falls until the preponderance of magnetic flux due to the 1,500 Ω winding causes relay *DD* to operate. In this way an operate lag of some 250 msec is obtained. Thus the momentary operations of relay *P* referred to above, on insertion of inserted cord but is still able to operate relay *P* owing to the latter's high sensitivity. In these circumstances relay *P* operates but is not released again as previously by *SC*1 and 2, and *P*1 therefore has time to operate relay *DD*. *DD*1 lights an engaged lamp, whilst *DD*2 spaces the relay *CR* which in turn causes the teleprinter to race. As relay *SC* fails to operate, no interference with the engaged circuit takes place as *SC*3 and *SC*4 keep the tip and ring of the cord disconnected. The operator is thus informed that the line is engaged and the over-plugging cord is withdrawn to restore normal conditions.

Clearing. The clearing arrangements are exactly similar to those of the earlier switchboards and need no further description here. Should a telegraphist try to originate a further call before the operator has removed the answering cord from the jack she will not obtain a local record of her calling signals and from this will know that she must wait a little longer to give the operator time to clear.

Junction Call. The call so far described is a local call, i.e. one in which the calling and called stations are both connected to the same switchboard. If, for example, a station in London requires to be connected to another station in Glasgow, then an inter-switchboard circuit between London and Glasgow is required. The circuit of an inter-switchboard circuit of this type is shown in Fig. 8.38 and its action will now be described in relation to a call from London to Glasgow.

The London station telegraphist calls the London switchboard in the manner already described for a local call. The switchboard operator notes that the wanted line is obtained from the Glasgow switchboard and puts the calling cord into the outgoing jack of a free inter-switchboard circuit to Glasgow, advises "through" to the caller and retires from the circuit. The insertion of the calling cord operates the relay E on the sleeve of the outgoing junction jack. $E1$ operates relay F. $E2$ operates relay G and $G3$ engages the circuit by putting out the F.L.S. lamps and lighting those of the next free circuit in the group. On being advised "through" the calling telegraphist begins to send her calling signals again and these are now passed through the London cord circuit to the ring of the outgoing jack and over the VF line to Glasgow. They then pass via the relay L or $MR2$, $J1$, over the other leg of the line and back to the caller, who again receives a local record. When the Glasgow operator answers, relays H and J operate and the local record circuit is disconnected at $J1$. Again the signals are continued for a few seconds longer, so that the Glasgow operator may note the request. She then inserts the calling cord into the wanted line in the manner already described for a local call and through transmission between the two stations is now possible.

Clearing of Junction Call. When a clearing signal is given, clearing lamps are lit simultaneously in the cord circuits at Glasgow and London. What follows depends upon which operator withdraws her cords first; assume the London operator does. Hence relay E releases and $E1$ in turn releases relay F slowly. After the release of $E4$ and during the slow release of $F1$, a positive battery is applied to the send line but this has no effect on the inter-switchboard circuit for this particular call. Relay G remains held by $G1$ and hence $G3$ keeps the circuit marked engaged. This is important, for although the plug has been removed from the outgoing end, the circuit must not be used again until

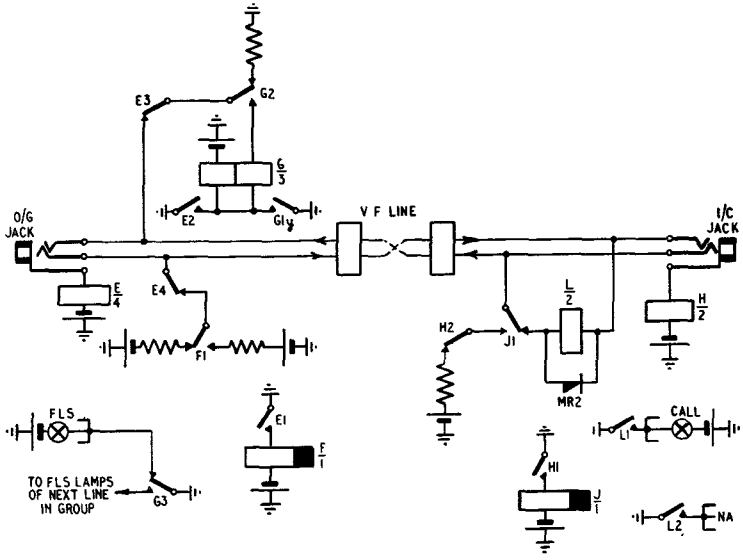


FIG. 8.38. INTER-SWITCHBOARD CIRCUIT (2-WAY SIMPLEX WORKING)

it has been cleared at the incoming end. When the Glasgow operator clears relay H releases and $H1$ in turn releases the relay J slowly. After the release of $H2$ and during the slow release period of $J1$, a pulse of positive battery is applied to the send line. This passes to the outgoing end and goes via $E3$, $G2$, coil of G, $G1y$ to earth. The windings of G are so arranged that the magnetic flux produced by this pulse of current neutralizes the flux already existing in the other winding of relay G. Hence relay G is released and at $G3$ the engaging condition is removed.

In the alternative case when the Glasgow operator is the first to clear, relays H and J release before the relays at the London end. Thus the pulse generated by $H2$ and $J1$ serves no purpose. When the London operator withdraws, the positive pulse generated by $F1$ and $E4$ passes via the line, L relay, $J1$, over the other path of the line, $E3$, $G2$, coil of G, $G1$ to earth. Relay G is therefore released and the circuit again made available for traffic.

Comparison of Pulse and Sequence Signalling Systems

The signalling system employed in all the switchboards so far described is based on the principle that a marking signal (which corresponds to "tone on" in an amplitude-modulated VF channel) is maintained, not only as the rest condition when the channel is in use for teleprinter signals but also for when the channel is disengaged. This principle was originally adopted to avoid leaving VF channels for prolonged periods with no tone on the line, a condition for which VF channels were not originally designed. Subsequent investigation has shown, however, that provided the amplifier-detector is designed to prevent "lock-out" occurring (see Chapter 10) after a prolonged spacing signal, and provided line noise is not excessive, no difficulty arises from the use of a prolonged "no-tone" condition. The use of an anti-lock-out feature in the amplifier-detector circuit of B.P.O. M.C.V.F. equipment has, therefore, been standardized and this has removed the previous inhibition in the choice of signals to be used for switching systems.

The use of "tone on" as the normal condition of disengaged circuits means that the calling signal must be made by interruption of the continuous tone. It is thus possible for transient line interruptions to cause false calling signals and in the case of automatic switching systems this effect may be serious, as it causes false seizure and stepping of disengaged switches. In this connexion the nature of the clearing signal is also of importance. On the one hand it is essential that false calls or falsely held connexions (in the automatic switching case) are cleared as quickly as possible; whilst on the other hand, the possibility of false clearing of properly established connexions must be reduced to a minimum.

To meet the signalling requirements of manual and automatic telegraph switching systems only two basic conditions are available namely marking and spacing and the distinction between various signals must therefore be one of sequence and duration. The two basic signalling systems which are available to meet the signalling requirements of a telegraph switching system are as follows—

1. *Pulse signalling system.* In this system all signals are pulses of spacing current separated by marking periods, the normal rest condition being marking. This is the system employed in the manual switchboards so far described and may also be used for automatic switching systems.

2. *Sequence signalling system.* The basis of this system is that calling and clearing signals are effected by a change of conditions from spacing to marking and vice versa, and thus defined pulses are unnecessary. Use of this system necessitates, however, that the line condition for the disengaged circuit is different from that for the idle circuit, namely, spacing when disengaged and marking when idle.

A typical application of this system is as follows—

Calling. Change from spacing to marking current.

*Dialling.** 66 msec pulse of spacing current with 33 msec of marking current between digits.

Teleprinter Signals.

Start signal: 20 msec of spacing current.

Five code elements: sequence of marking and spacing pulses of 20 msec duration each; the combination depending upon the character transmitted.

Stop signal: 30 msec pulse of marking current.

Clearing Signal. A period of spacing current of at least 300 msec duration.

The pulse signalling system has been widely used in the United Kingdom and elsewhere up to recent times but experience has indicated that a sequence signalling system is to be preferred, more especially for automatic switching systems, both as regards simplicity of design and robustness in performance.

The C.C.I.T. has supported this conclusion and desiring the maximum degree of unification between the signalling systems of the different countries participating in the International Telex Service, issued a recommendation at the sixth Plenary Assembly, Brussels, in May 1948, that a sequence signalling method should be used for the International Telex Service. This recommendation may be expressed as follows—

The *free condition of a line* will be characterized by a signalling condition corresponding to the Start signal of the International Telegraph Alphabet No. 2, *calling* by an inversion of that condition (i.e. to marking), and the *clearing* condition by reversion to the same condition as that for a free line (i.e. to spacing) for a period of at least 300 msec duration.

The circuit arrangements of a switching system designed to meet these requirements differ radically from those so far described in this chapter. This will be clear from Fig. 8.39 which contrasts graphically the C.C.I.T. conditions with pulse signalling conditions.

* Dialling signals are needed primarily in automatic switching systems but they also have relevance to a manual switching system in so far as concerns a call routed from a manual to an automatic system.

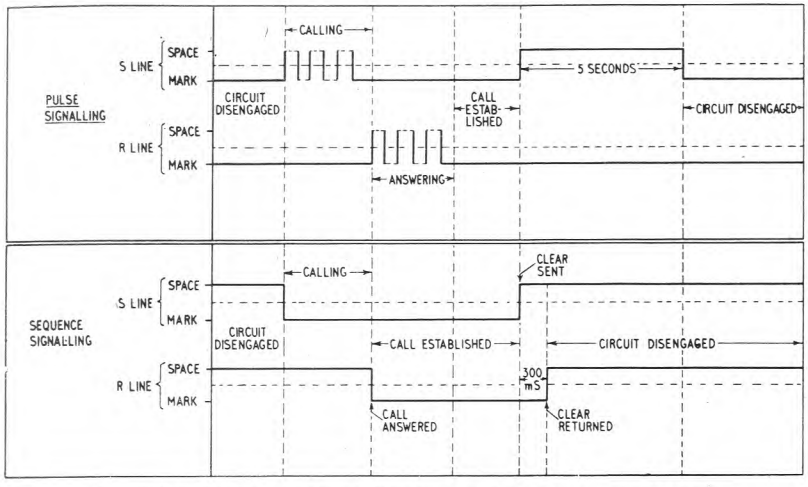


FIG. 8.39. COMPARISON OF PULSE AND SEQUENCE SIGNALLING

Teleprinter Switchboard Conforming to International Sequence Signalling Standards

The principles of operation of the type of teleprinter switchboard which has been designed by the B.P.O. to conform with C.C.I.T. signalling standards will now be described. This type of switchboard incorporates a number of novel features and is used in the United Kingdom for the International Telex Service, also for the new National Telex Service which operates over purely telegraph channels. Switchboards of this type will also be adopted in future for Teleprinter Private Wire Services.

Subscriber's Station Circuit. Associated with the subscriber's teleprinter is a signalling unit having two press buttons, one for calling and the other for clearing, whilst on top of the unit are two indicating lamps coloured red and green. A general view of this unit is given in Fig. 8.40. The principle of the circuit is shown in Fig. 8.41 and the line circuit on which the line terminates at the switchboard is shown in Fig. 8.42. In the disengaged condition of the line, a positive battery obtained via $R10$ and $E1$ of the line circuit holds the polarized relay RA in the signalling unit to spacing. The teleprinter electromagnet is disconnected from the line by $RB3$ and held marking by the negative battery from resistor $R1$ and the teleprinter motor is switched off. A spacing current is transmitted to the switchboard from resistor $R2$, $A3$, $RB4$, $Z2$ and is received via $E2$, $R11$, rectifier $MR1$ to earth in the line circuit.

Subscriber Originates a Call. To originate a call, the subscriber presses the non-locking "call" button (KK) of the signalling unit so operating the calling relay A. $A1$ locks relay A to earth via $RB2$. $A2$ operates the motor-start relay MS whose mercury tube contacts start the teleprinter motor. $A3$ sends negative battery via $RB4$ and $Z2$ to the send line and this constitutes the calling signal, which is received in the line circuit via $E2$ and relay L which operates. $L1$ lights the calling lamp and $L2$ sounds the night alarm if required.

Operator Answers. The simple elements of an operator's cord circuit are shown in Fig. 8.43 and the associated position circuit is in Fig. 8.44. The operator takes an answering cord and with the print (KP) and answer (KA) keys operated, inserts the cord into the calling jack. $KP1$ operates the cord connecting relay CC, which provides the usual facility for guarding against the simultaneous operation of two CC relays. $KP2$ operates relay P.



FIG. 8.40. TELEX SUBSCRIBER'S STATION EQUIPMENT

(By courtesy of H.M. Postmaster-General)

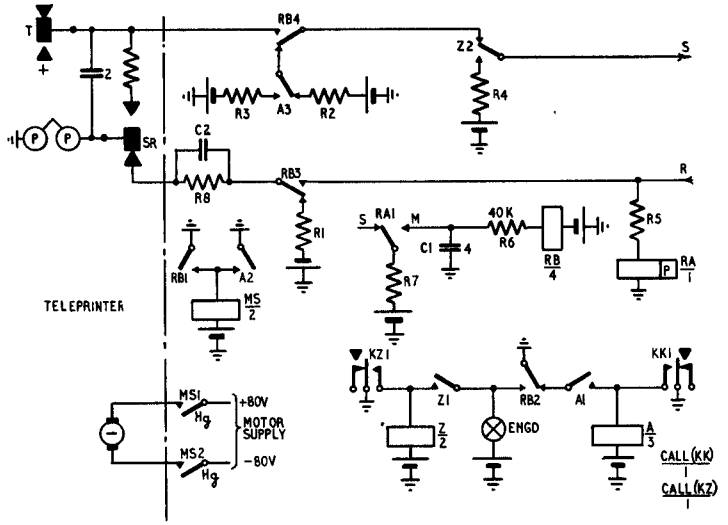


FIG. 8.41. TELEX SUBSCRIBER'S SIGNALLING UNIT

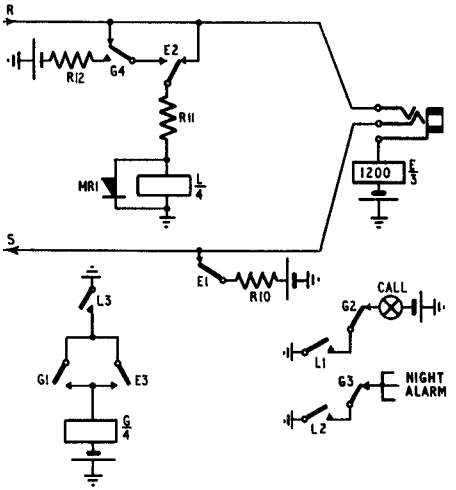


FIG. 8.42. SUBSCRIBER'S LINE CIRCUIT (TELEX)

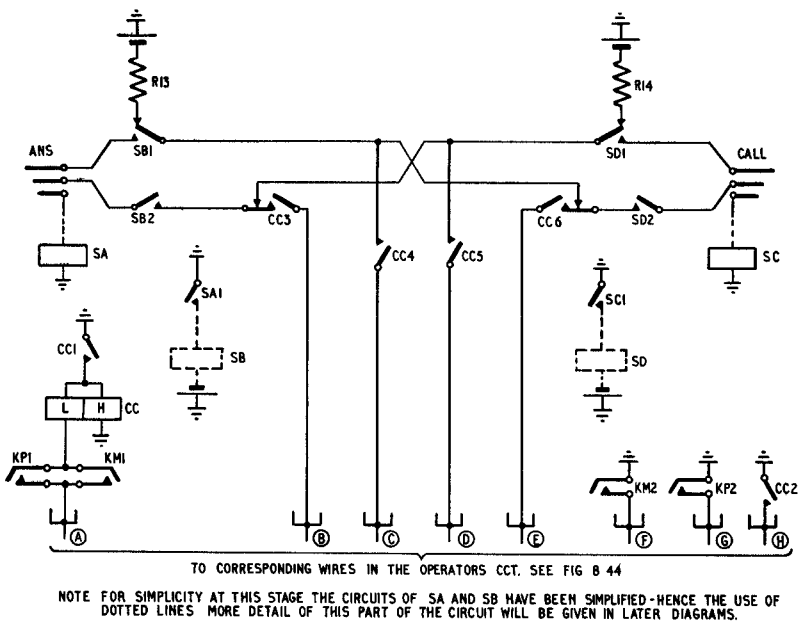


FIG. 8.43. CORD CIRCUIT (TELEX)

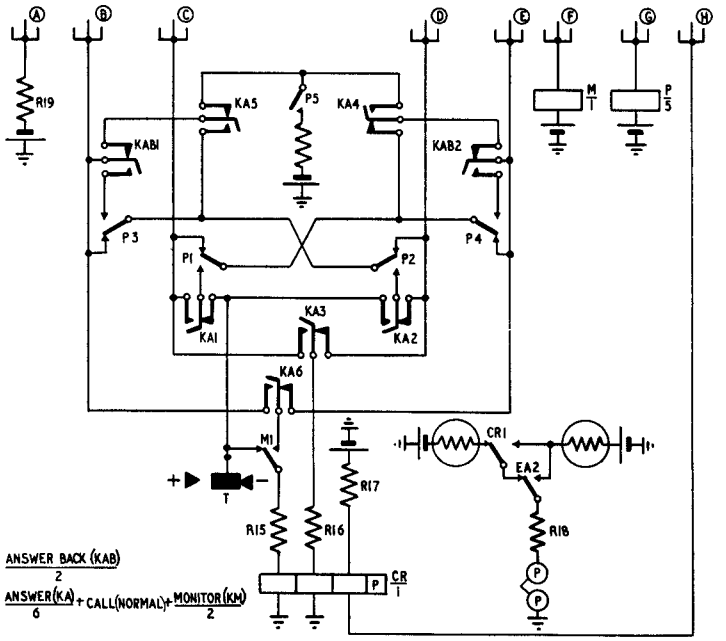


FIG. 8.44. OPERATOR'S POSITION CIRCUIT (TELEX)

As the plug is inserted relay *SA* operates in series with the relay *E* in the line circuit. *E*1 removes the positive battery from the send line. *E*3 operates relay *G* which locks via *G*1. *E*2 and *G*4 lock relay *L*. *G*2 puts out the calling lamp and *G*3 stops the night alarm.

In the cord circuit, *SA*1 operates relay *SB* which switches the line. Thus negative battery from the operator's teleprinter transmitter is connected via *KA*2, *P*2, *KA*5, *KAB*1, *CC*3, *SB*2, into the line circuit, thus replacing the positive battery originally applied via *E*1. On arrival in the subscriber's circuit (see Fig. 8.41) this negative battery causes relay *RA* to operate to mark and *RA*1 operates relay *RB*. (The charging of capacitor *C*1 is rapid, hence relay *RB* operates quickly.) *RB*1 takes over control of relay *MS*. *RB*2 lights the green engaged lamp and releases relay *A*. *RB*3 switches the receive line to the teleprinter electromagnet in readiness for teleprinter signals. *RB*4 applies negative battery from the teleprinter transmitter to the send line and this is received in the cord circuit via *SB*1, *CC*4, *KA*3, *R*16 and one winding of the polarized relay *CR*. At the same time the operator's transmitter is connected via *M*1 and *R*15 to a second winding of relay *CR* whilst the third winding is provided with a spacing current by *CC*2. Thus transmission conditions are set up and the subscriber makes known his request.

Selection of Called Line. The operator now takes the calling cord and places it in the jack of the wanted line. Relay *SC* operates in series with the relay *E* in the called line circuit and *SC*1 operates relay *SD*. Negative battery is now applied via *P*5, *KA*4, *KAB*2, *CC*6, *SD*2 to the send line, in place of the positive battery via *E*1 in the called line circuit. This causes the relay *RA* in the called subscriber's signalling unit to operate to marking. (The called subscriber's circuit is exactly similar to that of the calling subscriber—see Fig. 8.41.) *RA*1 operates relay *RB*. *RB*1 operates relay *MS* which in turn starts the teleprinter motor. *RB*2 lights the green engaged lamp. *RB*3 connects the receive line to the teleprinter receiving magnet and *RB*4 applies negative battery from the teleprinter transmitter via *Z*2 to the send line. This is received in the cord circuit via *SD*1 and *CC*5 but for the moment goes no further.

At this stage in the progress of the call the operating procedure may differ from that of the earlier types of switchboards already described. Instead of leaving the caller to check that he has the correct connexion and to announce his identity to the called subscriber, the operator may take both answer back signals. To do this she first restores the *KA* key to its call position, operates the "answer back" key (*KAB*) and then depresses in turn the *Figs* and *D* keys of her teleprinter. The signals so transmitted are passed via *KA*1, *P*1, *P*4, *KAB*2, *CC*6, *SD*2 to the send line and are received by the called subscriber's teleprinter. (Although the relay *RA* responds to these signals, relay *RB* does not release during the short spacing periods when *RA*1 leaves the marking contact disconnected. This is because the charge on capacitor *C*1 is capable of holding the relay *RB* for a period of 300 msec.)

The called teleprinter now automatically transmits its answer back code (see Chapter XI) and the signals are passed via *RB*4, *Z*2, over the send line to the cord circuit and via *SD*1, *CC*5, *KA*3, *R*16 to a winding of relay *CR*. At the same time these signals also pass via *KA*2, *P*2, *P*3, *KAB*1, *CC*3, *SB*2 to the calling subscriber's receiving electromagnet. Thus, since the called teleprinter provides a local record of its own transmission via its send-receive switch, each of the three teleprinters receives a record of the answer-back signals. The operator then places the key *KA* into the "answer" position and again depresses the *Figs* and *D* keys of her teleprinter. This time the signals pass to the calling teleprinter and when its answer-back signals are returned, they are received by the operator and the called subscriber. The operator then transmits a "go ahead" signal to the caller and retires from the circuit by releasing the print key (*KP*). With the consequent release of relay *CC*, contacts *CC*3, *CC*4, *CC*5 and *CC*6 provide a direct connexion between the answering and calling cords and disconnect the cord circuit from the position circuit which is now available for further use.

Monitoring Circuit. To monitor an engaged connexion, the operator places the cord circuit key into the "monitor" (*KM*) position. *KM*1 operates relay *CC* as described above, and *KM*2 operates relay *M*. Thus connexion between the cords is maintained as follows: tip of answering cord, *SB*1, *CC*4, *P*1, *P*4, *CC*6, *SD*2 to ring of calling cord and tip of calling cord, *SD*1, *CC*5, *P*2, *P*3, *CC*3, *SB*2 to ring of answering cord. At the same time it will be seen that a winding of relay *CR* is teed on to each of the above paths, whilst the third winding is polarized via *CC*2. Hence the relay *CR* responds to whatever signals are present and controls the operator's teleprinter accordingly. While this is going on it will be seen that the teleprinter transmitter is disconnected from the circuit and hence the operator cannot interfere with the engaged connexion. The release of the monitor key (*KM*) restores the original conditions.

Clearing Circuit. Before dealing with the actual clearing circuit, which is shown in Fig. 8.45, the

condition of relays *CLA*, *CLB*, *CLC* and *CLD* should be noted. When the cord circuit is not in use relay *CLA* is held marking by the battery from *R*13. *CLA*1 therefore keeps the relay *CLB* operated and *CLB*1 prevents the lighting of the answering supervisory lamp. Relays *CLC* and *CLD* similarly control the calling supervisory lamp. When the cord circuit is engaged but not carrying traffic, relays *CLA* and *CLC* are still held marking

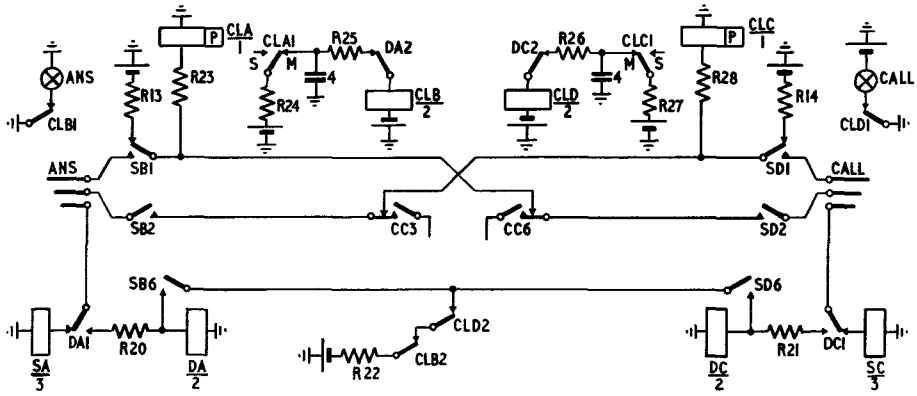


FIG. 8.45. CLEARING CIRCUIT AND FOLLOW-ON-CALL TRAP (TELEX)

by the line signalling batteries but when telegraph signals are passing they respond to these signals.

The circuits of relays *CLB* and *CLD* are similar to that of relay *RB* in the subscriber's circuit (see Fig. 8.41) and hence these relays do not release during the transmission of teleprinter signals. Assuming now that the calling subscriber has completed his message and is ready to clear the call, then the "clear" button (*KZ*) of his signalling unit is momentarily pressed (Fig. 8.41) and this operates relay *Z* which locks via *Z*1 and *RB*2. *Z*2 applies to the send line a positive battery which constitutes the clearing signal. As this signal passes through the cord circuit to the called subscriber's circuit it causes relay *CLA* to space. *CLA*1 disconnects relay *CLB* and after a delay period of 300 msec it releases as explained above. *CLB*1 lights the answering supervisory lamp.

In the called subscriber's circuit the clearing signal causes relay *RA* to space. *RA*1 causes relay *RB* to release after 300 msec. *RB*1 stops the teleprinter motor. *RB*2 puts out the green engaged lamp. *RB*3 applies a negative battery to hold the teleprinter receiving electromagnet in a marking condition. *RB*4 disconnects the negative battery of the teleprinter transmitter from the line and puts in its place the positive battery from resistor *R*2 and *A*3. Thus the clearing signal is returned on the other line and while passing through the cord circuit to the calling subscriber's circuit causes relay *CLC* to space. Thus after 300 msec, relay *CLD* releases and *CLD*1 lights the calling supervisory lamp. *CLD*2 and *CLB*2 now operate relays *DA* and *DC* via contacts *SB*6 and *SD*6 respectively. *DA*1 releases relay *SA* and locks the sensitive relay *DA* in series with relay *E* in the line circuit. This holding current, however, is very small and not sufficient to hold relay *E* which therefore releases. *SA*1 releases relay *SB* (see Fig. 8.43). *SB*1 and 2 break the direct connexion between the plugs of the cord circuit. *SB*1 also causes relay *CLA* to mark again but *DA*2 prevents the re-operation of relay *CLB*.

With the release of relay *E* in the line circuit, *E*1 applies a spacing battery to the send line to take the place of the one cut off by the release of *SB*2 in the cord circuit. *E*2 releases relay *L* and *L*3 releases relay *G*. Thus although the answering cord is still in the jack the line circuit is completely restored to normal. On the calling cord side of the cord circuit, relays *DC*, *SC* and *SD* function similarly and the called subscriber's line circuit is also fully released.

The return of the clearing signal in the receive line of the calling subscriber's circuit causes relay *RA* to space and after 300 msec *RA*1 releases relay *RB*. *RB*1 stops the teleprinter motor. *RB*2 puts out the green engaged lamp and releases relay *Z*. *RB*3 applies a negative battery to hold the teleprinter to mark. On the release of *Z*2, *RB*4 maintains a spacing battery to the send line. Thus both subscribers' circuits and both line circuits are fully restored and although the cords have not yet been withdrawn, direct connexion between the subscribers has been severed. If, therefore, either of the subscribers should wish to make another call, he may press his call button and the calling stage of the circuit will function normally even though the

cords have not been removed. (In the switchboards described earlier in this chapter the subscribers cannot cause the calling lamp to light again until the cords are removed. Furthermore, as the subscribers remain connected through after a clearing signal, then if either subscriber attempts to make a follow-on call the signals are transmitted to the other subscriber until the cords are removed. Also if two or more switchboards are involved in a connexion and delay occurs in removing the cords at any one of the switchboards there is a risk of connecting follow-on calls incorrectly.)

Although it was assumed above that the calling subscriber initiated the clear, an exactly similar sequence of events would take place if the called subscriber were to press his "clear" button.

When the operator withdraws the cords, relays *DA* and *DC* will release as the answering and calling cords respectively are removed. *DA*1 and *DC*1 restore the sleeve circuits to normal. *DA*2 and *DC*2 operate relays *CLB* and *CLD*, and *CLB*1 and *CLD*1 put out the supervisory lamps.

Engaged Conditions. In Fig. 8.43 the circuits of relays *SA* and *SB* were simplified so as not to confuse the main principles of the circuit. Fig. 8.46 shows the circuits of these relays in more detail in conjunction with the engaged test circuit.

When the answering cord is placed into the jack of a disengaged subscriber's line, relays *SA* and *E* operate in series. The electrical potential on the sleeve of the plug is thus reduced to

$$\frac{2{,}000}{2{,}000 + 1{,}200} \times (-80\text{ V}) = -50\text{ V}.$$

Now the mid-point between the equal resistors *R*29 and *R*30 has a potential of −40 V and is therefore positive with respect to the −50 V now on the sleeve. Hence *SA*2 causes current to flow from the mid-point of *R*29 and *R*30 via one winding of relay *T*, *EA*2, *SB*5*y* and *DA*1 to the sleeve. This causes the relay *T*, which is normally held marking by a biasing current in its other winding, to space. *T*1 with *SA*1, therefore, operates relay *SB* via *SB*3. *SB*1 and 2 switch the cord circuit as already explained. *SB*3 locks relay *SB* independent of *T*1. *SB*4 prevents the operation of relay *EA* when *SB*5*y* disconnects the spacing circuit of relay *T* which therefore reverts to mark. This is the normal operation of relay *SB*.

If now the operator puts an answering cord into the jack of a circuit that is already engaged, then two *SA* relays will be connected in parallel to the same relay *E*. The effective resistance of the 2,000 Ω *SA* coils in parallel is 1,000 Ω and hence the sleeve potential then becomes

$$\frac{1{,}000}{1{,}000 + 1{,}200} \times (-80\text{ V}) = -36\text{ V}$$

Thus, on *SA*2 closing, the current flowing in the

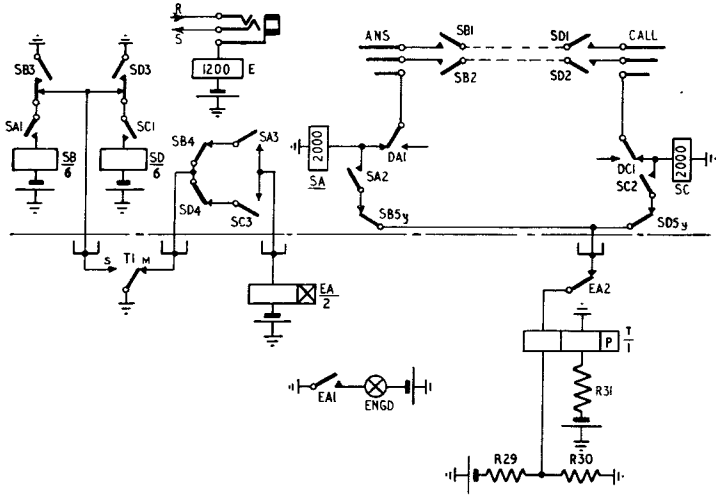


FIG. 8.46. ENGAGED TEST CIRCUIT (TELEX)

relay *T* is of opposite sense to that which obtained in the disengaged line and relay *T* therefore remains marking. *SA*3 operates relay *EA* after a slow operate period which ensures that relay *T* has had time to operate if the conditions are right. *EA*1 lights the engaged lamp and the operator then knows the line is engaged. As relay *SB* has failed to operate, the tip and ring of the cord are not switched and so no interference with the engaged connexion takes place. The operator then withdraws the cord and relay *SA* releases. *SA*3 releases relay *EA* and the circuit becomes normal again. By using this arrangement, it is not necessary to provide engaged lamps adjacent to each subscriber's line jack and in large exchanges in particular, this effects a considerable saving of multiple space.

Junction Working. When it is necessary to connect a subscriber to another who is served from a different switchboard, a junction or trunk circuit between the relative centres is required. Whilst the line circuit of a junction is largely similar to that of a subscriber's line, a few additional facilities are required of the junction circuit. A bothway junction connecting exchanges *A* and *B* and showing

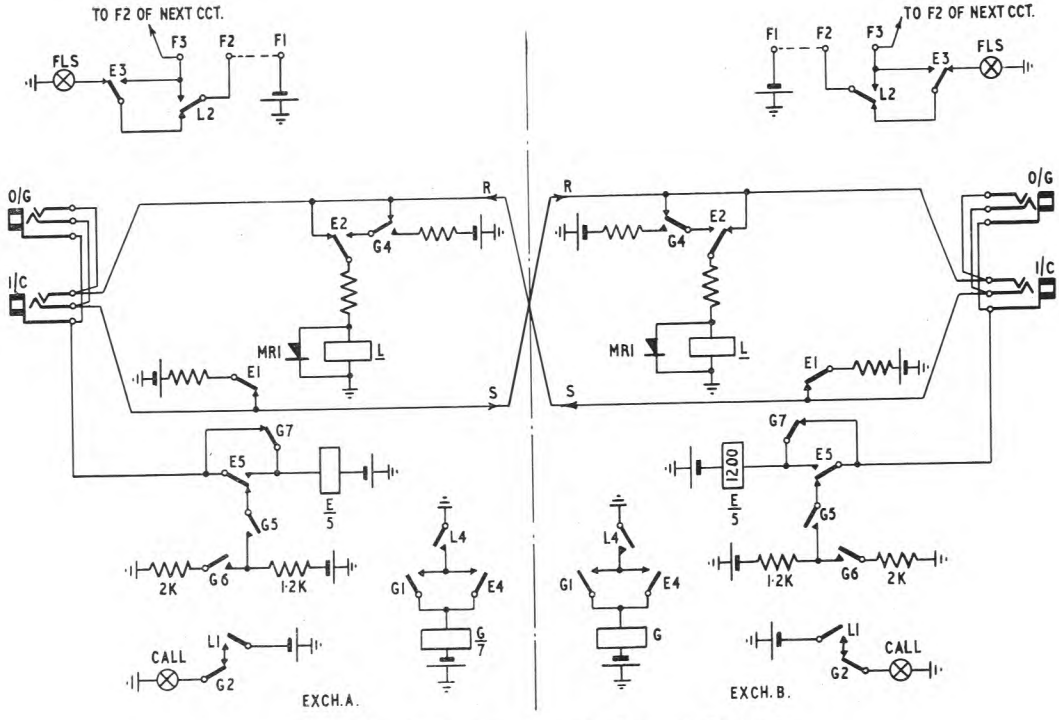


FIG. 8.47. INTER-SWITCHBOARD CIRCUIT (TELEX)

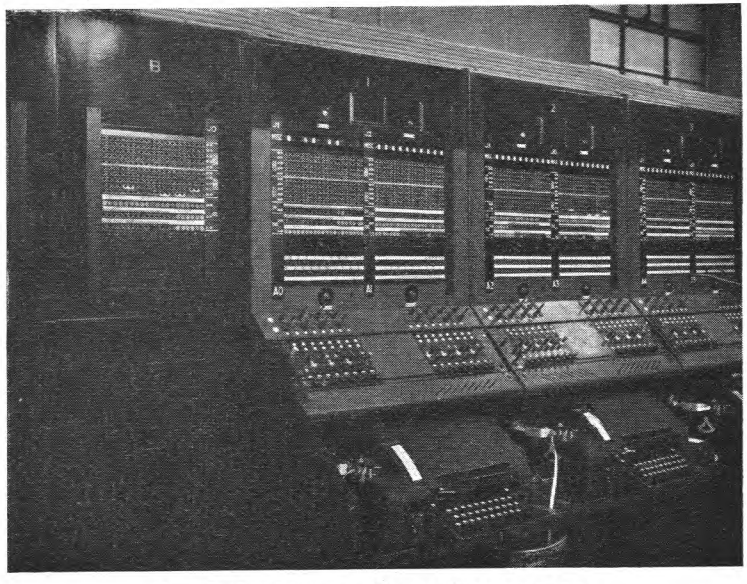


FIG. 8.48. SUITE OF TELEX SWITCHBOARDS

(By courtesy of H.M. Postmaster-General)

the line terminations at each end is shown in Fig. 8.47 and the circuit will be explained by describing a call from *A* to *B*.

Having received a request for a subscriber on exchange *B*, the operator at *A* selects a circuit to *B* (using the F.L.S.) and inserts a calling cord into the jack. This causes the relay *E*, at exchange *A*, to operate. *E*3 controls the F.L.S. lamp appropriately. *E*1 removes the spacing battery from the send line and allows marking battery from the cord circuit to go out in its place. This operates the calling relay *L* at exchange *B* and *L*1 lights the calling lamp. At the same time *L*2 engages the circuit on the F.L.S., so that the line will not be used in the opposite direction.

On the other line of the circuit, *E*1 at exchange *B* maintains a spacing condition which causes the supervisory lamp of the exchange *A* operator's cord circuit to light. When the operator at *B* answers, the relay *E* operates and *E*4 operates relay *G*. *E*2 and *G*4 lock relay *L*, whilst *G*2 puts out the calling lamp. *E*1 removes the spacing condition from the send line at *B* and allows a marking condition from the cord circuit to go out in its place. The calling supervisory lamp at *A* now goes out and the operator at *B* signals her identity. The number required is then requested by the operator at *A* and the operator at *B* completes the connexion, signals *DF* ("You are through to the subscriber") and retires from the circuit. Finally, the operator at *A* takes the answer-back signals as already described and signals to the caller to go ahead.

When the caller clears, the clearing signal is passed from end to end of the circuit and is returned on the other line by the distant subscriber's signalling unit. Thus both cord circuits give double clears and as already described above both relays *E* release. At each end, *E*1 maintains the spacing disengaged line condition and *E*2 releases the relay *L*. Each relay *G* therefore also releases and at each end, the junction is made immediately available for further calls even though the cords have not yet been removed.

Junction Guard. If for some reason, the operator at *A* were to clear the junction by removing the plug before the operator at *B* had made connexion to a subscriber, then it is important that the circuit engaging conditions at *A* should be maintained until the cord is removed at *B*. If then the cord is removed at *A*, but not at *B*, relay *E* releases and *E*1 applies a spacing battery to the circuit and causes the clearing lamp in the cord circuit at *B* to be lit. *E*2, however, does not release relay *L*, since a marking condition is still being received from the cord at *B*. Relay *G* therefore remains operated. *G*5 and *G*6 apply to the sleeve of the jacks a potential equivalent to that of an engaging cord, thus ensuring an engaged condition if the circuit happens to be over-plugged. At the same time *L*2 keeps the circuit marked engaged by the F.L.S.

CHAPTER 9

AUTOMATIC SWITCHING OF TELEGRAPH CIRCUITS

ALTHOUGH telegraph engineers have for many years been keenly interested in the application of automatic switching methods to telegraph circuits, in order to achieve staff economies and improvement in the rapidity and quality of service, the practicability of employing such methods on a national and international scale is a comparatively recent development. Many of the operations to be performed in switching telegraph circuits are similar to those necessary in switching telephone circuits and it is therefore not surprising that the switching techniques used in the design of telegraph automatic switching systems closely follow those already developed for the telephone service.

The interconnexion of teleprinters by automatic switches enables many different user requirements to be met but the precise facilities incorporated in a particular system depend upon the specific requirements of the traffic to be handled. Thus for a Telex service, in which subscribers rent a teleprinter set and can communicate with one another as required, it is necessary to include facilities for recording information concerning calls made in order that accounts can be rendered to the subscribers. In the case of a public telegram service, however, call charging is not a requirement but facilities for alternative routing in the event of route congestion or breakdown and arrangements for the automatic disposal of traffic when a minor office closes, are of some importance. The requirements for private wire networks tend to be somewhat similar to those of the public telegram service.

Many European Administrations have automatized their Public and Telex teleprinter networks and use either a telephone type dial or the teleprinter keyboard for signalling particulars of the required connexion. Some continental systems are arranged so that a common switching network handles both telex and public telegram traffic. The British Post Office, however, has standardized dial selection for its teleprinter systems and has developed separate networks for public service, telex and private services.

The public service was the first to be converted to automatic working by a system known as the Teleprinter Automatic Switching System (T.A.S.S.) the following description of which may be regarded as typical of teleprinter automatic switching practice.

A general view of a teleprinter automatic switching centre is given in Fig. 9.1.



FIG. 9.1. GENERAL VIEW OF A TELEPRINTER AUTOMATIC SWITCHING CENTRE

(By courtesy of H.M. Postmaster-General

Characteristics of Inland Telegraph Traffic

Although the general characteristics of inland telegraph traffic in the U.K. were already known from studies of the teleprinter manual switching network which was employed for public telegram service, a full study of telegraph traffic handled automatically in the U.K. was only practicable when automatic teleprinter switching was actually introduced. A number of assumptions were

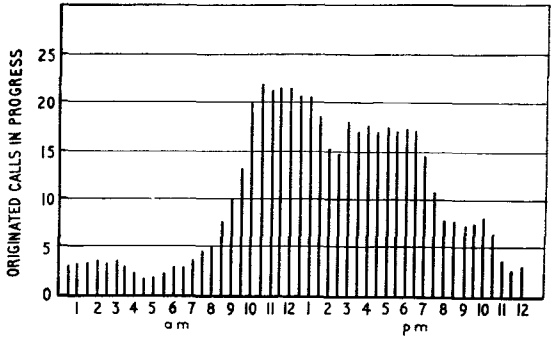


FIG. 9.2. TYPICAL HOUR-TO-HOUR VARIATIONS IN THE VOLUME OF ORIGINATED TRAFFIC (SMALL SWITCHING CENTRE)

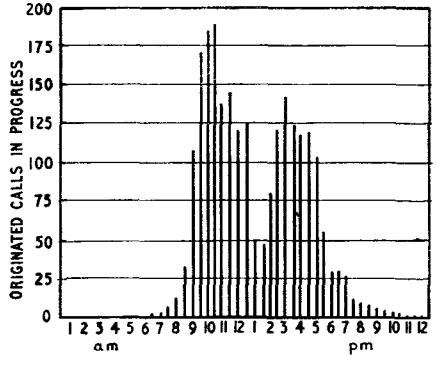


FIG. 9.3. TYPICAL HOUR-TO-HOUR VARIATIONS IN THE VOLUME OF ORIGINATED TRAFFIC (LARGE TELEPHONE EXCHANGE)

necessary to permit the trunking design of the teleprinter automatic switching centres and some of the factors involved will now be examined.

Hourly Traffic Variations. In common with telephone traffic, the telegraph traffic originated in a switching centre varies throughout the day. Fig. 9.2 is a composite graph prepared from a continuous record taken at a representative small switching centre and illustrates the variation of originated traffic during a typical 24 hour period.

The gradual rise in traffic between 7 a.m. and 9 a.m. is produced by the daily programme of position equipment routine testing. The traffic rises rapidly soon after 9 a.m. and, following an ill-defined peak between 10 a.m. and 11 a.m., is maintained at a high level until about 12 noon. A slight decline during lunch period is followed by a rise between 2 p.m. and 3 p.m. to a level only slightly lower than the morning peak. This level is maintained until 6 p.m. and a further minor peak occurs in the late evening.

It is instructive to compare Fig. 9.2 with a similar graph relating to a typical telephone exchange as shown in Fig. 9.3.

The most striking dissimilarity is the relatively constant level of telegraph traffic during the greater

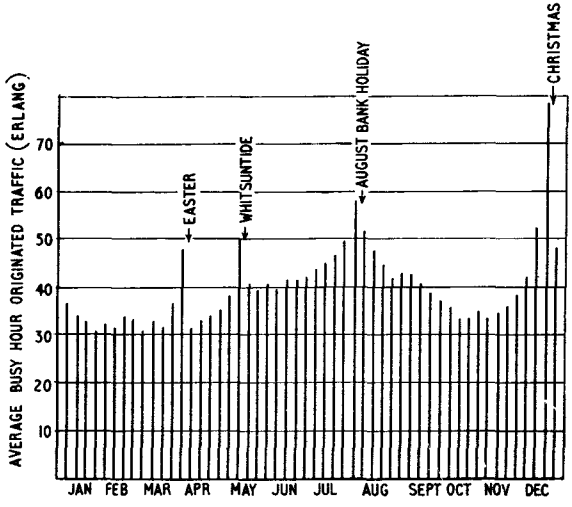


FIG. 9.4. TYPICAL WEEK-TO-WEEK VARIATIONS IN THE VOLUME OF ORIGINATED TRAFFIC (LARGE SWITCHING CENTRE)

part of the working day and this characteristic is one of the fundamental differences between telephone and telegraph traffic. Thus, whereas telephone traffic originating in an automatic network must be handled as it occurs, telegraph traffic, which originates as written messages handed-in over a Post Office counter or prepared at phonogram positions, can accumulate during peak periods in an instrument room and on route to it, before reaching the automatic switching network. The traffic peaks therefore tend to be flattened by this inherent storage process and the traffic level is thereby rendered more uniform. The effect on individual telegrams is reflected in the time which elapses between handing-in and their subsequent transmission over the automatic network.

Seasonal Variations. Public telegraph traffic accurately reflects national and occasionally international events. Fig. 9.4 illustrates the variation

of originated traffic at a typical large switching centre over a period of twelve months.

Traffic declines rapidly at the beginning of the year and remains relatively low until immediately preceding Easter weekend. A further peak occurring during the pre-Whitsuntide period is followed by a more significant rise preceding the August Bank holiday. Traffic during the late summer and autumn declines but rises sharply from mid-December to reach its annual peak level during the pre-Christmas period. This annual traffic pattern is typical of the majority of switching centres but cases do arise where, due to the special character of the traffic, the seasonal peak occurs at a time other than the few days immediately preceding Christmas.

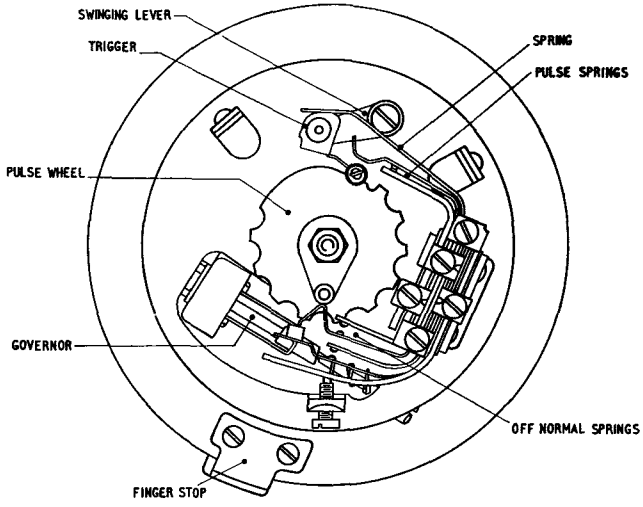


FIG. 9.5. REAR VIEW OF DIAL AUTO NO. 14

Fortuitous events such as national calamities can produce local and occasionally more widespread traffic peaks of unusual magnitude. International events can change the pattern of telegraph traffic in a startling manner. During the 1939–45 war telegraph traffic, which for some years had shown a steady decline, increased to approximately 125 per cent of the 1938 level. Since 1945 telegraph traffic has resumed the pre-war tendency to decline by a few per cent per year, and is mainly attributable to the more widespread use of the telephone.

Busy Hour. The busy hour is defined as the hour during which the traffic passing through a switching centre, or over a group of trunks, is greatest. For the sake of convenience the busy hour is always considered to commence at the beginning of an hour or half-hour.

As already stated, telegraph traffic remains reasonably constant between 10.30 a.m. and 12 noon and traffic records are normally taken between these times to ensure that busy hour traffic is recorded.

Busy Hour/Day Ratio. Busy hour telegraph traffic is frequently expressed as a proportion of the total traffic occurring during the 24 hours of the day. The relationship between busy hour traffic and total daily traffic is termed the Busy Hour/Day Ratio. During the greater part of the year the average value of this ratio is 1:6·8. During the pre-Christmas seasonal traffic peak the ratio rises to about 1:8.

Average Call Duration. It will be obvious that the duration of a particular switched telegraph call may fall between quite wide limits, the most significant factor being the length of message to be transmitted. To enable traffic estimates to be prepared from call quantities it will be appreciated that a knowledge of the average call duration is important. An average call duration of 60 seconds was used for the original traffic design of the Inland Teleprinter Automatic Switching System.

Switching Mechanisms

The switching mechanisms used are the same as those of the telephone service and full descriptions are beyond the scope of this book. The following information is intended to cover only the important characteristics and for more detailed information reference should be made to *Telephony*, Vol. II, J. Atkinson.

Dial Auto No. 14. The dial used is the B.P.O. Dial Auto No. 14 which is designed to produce at the pulsing contacts a train of pulses according to the digit dialled. The number of pulses in the train corresponds to the digit dialled, apart from digit 0, for which the number of pulses is 10. The nominal ratio of the pulses is 67 per cent break, 33 per cent make and the nominal speed 10 pulses per second (PPS).

A view of the dial mechanism is given in Fig. 9.5.

When the dial is at rest, the pulsing contacts are closed and the trigger takes up the position shown in Fig. 9.5. Forward rotation of the dial by the caller winds the main spring (not shown) and also rotates the pulse wheel in an anticlockwise direction, viewed from the rear, and in so doing moves the trigger into the position shown in Fig. 9.6.

On the release of the dial, the pulse wheel is rotated clockwise under the control of the main spring. The trigger engages with the teeth on the pulse wheel and is pulled to the right as shown in Fig. 9.7.

Further rotation of the pulse wheel causes the pulse springs to be opened as the trigger rides over

the teeth on the pulse wheel. The number of pulses in the train is equal to the number of teeth over which the trigger rides and this in turn is governed by the digit dialled. The dial is fitted with a centrifugal governor which maintains the pulsing speed within the limits 9–11 PPS.

To enable the switching centre equipment to distinguish between successive digits, two consecutive pulse trains must be separated by an interval of at least 500 milliseconds duration,

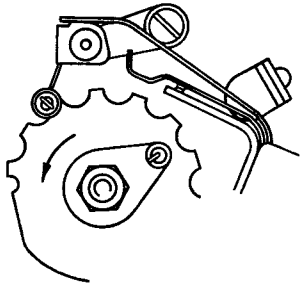


FIG. 9.6. FORWARD ROTATION OF DIAL, POSITION OF TRIGGER ASSEMBLY

known as the interdigit pause. With this in mind the pulse wheel has been proportioned so that on the release of the dial the transmission of the first pulse occurs approximately 240 milliseconds after the pulse wheel commences to rotate. This period

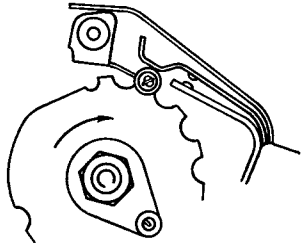


FIG. 9.7. BACKWARD ROTATION OF DIAL, SHOWING THE TRIGGER POSITION DURING PULSING

is known as the minimum pause period and, together with the time taken by the caller to rotate the dial in a forward direction, ensures that the required interdigit pause is produced. The off-normal spring set is not used on teleprinter switching positions and is therefore not connected.

Selectors. Two types of selectors are used. One is the uniselector in which the wipers are rotated in fixed planes over banks of contacts arranged in arcs each of 25 contacts. The other is the 2,000-type selector using the well known Strowger principle in which the bank contacts are arranged in 10 levels each of 10 contacts, so that to connect the wipers to a given bank contact the wipers must first be stepped vertically to select the appropriate level and then horizontally, by rotary stepping, to select the required contact in the level.

No. 2-type Uniselector. The uniselector used is the standard B.P.O. No. 2-type uniselector and Fig. 9.8 shows the mechanical arrangements in a simplified form.

On energizing the electromagnet the armature is

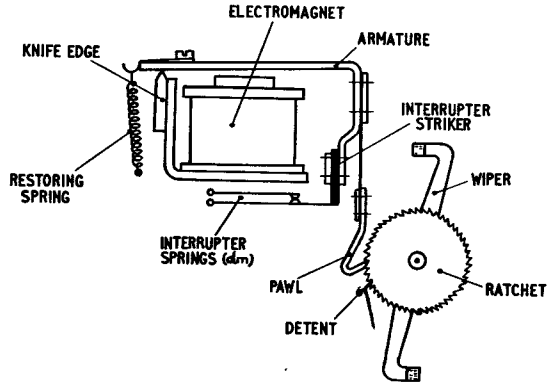


FIG. 9.8. SIMPLIFIED MECHANICAL ARRANGEMENT OF NO. 2-TYPE UNISELECTOR

attracted downwards against the pull of the restoring spring so allowing the pawl to drop into the next tooth on the ratchet. Whilst the pawl is moving downwards the ratchet is restrained from rotating by the detent.

When the electromagnet is de-energized the restoring spring causes the armature to pivot at the knife edge, so forcing the pawl upwards thus causing the ratchet to rotate by an angular displacement equal to one tooth position. The wipers, which are rigidly fixed to the ratchet, are also rotated and the size of the teeth on the ratchet wheel is such as to ensure that one step causes the wiper tips to pass from one bank contact to the next. Since the wipers are stepped when the electromagnet is de-energized, the uniselector is said to be of the reverse acting type in contradistinction to the forward acting type in which the wipers are stepped during the period in which the electromagnet is energized.

On the operation of the armature the interrupter striker opens the interrupter springs (dm). If these springs are wired in series with the electromagnet, the armature is repeatedly operated and released, since as soon as the armature operates the electromagnet circuit is broken and the armature must therefore release, whilst as soon as the armature releases the electromagnet circuit is completed and

the armature reoperates. This repeated operation of the armature causes the wipers to be stepped continuously and is known as "self drive."

The bank contacts are arranged in semi-circular arcs of 25, and the ratchet wheel has 50 teeth. When double ended wipers are used there are two positions of the wheel at which the wiper connects with a particular contact. Thus the 25 outlets are swept over every half revolution of the ratchet wheel. By using single ended wipers it is possible

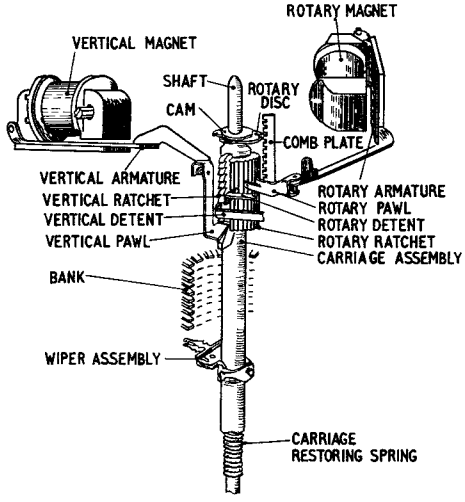


FIG. 9.9. SIMPLIFIED ARRANGEMENT OF 2,000-TYPE SELECTOR MECHANISM

to obtain a 50 outlet switch and for this it is necessary to use two single ended wipers, staggered by 180°, sweeping over separate arcs. Thus in one revolution of the switch the two wipers will sweep over 50 different contacts. Connexion to the wipers is made by means of flat spring brushes riding in parallel sided collector rings carried on the ratchet spindle.

For some applications, instead of the normal arc of 25 separate contacts, a special arc consisting of two contacts is used. One contact corresponds to the rest, or "home" position, of the uniselector, whilst the other is a continuous curved strip occupying the remaining 24 outlet positions. Such an arc is known as a "homing" arc because one of its main uses is to provide a means of self-driving the switch to its home position.

The 2,000-type Selector. The important mechanical features of the 2,000-type Selector are shown in Fig. 9.9. The wiper shaft carries sets of wipers which may be positioned on bank contacts by successive vertical and horizontal (rotary) movements.

The carriage assembly, which is hollow and surrounds the fixed shaft, carries the vertical and rotary ratchet assemblies as well as the wipers. When the vertical magnet is energized, the vertical armature is drawn upwards causing the vertical pawl to engage with the vertical ratchet, thereby raising the carriage assembly by one step. On the release of the vertical armature, the carriage assembly is restrained from dropping by the action of the vertical detent which engages with the vertical ratchet. By feeding successive pulses of current into the vertical magnet the carriage assembly, together with its wipers, is raised a number of steps equal to the number of pulses applied to the magnet.

To rotate the wipers into the bank it is necessary to energize the rotary magnet. This causes the rotary armature to move to the left so engaging the rotary pawl in the rotary ratchet. The carriage assembly is rotated against the tension of the restoring spring and in so doing disengages the vertical detent from the vertical ratchet. The carriage assembly is prevented from dropping, however, by the rotary disc which engages with the comb plate. On the release of the rotary magnet, the rotary armature moves to the right under the control of the restoring spring but the carriage assembly remains locked by the rotary detent. Successive operations of the rotary armature result in the wipers being stepped over successive bank contacts on the level to which the carriage assembly has been raised.

To restore the switch to its normal, or disengaged, position the carriage assembly is rotated to the twelfth rotary position. This drives the wipers clear of the bank contacts and also brings a slot in the rotary disc opposite the comb plate. The carriage assembly is then free to fall vertically, the slot in the rotary disc clearing the projections on the comb plate. When the carriage assembly has dropped so that the wipers are below the bottom (first) level of bank contacts, the rotary detent disengages from the rotary ratchet and the carriage assembly is rotated to the normal position under the control of the carriage restoring spring.

In order to facilitate the electrical control of the selector mechanically operated spring sets are provided. These spring sets are actuated by cams fitted to the carriage assembly, or by projections from the vertical or rotary armatures.

Vertical Off Normal Spring Set (*N*). These contacts are operated as soon as the switch is stepped vertically and remain operated until the switch is restored to the rest or normal position.

Rotary Off Normal Spring Set (*NR*). These contacts are operated when the wipers are given the

first rotary step. The contacts remain operated until the wipers leave the level.

Vertical Interrupter (*VI*). These contacts operate when the vertical armature is operated and restore when the vertical armature is released. A toggle action is provided to ensure late operation in both directions of armature movement. By connecting a vertical interrupter break contact in series with the vertical magnet it is possible to obtain a self-drive action.

Rotary Interrupter (*RI*). These contacts are similar to the vertical interrupters except that they serve the rotary function.

Level Spring Set (*NP*). These contacts can be arranged to operate when the wipers are stepped to any selected level (or levels) and release when the wipers leave that level.

Eleventh Step Spring Set (*S*). These contacts are operated when the wipers are rotated to the eleventh rotary position on each level. The contacts release when the wipers leave the eleventh step.

Step-by-Step Switching Principles

The teleprinter automatic switching system is based on step-by-step switching principles, in which the pulses produced when each digit is dialled, position the wipers of successive selectors and thereby establish a switched connexion between the calling office and the called office. The main items of switching equipment employed in a switching centre to permit the required selections to be made and the principles upon which they are interconnected will now be considered.

Final Selector. The final selector uses a 2,000-type two-motion selector mechanism and is arranged to accept the last two digits, i.e. "tens" and "units" of the sequence dialled. The "tens" digit steps the wipers vertically to the level corresponding to the "tens" digit dialled and the "units" digit steps the wipers horizontally into the bank to connect to one of the station lines connected to the bank contacts.

It will be clear that 100 different final selector numbers are available on the final selector bank and thus a maximum of 100 offices may be connected. As will be explained later, the final selector is arranged, by wiper switching, to provide access to a maximum of 200 station lines and to accommodate office groups of up to 20 lines: the selector hunts for the first free line within the group.

The bank contacts of a group of final selectors are "multipled" to provide access from each selector in the group to all lines in the multiple. Simultaneous calls may thus take place to different lines in the multiple, the number of such calls being equal to the number of final selectors serving the group.

Group Selector. A final selector multiple can accommodate a maximum of 100 offices, therefore to extend the capacity of a switching centre beyond 100 offices it is necessary to introduce a further stage of selection by means of group selectors. The group selector, like the final selector, uses a two-motion selector mechanism but is arranged to accept only one digit, which steps the selector wipers vertically to the level corresponding to the digit dialled. During the subsequent interdigit pause, the selector wipers are rotated automatically into the bank to seize, via the bank contacts, a free final selector in the required group.

In addition to affording access to final selectors, the levels of group selectors are also used to provide access to further stages of group selection and to trunk routes. So that all group selectors in a group have access to all outlets on a particular level these outlets are multipled over the banks of all the selectors in the group.

Group selector banks provide 10 outlets per level but, by the introduction of wiper switching relays (to be described later), this may be increased to 20 outlets per level. The total bank capacity thus becomes 200 outlets, hence such a selector is known as a 200 outlet group selector.

Group selectors are designated First, Second or Trunk selectors according to their position in the switching train. A first selector receives the first digit of a selecting train. A trunk selector terminates the incoming end of a trunk circuit, and a second selector is one which is connected as an outlet on the bank multiple of first and/or trunk selectors.

Station Line Circuit. Since group selectors are relatively expensive it is uneconomic to provide separate selectors for each station line. This difficulty is overcome by terminating the switching centre end of the station line on a Station Line Circuit (S.L.C.), comprising a uniselector and a small relay group.

The main purpose of the S.L.C. is to connect the station line to a group selector when an outgoing call is to be made. This is accomplished by connecting the station line to the wiper side of the uniselector and cabling the 25 uniselector bank contacts to a maximum of 25 group selectors. On receipt of a calling signal from the office, the uniselector steps to connect the line to a disengaged group selector. The bank contacts of uniselectors serving a number of S.L.C.'s are multipled so that a small pool of group selectors is shared by the station lines. The S.L.C. also connects the station line to the final selector multiple for calls incoming to the teleprinter office.

Bothway Trunk Relay Set. To permit the seizure

of a trunk circuit from a group selector level it is necessary to provide a relay set at the outgoing end of each trunk circuit. When the trunk is operated on a "bothway" basis the relay set also allows incoming calls to be connected direct to the trunk selector and for this reason is known as a Bothway Trunk Relay Set.

Outgoing Selector Level Relay Set. This relay set allows station lines to be connected to group selector levels. The main instrument room associated with each switching centre may therefore be served direct from a first group selector level, thereby economizing in switching equipment and minimizing dialling time as fewer digits are dialled.

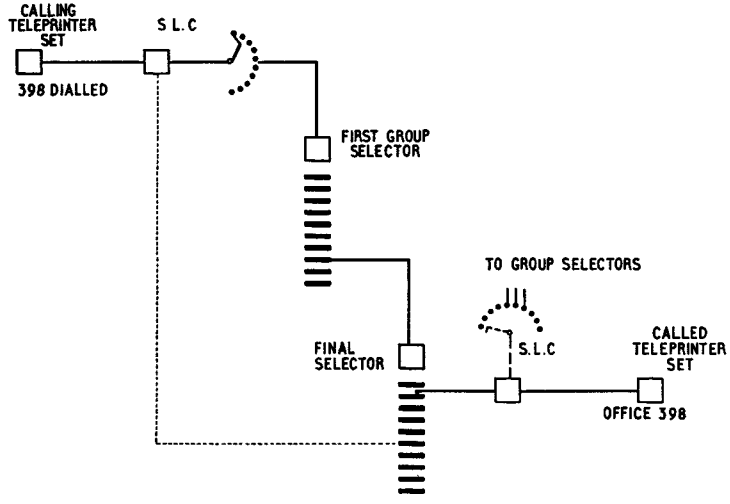


FIG. 9.10. CALL TO OFFICE "398" ON SAME SWITCHING CENTRE

Routing of Typical Calls. Fig. 9.10 shows the routing of a call from one teleprinter office to another on the same switching centre. The directory number of the called office is "398" and this is the digit sequence dialled by the calling operator.

The calling operator initiates the call by operating a key on the teleprinter position. A signal transmitted over the station line causes the uniselector incorporated in the S.L.C. to hunt for and seize a free first group selector. The operator dials 398 and the hundreds digit (3) steps the wipers of the first group selector to level 3. The wipers rotate around the level to find and seize a free final selector serving the group of 100 lines containing the required office. The wipers of the final selector are then stepped to level 9 by the tens digit and rotated 8 steps into the bank by the units digit. The wipers then rest on the bank position corresponding to office "398," thus the required selection has been made.

Fig. 9.11 shows the routing of a call between offices on two different switching centres. The digit train to be dialled from the originating office on switching centre *A* must include an additional digit to select the trunk route. In the example shown it is necessary to dial "7485" to reach the required objective office. Digit 7 steps the wipers of the first group selector to level 7 to select a free trunk circuit to switching centre *B*. Connexion to the trunk circuit is made by means of a bothway trunk relay set at switching centre *A*. At switching centre *B* the trunk circuit is connected via a second bothway trunk relay set to an incoming trunk selector. The next digit 4 steps the wipers of the incoming trunk selector to level 4, the tens and units digits position the final selector wipers as already described to complete the connexion.

Fig. 9.12 illustrates an example of the use of the outgoing selector level relay set.

Trunking Principles

In an automatically switched telegraph or telephone network it is essential in order to ensure efficient and economic handling of calls, both at the opening date, and subsequently, that the traffic is routed in the most advantageous manner and the quantities of switching apparatus and circuits provided are adequate to carry the traffic. The branch of engineering switching design which embraces these matters is called "Trunking." It is a most important aspect of the design of a switching network as the improved efficiency and economies attained from the use of automatic switching methods can only be fully realized by efficient trunking arrangements.

Definitions of Basic Trunking Terms are as follows—

Pure Chance Traffic. The number of calls in progress in a switching centre changes from instant to instant depending upon the relative times of incidence and duration of individual calls. Pure chance traffic may be defined as traffic in which a call is as likely to originate at any one instant as at any other. This definition implies that the number of traffic sources is infinite, a premise which is obviously only approximately true in practice.

Grade of Service. Since at every switching centre (or exchange) the number of calls simultaneously in progress changes continuously, it follows that the traffic carried will be greatest during one particular period. This period is generally specified as an hour,

the hour of heaviest traffic being defined as the Busy Hour.

Since the number of calls simultaneously in progress during the Busy Hour varies within certain limits, switching equipment and circuits must be provided in some methodical manner. It would be uneconomic to provide sufficient switches to carry the maximum number of simultaneous calls possible, and in practice a definite proportion of calls is permitted to fail to establish connexion at each switching stage due to insufficiency of apparatus or circuits. The calls which fail are termed "Lost" although this does not infer that the message is lost, as the originating operator is made aware that the call is unsuccessful and that a further attempt to establish connexion must be made. The proportion of calls allowed to fail for this reason is termed the Grade of Service and is generally represented by the symbol B.

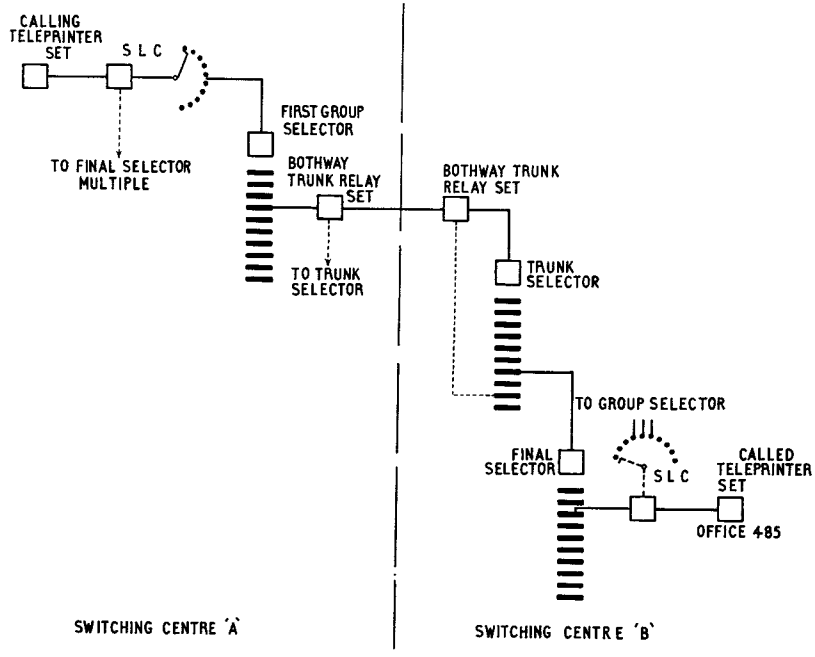


FIG. 9.11. CALL TO OFFICE "485" ON DISTANT SWITCHING CENTRE

If one call in 500 is lost the Grade of Service is expressed as $B = \frac{1}{500}$ or $B = 0{\cdot}002$.

Unit of Traffic. The quantity of switching equipment or circuits required to carry the traffic with a specified grade of service depends upon the number of calls and their duration. To facilitate the calculation of equipment and circuit quantities it is necessary to express the traffic in a suitable unit. The unit chosen is called the Erlang, named after A. K. Erlang a Danish engineer. The unit of traffic was formerly known as a Traffic Unit (TU). In any given volume of traffic the traffic flow for a specified period, generally the Busy Hour, is said to be unity when the average number of simultaneous calls during the period is also unity. In these circumstances the traffic flow is 1 Erlang. An Erlang is thus equivalent to the traffic flow in one circuit continuously occupied.

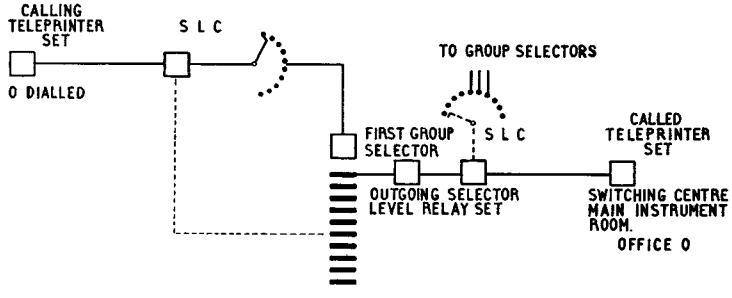


FIG. 9.12. CALL TO OFFICE "0" ON SAME SWITCHING CENTRE

The traffic flow in Erlangs for a specified period

is therefore the arithmetic product of the number of calls originated during the period and the average call duration expressed as a fraction of the period. It will be seen that the traffic flow in Erlangs will also be numerically equal to the average number of calls simultaneously in progress during the period. If C is the number of calls originated during a specified period and T is the average call duration

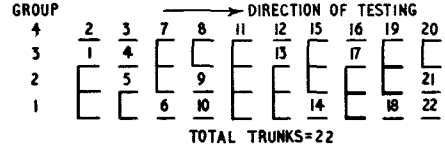


FIG. 9.13. EXAMPLE OF INTERCONNECTING

expressed in terms of this period, then the traffic in Erlangs is usually symbolized as—

$$A = C \times T.$$

Availability. In automatic switching the term Availability is used to express the number of outlets in a group to which a selector has access.

The availabilities afforded by a 24-point uniselector and a 200 outlet two-motion selector are respectively 24 and 20. The term Full Availability is used to describe the condition under which all traffic sources in one group have access to every connecting circuit or trunk to another group. Limited Availability describes the condition where a traffic source in one group has access to only a proportion of the trunks to another group.

Erlang's Full Availability Theory. A fundamental requirement for the design of switching centres is a means of estimating the equipment and circuit quantities necessary to carry given volumes of traffic at a specified Grade of Service. A number of theoretical formulae has been developed by different investigators. That adopted by the B.P.O., as best suiting the conditions obtaining in the U.K. telephone network, is the theory deduced by Erlang. Although, as will be mentioned later, the assumptions made by Erlang do not appear to apply exactly to the traffic carried by the U.K. Inland Teleprinter Automatic Switching System, practical discrepancies have not justified an alternative standard.

Erlang's theory states that—

$$B = \frac{\dfrac{A^N}{\underline{|N}}}{1 + A + \dfrac{A^2}{\underline{|2}} + \dfrac{A^3}{\underline{|3}} + \cdots \dfrac{A^N}{\underline{|N}}}$$

where B = Grade of Service,
A = Traffic offered in Erlangs,
N = Number of trunks required,
$\underline{|N} = N(N-1)(N-2) \ldots (2)(1)$

Traffic Capacity Tables calculated from this formula are readily available (see *Traffic and Trunking Principles in Automatic Telephony*—G. S. Berkeley). Tables 9.1, 9.2 and 9.3 provide examples.

Grading. Full Availability conditions exist only if the number of trunks required to carry the volume of traffic does not exceed the "availability" of the switching equipment. Clearly the boundary could be raised by increasing the number of contacts in the bank multiple (i.e. the availability) of the switches. However, practical and economic limitations enforce the acceptance of an alternative solution.

A large volume of traffic could be handled by subdivision into separate smaller blocks each within the capacity of a full availability group. Examination of traffic tables will show this method to be inefficient from a quantitative viewpoint. The practical solution to the problem is found in the process of "Interconnecting." The bank multiples of the selectors are brought out in separate groups and each group of outlets is given access to a number of trunks corresponding to the number of bank contacts. A proportion of these trunks is, however, connected to two or more groups of outlets. Any scheme for connecting bank multiple outlets to share a proportion of the trunks between

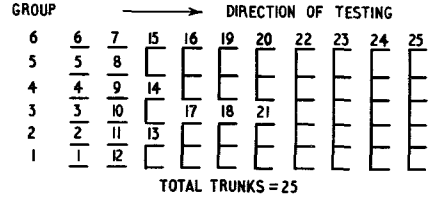


FIG. 9.14. EXAMPLE OF GRADING

two or more groups is known as interconnecting. An example of interconnecting is shown in Fig. 9.13.

One form of interconnecting, termed grading, is widely employed by the B.P.O. In this method of interconnecting, a group of selectors is given access to individual trunks on the early choices of the bank multiple but shares trunks with other groups in later choices. An example of grading is shown in Fig. 9.14.

The number of groups required in a grading to give access to a particular number of trunks may,

with certain exceptions, be determined from the following formula—

$$g = \frac{2n}{a}$$

where

g = number of groups
n = number of trunks in the grading
a = availability of the selectors.

For any given value of g and n many different grading arrangements may be possible. The most efficient grading or "best grading" is provided by the scheme which achieves the smoothest progression from individuals through the various partial commons to full commons. Best gradings may be selected by the algebraic summation of the successive differences between the numbers of individuals, pairs, threes, etc., required by the various possible arrangements.

In a book of this nature it is only possible to include brief notes on basic traffic and trunking factors. A more detailed treatment may be found in other works (see *Traffic and Trunking Principles in Automatic Telephony*—G. S. Berkeley, and *Telephony*, Vol. II—J. Atkinson).

Delayed Hunting and Overflow Facilities. The traffic originated and received by the majority of Inland Telegraph Offices will justify only relatively few circuits.

The inefficiency of small circuit groups when handling automatically switched traffic at a reasonable Grade of Service can readily be seen by reference to Tables 9.1, 9.2 and 9.3.

The proportion of calls meeting engaged conditions on groups of lines to telegraph offices may be greatly reduced by allowing a proportion of such calls to "wait," or queue, for a line in the required group to become free. The provision of indefinite wait or suspense facilities is possible but this procedure could result in excessive waiting time, particularly under fault conditions. The obvious advantages of permitting limited waiting time have been exploited by arranging for calls delayed in this way to be released from "suspense" at the end of an unsuccessful wait period of predetermined length.

Calls released after waiting unsuccessfully for the prescribed period are re-routed automatically to one of a group of "Overflow" teleprinter positions situated in the main instrument room associated with the switching centre serving the objective office. The message is subsequently retransmitted to its destination by the "overflow" Centre staff. This artifice restricts the number of repeat calls necessitated by encountering "engaged" conditions on called stations, with a consequent reduction of ineffective holding time on long distance connexions.

The delayed hunting and overflow facilities incorporated in the final selector are controlled by a relay set, known as the "Suspense Relay Set," which is linked to all the lines serving a particular office. For groups of lines not exceeding four in number a single queue place or "wait" contact is

TABLE 9.1

Traffic Capacity Table: Availability 20; G.O.S. 0·02.

No. of Trunks	Erlangs Carried	No. of Messages	No. of Trunks	Erlangs Carried	No. of Messages
1	0·02	1	21	13·62	817
2	0·22	13	22	14·35	861
3	0·59	35	23	15·08	904
4	1·07	64	24	15·81	948
5	1·63	97	25	16·54	992
6	2·23	133	26	17·27	1,036
7	2·87	172	27	18·00	1,080
8	3·56	213	28	18·73	1,123
9	4·26	255	29	19·46	1,167
10	4·98	298	30	20·19	1,211
11	5·72	343	31	20·92	1,255
12	6·48	388	32	21·65	1,299
13	7·25	435	33	22·38	1,342
14	8·04	482	34	23·11	1,386
15	8·83	529	35	23·84	1,430
16	9·63	577	36	24·57	1,474
17	10·44	626	37	25·30	1,518
18	11·25	675	38	26·03	1,561
19	12·07	723	39	26·76	1,605
20	12·91	774	40	27·49	1,649

TABLE 9.2

Traffic Capacity Table: Availability 20; G.O.S. 0·001.

No. of Trunks	Erlangs	No. of Messages	No. of Trunks	Erlangs	No. of Messages
1	0·001	—	21	10·00	600
2	0·046	3	22	10·59	635
3	0·19	11	23	11·19	672
4	0·43	26	24	11·78	707
5	0·76	46	25	12·38	743
6	1·14	68	26	12·98	778
7	1·58	95	27	13·57	814
8	2·05	123	28	14·17	850
9	2·56	154	29	14·76	885
10	3·09	185	30	15·36	922
11	3·65	219	31	15·96	958
12	4·23	254	32	16·55	993
13	4·83	290	33	17·15	1,029
14	5·44	326	34	17·74	1,064
15	6·08	365	35	18·34	1,100
16	6·72	403	36	18·94	1,136
17	7·38	443	37	19·53	1,172
18	8·04	482	38	20·13	1,208
19	8·72	513	39	20·72	1,243
20	9·41	565	40	21·32	1,279

TABLE 9.3

Traffic Capacity Table: Availability 24; G.O.S. 0·001.

No. of Trunks	Erlangs	No. of Messages	No. of Trunks	Erlangs	No. of Messages
1	0·001	—	21	10·11	607
2	0·046	3	22	10·81	649
3	0·19	11	23	11·52	691
4	0·43	26	24	12·24	734
5	0·76	46	25	12·88	773
6	1·14	68	26	13·51	811
7	1·58	95	27	14·15	849
8	2·05	123	28	14·79	887
9	2·56	154	29	15·42	925
10	3·09	185	30	16·06	964
11	3·65	219	31	16·70	1,002
12	4·23	254	32	17·33	1,040
13	4·83	290	33	17·97	1,078
14	5·44	326	34	18·61	1,117
15	6·08	365	35	19·25	1,155
16	6·72	403	36	19·88	1,193
17	7·38	443	37	20·52	1,231
18	8·04	482	38	21·16	1,270
19	8·72	513	39	21·79	1,307
20	9·41	565	40	22·43	1,346

N.B. Average call duration = 60 sec.

provided. A second "wait" contact is associated with line groups in excess of four.

Numbering Schemes

For obvious reasons it is desirable to be able to issue a single national directory in which each office has a unique directory number. There are two basic methods of achieving this: by using dial code lists or by setting up a linked numbering scheme.

Dial Code Lists. In a dial code list scheme the directory entry for each station shows the name (or letter code) of the switching centre, together with its local number on the switching centre. Each station is provided with a dial code list giving the routing codes to be dialled to reach other switching centres, so that to call a distant station the procedure is to first dial the routing code corresponding to the distant switching centre followed by the digits of the required station's local number. It follows that there is a distinctive code list for each switching centre in the network.

Linked Numbering Scheme. A linked numbering scheme is one in which a given station is reached by dialling the same number from any point in the network. There are various methods of achieving a linked numbering scheme but in general they require either more complex circuits, such as register translators or discriminators, or are restrictive in the traffic routings which can be employed. Linked numbering schemes are commonly used in telephone engineering and are of advantage in handling subscriber dialled traffic. For further information reference should be made to *Telephony,* Vol. II—J. A. Atkinson.

Numbering Scheme for Inland Teleprinter Switching System. The numbering scheme chosen for the B.P.O. Teleprinter Automatic Switching System uses dial code lists in order to obtain a high degree of flexibility in the routing of trunk traffic without requiring the use of complex switching equipment. A national directory is issued in which the entry for each office is in the form of a mixed letter and figure code. Thus the entry for Birkenhead might be LV 794. The letters chosen are the telegraphic code of the switching centre serving the section of the country in which the office is situated, and the numerical digits correspond to the Final Selector number on this switching centre allocated to the particular office. Three digit local numbering schemes have been adopted at most switching centres but recourse to four digit schemes has been necessary in a few instances.

The numerical digits to be dialled to reach Birkenhead from a teleprinter position in any other office connected to the network will depend upon the switching centre to which the calling office is connected. To determine the complete sequence of digits to be dialled, the calling operator obtains the numerical equivalent of the letter designation (this may be 36 for LV) from a dialling code list prepared for each switching centre. In this example the complete sequence to be dialled would be 36794. The number of digits required to establish a connexion will vary from one to seven, the average being about four.

National Directory. A National Directory of offices connected to the switching network is published in alphabetical order, the entries being in the form "Blanktown XN 793."

To facilitate the rapid identification of offices from their dialling code, a further directory is available in which offices are arranged in numerical order under the appropriate switching centre.

Traffic Circulation. Telegram forms reaching a teleprinter office connected to the automatic switching network are passed initially to a Circulation Position. The Circulation Officer obtains the Routing Code of the destination office from the National Directory and enters these details on the form. The form is then passed by hand or, in the larger offices, by conveyor belt, to a teleprinter position handling outgoing traffic. The dialling code corresponding to the letters portion of the routing code is obtained from the dialling code list displayed on the position. The layout of this code list is shown in Table 9.4. It will be noticed that "Normal" and "Alternative" codes are listed. The

operator attempts initially to complete the call by making use of the primary, i.e. Normal, dialling code. This code connects the call over the most direct route to the objective switching centre. If two attempts via the primary route meet engaged selector or trunk conditions, the alternative dialling code is employed. Connexions resulting from the use of alternative dialling codes may be less direct than the corresponding primary routes

TABLE 9.4

Typical Teleprinter Switching Centre Dial Code List Card

Letter Code	Dialling Code		Letter Code	Dialling Code		Letter Code	Dialling Code	
	Normal	Alternative		Normal	Alternative		Normal	Alternative
AB	27	71	EA	43	533	NA	45	535
BA			EB	272	712	NB	273	713
BB	4	53	GA	57	657	SA	64	524
BC	32	672	GB	54	654	SB	35	675
CA	27	717	HA	3	67	SC	44	534
CD	34	674	LA	38	678	TD	66	526
DA	5	65	LB	47	537	XE	7	677
DF	6	52	MA	48	538	XF	63	523

NOTE: Do not dial the alternative code unless 'NC' or 'DER T' has been received twice on the normal route.

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to indicate that a group selector is connected to the calling line and that dialling may therefore commence. The signal is a 25 msec pulse of marking polarity and is sent from the switching centre back to the calling station.

Call Confirmation Signal. This signal is used on trunk lines, immediately following seizure for a call, to prove the continuity of the line and the response of the switching equipment at the called switching centre. The signal is a 25 msec pulse of marking polarity and is sent from the called end of the circuit back to the calling end.

Dialling. One of the most important signals in an automatic system is that of dial pulsing. The dials used have break pulsing contacts and it is necessary therefore to introduce a relay with a changeover contact to convert the pulses into double-current signals for transmission over telegraph lines. The break of the dial pulsing contacts is arranged to correspond with a spacing signal and therefore the double-current pulses have a nominal ratio of 67 per cent spacing to 33 per cent marking at a speed of 10 p.p.s.

To ensure that distant selectors are stepped correctly, it is essential that the aggregate distortion of the dial pulses during transmission is small. In practice this is not difficult to achieve as a transmission system which is capable of transmitting teleprinter signals without excessive distortion should, if the required performance has been obtained without signal regeneration, be

but will nevertheless fall within the agreed transmission standards, and by their use it is possible to minimize the effects of breakdowns or temporary traffic overloads on particular routes.

Signalling Principles

The method of signalling used in the B.P.O. Teleprinter Automatic Switching System is based upon the sequence signalling system already described in Chapter 8, but in order to ensure a satisfactory service from an automatic system it is necessary to provide many more signals than are required for a manual system. The following are details of the signalling conditions used.

Disengaged Line. A spacing signal is transmitted in both directions of transmission.

Calling Signal. The spacing signal is changed to marking signal in the forward, i.e. sending, direction. The same signal is used for both trunk and station lines.

Proceed to Select Signal. This signal is used on station lines, when an outgoing call is being made,

capable of handling dial pulses with comparatively little distortion as the pulse duration is longer than teleprinter signal elements.

Call Connected Signal. This signal is used to indicate to a caller that connexion has been made either to a teleprinter or a source of service signals. It consists of a change of polarity in the backward, i.e. receiving direction, from spacing to marking, followed either by the answer-back code of the called teleprinter or the appropriate service signal.

Clearing Signal. This signal is used to release a connexion and consists of a changeover from marking to spacing signal maintained for at least 300 msec. The circuit arrangements permit a clearing signal to be initiated either by the calling or called party, thereby providing an "either party release" system. The switching equipment is so designed that a clearing signal initiated in either direction of transmission is repeated in the other, thereby ensuring that the line signals revert to the disengaged line conditions.

Immediate Release (IR) Signal. This signal consists of 250 msec marking and 1,250 msec spacing, continuously repeated, and is connected to spare levels and numbers. It applies immediate forced release conditions to any call established to a spare level or number.

Service Signals. These are provided so that by means of characters printed on the teleprinter tape at the calling position, an operator can be informed of specific congestion or fault conditions encountered during dialling.

The signals provided and their significance are as follows—

OCC	All lines to the called office are busy.
NC	Trunks busy.
DER S	The selected station line is faulty.
DER T	The selected trunk line is faulty.
MOM	Wait.

Teleprinter Office Arrangements

The equipment provided at a teleprinter position includes, in addition to a teleprinter No. 11, a signalling unit on the front of which is a dial, dial supervisory lamp, keys and a small chart listing the dialling codes of the various switching centres. On the top of the unit are two supervisory lamps, one red and the other green, and inside is the switching apparatus, the main items being a plug-in relay set and a relay switch for controlling the teleprinter motor. At small offices the position equipment is mounted on L shaped tables, the general design allowing for considerable flexibility in office layout. The power supply is usually provided by mains driven rectifier units fitted under the tables.

In larger offices the equipment is mounted on long bench-type tables, the power supplies being taken from batteries. Figs. 9.15 and 9.16 show typical teleprinter office installations.



FIG. 9.15. A TYPICAL SMALL TELEPRINTER OFFICE
(By courtesy of H.M. Postmaster-General)

Facilities. The facilities provide for—

(*a*) Calling the switching centre by the operation of the DIAL press key.

(*b*) Lighting the DIAL lamp on the receipt of the "proceed to select" signal, to indicate that dialling may commence.

(*c*) Setting up connexions by dialling.

(*d*) Starting and stopping the teleprinter motor at the beginning and end of each call and connecting the teleprinter to the line on the receipt of the "call connected" signal.



FIG. 9.16. A LARGE TELEPRINTER OFFICE
(*By courtesy of H.M. Postmaster-General*)

(*e*) Lighting the CALL lamp to indicate the receipt of the "call connected" signal. For incoming calls cleared at the originating position the lamp remains lit until the RESET key is operated.

(*f*) Releasing a connexion by the operation of the CLEAR press key.

(*g*) Busying the line against seizure for traffic at the switching centre. This is achieved by key operation at the teleprinter position to extend an out-of-service signal to the switching centre. Operation of the out-of-service key also provides a circuit for testing the teleprinter in local.

(*h*) Guarding against loss of messages due to paper failure, by releasing the connexion, extending an out-of-service signal towards the switching centre and giving a local alarm in the event of operation of the paper failure contacts of the teleprinter.

Circuit Operation. Reference should be made to Fig. 9.17 which shows the circuit of the teleprinter position in a simplified form.

The disengaged, or free line condition, is signalled by positive battery connected in both directions of transmission.

Outgoing Call. To originate a call, the telegraphist depresses the DIAL key *KD*, which operates relay *C* at *KD*1.* Relay *C* locks at *C*3 and completes a circuit at *C*2 to operate relay *D*. *D*1 connects a negative battery to the *S* wire to call the switching centre. When the switching centre equipment is ready to receive the dialling pulses, a "proceed to select" signal (25 msec pulse of negative battery) is returned to the calling station over the *R* wire. Relay *R* marks for 25 msec and completes the circuit for relay *I* via *R*1, *I*3 and *C*4. Relay *I* has a short operate lag and therefore operates. Relay *RA* which is in parallel with relay *I* does not operate at this stage because it has an operate lag of approximately 60 msec due to the shunting effect of capacitor *QC* in conjunction with resistor *YH*.

Relay *I* in operating lights the DIAL lamp at *I*2: this contact also removes the short-circuit from the pulse springs of the dial. *I*1 completes the circuit for the relay switch *M* which operates to start the teleprinter motor. The telegraphist now dials the

* *KD*1 indicates that contacts *KD*1 are operated. This method of indicating operated contacts will be employed for simplicity throughout the following circuit descriptions.

required number, and the make and break pulses of the dial are converted, at contact $D1$, into double-current signals for transmission over the line. When the called station is connected, a "call connected" signal (steady negative battery) is returned to the calling station and causes relay R to mark. $\underline{R1}$ completes the circuit for relay RA which operates after approximately 60 msec. $\underline{RA2}$ lights the CALL lamp and also operates relay RB. $\underline{RB2}$ and $\underline{RB3}$ connect the teleprinter to line and $\underline{RB5}$ operates relay RC via $\underline{C1}$. $\underline{RC6}$ extinguishes the DIAL lamp and restores the short-circuit across the dial pulse springs.

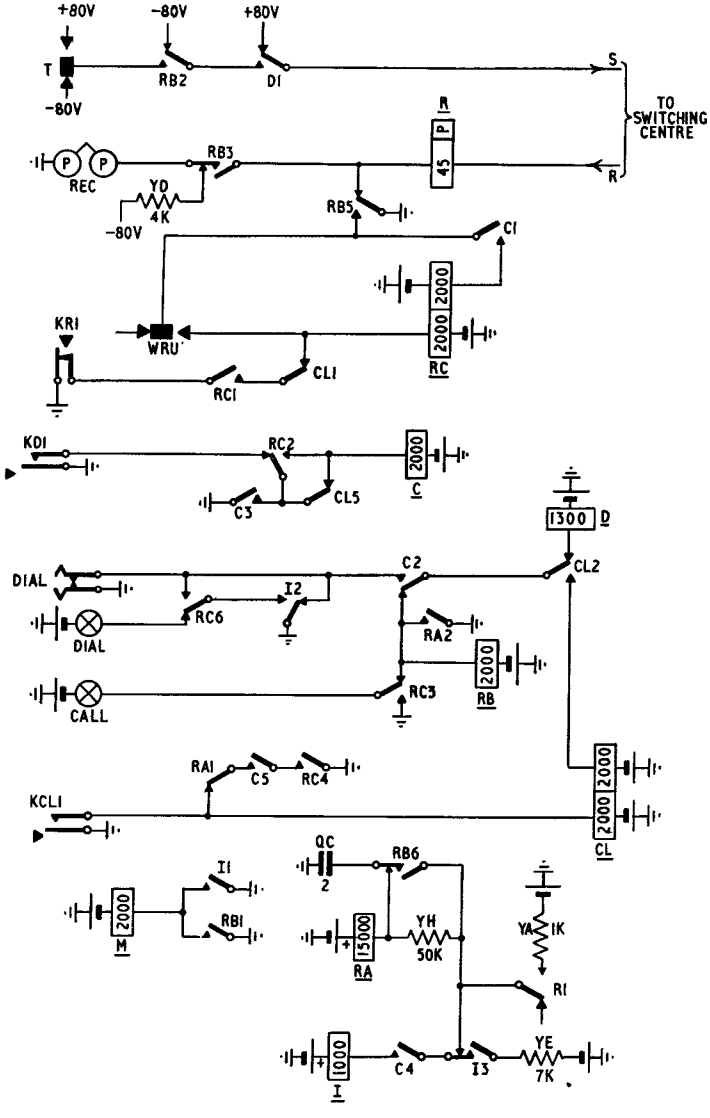


FIG. 9.17. SIMPLIFIED POSITION CIRCUIT

The "call connected" signal is almost immediately followed by the called station's answer-back code, which is returned automatically in response to signals fed to the called teleprinter from the switching centre equipment.

Relay R at the calling station responds to the incoming teleprinter signals and during the periods in which a marking signal is received, $\underline{R1}$ connects negative battery via resistor YA, to capacitor QC and relay RA in parallel. When the incoming signal is spacing, $R1$ disconnects resistor YA and relay RA is dependent upon the discharge current from capacitor QC via resistor YH and $\underline{RB6}$. The time constant of the circuit is such that the release lag of relay RA is approximately 300 msec. Relay RA therefore remains operated during the pulsing of relay R to incoming teleprinter signals, as the longest spacing element in any teleprinter character is very much less than 300 msec.

To release the connexion, the telegraphist depresses the CLEAR key, KCL, to operate relay CL via contact $\underline{KCL1}$. Relay CL locks via $\underline{CL2}$, $\underline{C2}$ and dial pulse springs. $\underline{CL2}$ disconnects relay D which releases. Contact $D1$ connects a positive battery to the S wire. This releases the equipment at the switching centre, so causing the return of a positive battery on the R wire. Relay R spaces and $R1$ disconnects relay RA which releases when capacitor QC has sufficiently discharged. $RA2$ disconnects RB, $RB5$ disconnects relay RC, $RC2$ disconnects C, $C2$ disconnects CL, $C4$ disconnects relay I, and $I1$ disconnects relay switch M. The circuit is therefore restored to normal with the teleprinter disconnected from line and its motor stopped.

Alternatively the connexion can be cleared if a spacing signal of duration longer than 300 msec is received from line, to allow relay RA to release. $RA1$ operates relay CL and the connexion is released as previously described.

Incoming Call. Receipt of an incoming call is signalled by a long negative signal on the R wire. Relay R marks to operate relays RA, RB and D in turn. $\underline{RA2}$ lights the CALL lamp. $\underline{D1}$ returns a negative battery over the S wire to signal the "call connected" condition to the calling station. $\underline{RB2}$ and $\underline{RB3}$ connect the teleprinter to line and $\underline{RB1}$ operates the relay switch M, to start the teleprinter motor. After a delay of approximately

½ sec to allow the teleprinter motor to run up to speed, the *WRU* code is received from the switching centre. This actuates the answer-back mechanism of the teleprinter, which sends its station code to line. The mechanically operated *WRU* contacts close to complete the circuit to operate relay *RC* which locks at *RC*1.

After the message has been transmitted, the call is usually cleared by the calling telegraphist who operates the CLEAR key of his position. This causes the steady spacing signal to be received at the called position and relay *R* spaces. *R*1 disconnects relay *RA* which releases after 300 msec. *RA*2 disconnects relays *RB* and *D* which release. *RB*1 disconnects relay switch *M* to stop the teleprinter motor. Because relay *CL* has not operated, relay *RC* remains locked at *RC*1 and *RC*3 ensures that the CALL lamp remains lit. When the incoming message is removed from the teleprinter, the telegraphist operates the RESET key *KR*, which disconnects relay *RC* at *KR*1. *RC* relay releases and the CALL lamp is extinguished at the contact *RC*3. A further call can be switched to the position even if the CALL lamp has not been extinguished by the operation of the RESET key. Alternatively, if the clear is initiated at the incoming position, operation of the CLEAR key operates relay *CL*. *CL*2 releases relay *D*, and *D*1 sends a clearing signal to line which is recognized by the calling station and repeated back to release the switching equipment at the switching centre. The operation of relay *CL* breaks the holding circuit for relay *RC* at *CL*1 and therefore *RC* relay releases, and the CALL lamp is extinguished without requiring the additional operation of the RESET key.

Out of Service Facility. For various reasons, such as closing the office or giving maintenance attention or renewing the paper roll, it is sometimes necessary to close a position to incoming traffic, and to enable this to be effected at the teleprinter station an out of service facility is provided.

Reference should be made to Fig. 9.18 which shows schematically the complete position circuit.

To place the position out of service the telegraphist operates the OUT OF SERVICE key *KS*; *KS*2 releases relay *B* and *KS*4 connects the appropriate line signal to the *S* wire via *B*1. Two forms of out of service signal are used depending upon the type of line connecting the station to the switching centre. If the line is wholly physical, i.e. metallic pair, the out of service signal is a disconnection but if a V.F. channel is used the signal is a negative battery (a disconnexion cannot be transmitted by a normal V.F. channel as it is only designed for binary signalling). The switching centre equipment interprets either signal as the out of service condition and prevents the line from being seized for incoming calls.

To allow the teleprinter to be run in local for maintenance checks, the receiving electromagnet is connected via 4,000 Ω resistor *YD* to the transmitter tongue and the motor can be started and stopped by the operation of the MOTOR TEST START (*KX*) and MOTOR TEST STOP (*KY*) keys respectively. These keys control relay switch *M* which connects power to the teleprinter motor.

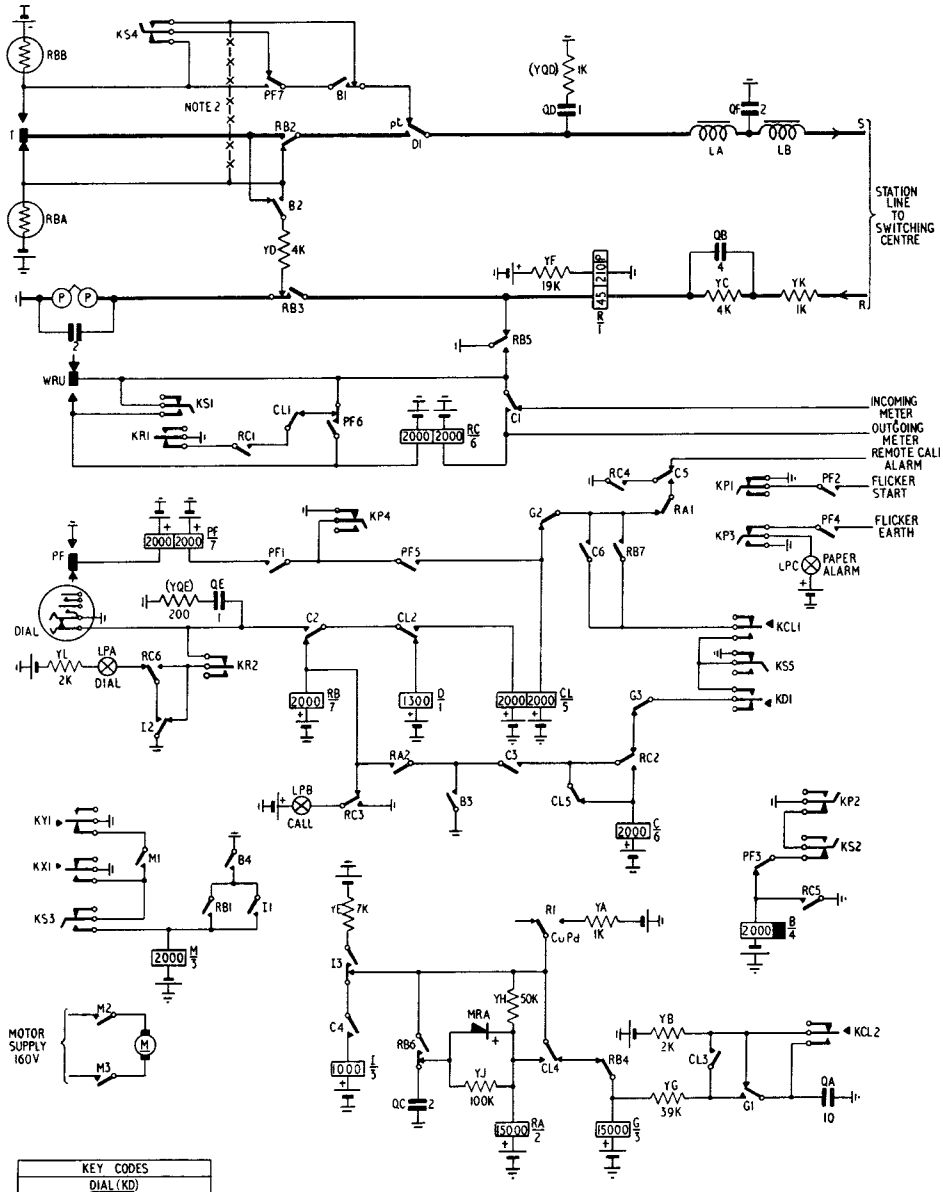
Paper Failure. To avoid lost messages it is necessary to ensure that failure of the paper to feed correctly in the teleprinter should be immediately detected and the machine withdrawn from service until the defect has been rectified. The position circuits enable this to be done automatically.

The teleprinter is fitted with a pair of paper failure contacts *PF* which close if the paper fails to feed correctly. *PF* contacts closing, operate relay *PF*. *PF*5 operates relay *CL* which releases the connexion thereby stopping the teleprinter motor and extinguishing the CALL lamps at both positions. The sending telegraphist is thus made aware immediately that the transmission has failed and a fresh call is necessary to repeat the message. Meanwhile at the faulty position the operation of relay *PF*, followed by the release of relay *RC* during the clear down, disconnects relay *B* at *PF*3 and *RC*5. Relay *B* in releasing connects the out of service signal to the *S* wire at *B*1. This busies the line at the switching centre to prevent further calls being connected. The release of relay *B* is delayed, firstly by the delay in releasing *RC* which has to await the return of the positive battery from the switching centre, and secondly by the slug on the core of relay *B*. This ensures that the out of service signal is not connected to the *R* wire until the clearing signal has fully released the switches at the switching centre.

Contact *PF*2 connects earth to the flicker start lead to start the flicker earth generator and raise an audible alarm. *PF*4 connects flicker earth to flash the PAPER FAIL lamp.

Before attending to the fault, the telegraphist operates the PAPER ALARM CUT OFF key *KP* which disconnects the audible alarm and causes the PAPER FAIL lamp to maintain a steady glow. *KP*2 disconnects the *B* relay circuit so that the position remains out of service. Operation of the OUT OF SERVICE key *KS*, allows a local test to be made before restoring the position to service.

Additional Features of the Position Circuit. It is important that simple faults and misoperations should not lead to loss of messages or lock-up of circuits and to ensure this several safeguards have been incorporated in the position circuit.



KEY CODES
DIAL (KD) 1
CLEAR (KCL) 2
RESET (KR) 2 + OUT OF SERVICE (KS) 5
PAPER ALARM CUT OFF (KP) 5
MOTOR TEST START (KX) 1
MOTOR TEST STOP (KY) 1

NOTES 1 BATTERIES ARE 80 VOLTS
2 THIS STRAP REQUIRED WHEN STATION LINE INCLUDES A CHANNEL IN A MCVF SYSTEM

FIG. 9.18. DETAIL CIRCUIT DIAGRAM OF A TELEPRINTER POSITION

One possible cause of difficulty is interruption of the transmission path by transient line faults and to minimize the risk of mutilated messages it is arranged that disconnexions of duration greater than 300 msec cause the release of the connexion. This is achieved in the position circuit by means of an auxiliary winding on relay *R* through which is passed a small current, so that in the absence of line current in the other winding the relay spaces and releases the connexion. For a similar reason all V.F. channels associated with the system have a positive bias potential connected to their static relays.

Another possible source of difficulty is mis-operation of the DIAL and CLEAR keys and to minimize this the guard relay *G* is provided. The circuit is so arranged that the discharge current from capacitor *QA* via *G*1 and resistor *YG* ensures that relay *G* has a release lag of approximately one second. Relay *G* is operated over the circuit *R*1, *CL*4 and *RB*4 on the receipt of the "call connected" signal both on incoming and outgoing calls. For incoming calls, the operation of relay *G* breaks the operating circuit of relay *CL* at *G*2. This prevents premature release of the connexion if the CLEAR key is operated at the instant the incoming call is switched. On outgoing calls, service signals may be received without a preceding "call connected" signal. In such circumstances relay *RA* may chatter before it is fully operated and to prevent relay *CL* being operated at contact *RA*1, *G*2 disconnects the operating winding of *CL* for a period long enough to permit relay *RA* to be fully fluxed and to cease chattering.

When a connexion is cleared by the operation of the CLEAR key *KCL*, relay *G* is operated and locks via *G*1 and *KCL*2 for as long as the key is operated. Contact *G*2 disconnects the circuit of relay *CL* to ensure that an incoming call maturing whilst the key is still operated is not released.

Contact *G*3 disconnects the operating circuit of relay *C* so that a calling signal cannot be originated until relay *G* has released. This ensures that the clearing signal is maintained long enough to be effective and that it is impossible to step the selectors at the switching centre by repeated operation of the DIAL and CLEAR keys.

It will be noted that the complete circuit of the *RA* relay element in Fig. 9.18 is more complex than the simplified element shown in Fig. 9.17. Rectifier *MRA* is provided to prevent relay *RA* being prematurely operated by a long "proceed to select" signal.

If the rectifier is not provided, when relay *R* spaces following the "proceed to select" signal, there is a surge of current via *RA* relay into capacitor *QC* because of the change in potential across *QC* which occurs whilst *R*1 is marking. This surge into capacitor *QC* is in the direction to assist the operation of relay *RA* and if the "proceed to select" signal approaches the upper limit of 40 msec, the surge will complete the operation of the relay. Rectifier *MRA* prevents this by limiting the surge current by diverting it through resistor *YJ*. The rectifier does not, however, impair the shunting action of capacitor *QC* on the normal operating circuit of relay *RA*.

A further point of interest in the RA relay element is contact *CL*4 which is included in the circuit so that when *CL* is operated the resistor in the discharge path of capacitor *QC* (with *RB* operated) is short-circuited and the release lag of *RA* is reduced to 140 msec. This ensures that when an outgoing call is cleared, the return of the positive battery signal from the switching centre, releases relay *RA* in 140 msec instead of the usual 300 msec. This speeds up the restoration of the position equipment to normal and thereby reduces the delay, which must be introduced automatically at the switching centre before another call can be safely offered.

The risk of fire due to a stalled teleprinter motor is eliminated by connecting a circuit breaker in the motor power supply circuit. If current in excess of the normal running current of the motor flows for more than 30 secs, the circuit breaker operates to disconnect the supply.

Remote Alarm and Flicker Earth Unit. A flicker earth pulse generator for the paper failure alarm circuit is required at every office and this is combined with the remote alarm control key to form a self-contained unit suitable for wall or rack mounting. The remote alarm facility for incoming calls and paper failures is normally only required at small offices where the instrument room is sometimes unattended and it becomes necessary to extend the alarm to a staffed room in the building. Fig. 9.19 shows the circuit arrangements.

The REMOTE ALARM CUT OFF key *KRC* enables the remote alarm to be disconnected when the instrument room is staffed. When a paper failure occurs on a teleprinter position an earth is connected to the flicker start lead to operate relay *FS*. *FS*2 connects earth to operate relay *FG*. Relay *FG* has a long operate lag because of the discharge current from capacitor *QA* which flows through the 4,500 Ω winding of relay *FG* to oppose the action of the current in the 1,500 Ω winding. When the discharge current from capacitor *QA* has fallen sufficiently for the flux due to the current in the 1,500 Ω winding to predominate, relay *FG* operates. *FG*1 disconnects the operating earth from relay *FG*, but the relay does not release

immediately because of the charging current passing into capacitor *QA* through the two windings of relay *FG* in series. As soon as this charging current has fallen sufficiently relay *FG* releases and *FG*1 reconnects the operating earth. Relay *FG* therefore pulses because of the continuous interaction of contact *FG*1 and the current in the coils of relay *FG*. The value of capacitor *QA* is chosen so as to produce a pulse rate of approximately two pulses per second. Contact *FG*2 connects flicker earth to

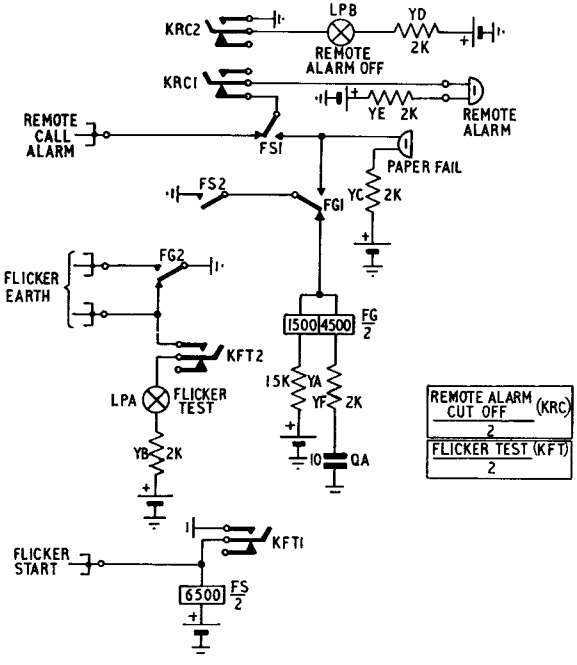


FIG. 9.19. FLICKER PULSE GENERATOR AND REMOTE ALARM UNIT

the position circuits. *FG*1 in addition to pulsing relay *FG* pulses the paper fail buzzer, which is fitted in the unit, to provide an audible alarm in the instrument room. *FG*1 also connects flicker earth to the remote alarm bell.

The FLICKER TEST key enables the relay to be tested for maintenance purposes.

The Relay Unit for Long Physical Lines. To ensure satisfactory transmission over long physical lines relay units are provided to repeat the incoming signals. Fig. 9.20 shows the circuit of the relayed line unit used at teleprinter stations.

It comprises two relays, a polarized relay *R* which repeats the double-current signals and a 3,000 type relay *A* which repeats the line disconnected condition. Capacitor *QA* and resistors *YC* and *YD* form a signal shaping network for relay *R*, whilst the rectifier bridge *MRA*, *MRB*, *MRC* and *MRD* ensure that relay *A* is operated by both negative and positive line signals. The relay unit is suitable for either two wire or two loop working.

Switching Centre Equipment

It is now convenient to consider details of the various items of switching equipment provided at each switching centre. The switching mechanisms and associated relays are operated from a 50 V battery but the line signalling currents are drawn from a ± 80 V battery supply. This latter battery is also used to feed some circuit elements in which the additional voltage is of advantage.

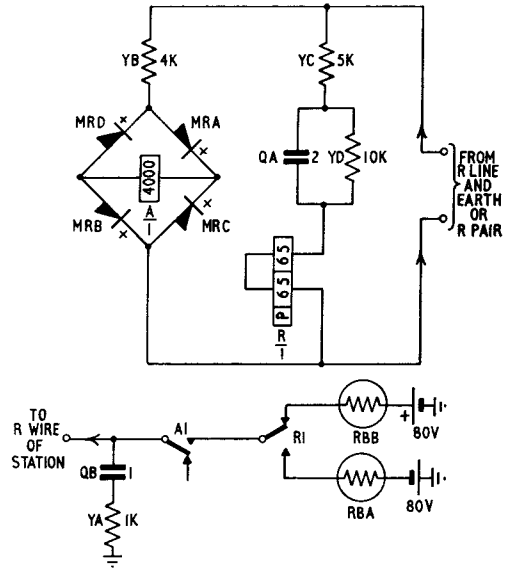


FIG. 9.20. LINE TERMINATING RELAY UNIT

Station Line Circuit. The station line circuit (S.L.C.) comprises a relay set and uniselector and is provided on the basis of one per station line. Its main functions are, in the case of calls originated at the teleprinter station, to extend the line to a free first group selector, chosen from a number of group selectors serving several station lines and, in the case of received calls, to indicate to the final selector whether the station line is free to be seized for traffic and to connect the final selector to the station line.

The following facilities are provided—

(*a*) Hunting for, and seizing, a free first group selector on receipt of a calling signal from the teleprinter station.

(*b*) Applying an engaged condition to the final selector multiple to prevent calls from other stations

being connected, if the station line is already engaged on a call or is out of service.

(*c*) Connecting an incoming call from another teleprinter station, via the final selector multiple, to the station line.

(*d*) Ensuring that on the release of a connexion, sufficient time elapses for the relays at the teleprinter station to restore fully before another incoming call is connected to the station line.

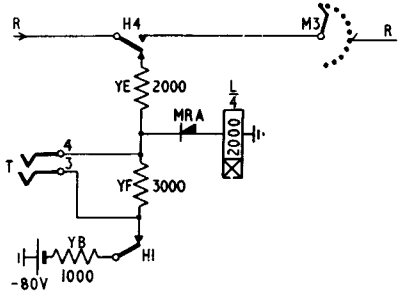


FIG. 9.21. STATION LINE CIRCUIT: L RELAY ELEMENT

(*e*) Indicating to the suspense relay set whether the station line is free, busy or out of service.

In considering the circuit arrangements used to provide these facilities it is helpful to examine the elements which make up the complete station line circuit.

"L" Relay Element. The *R* wire from the station terminates on the *L* relay element as shown in Fig. 9.21.

The line signals to which the relay has to respond are, spacing for the free condition, marking for the calling condition and disconnection for the out of service condition. It is arranged that the *L* relay is operated by the two last conditions but is not operated by the first condition.

Consider the out of service condition in which the *R* wire is disconnected. Relay *L* operates to current from — 80 V battery, *YB*, *H*1, *YF*, *MRA*, *L* relay to earth. If a calling signal, i.e. negative battery, is received, relay *L* again operates, the operating circuit being as before with the addition of an extra path from — 80 V battery, the *R* wire, *H*4, *YE*, *MRA*, *L* relay to earth.

For the disengaged, or free line condition, the *R* wire is connected at the distant end to + 80 V battery. Current will flow therefore from + 80 V battery, *R* wire, *H*4, *YE*, *YF*, *H*1, *YB*, to — 80 V battery. The potential taken up by the junction of *YE* and *YF* is governed by the line resistance and, provided this is always less than 1,060 Ω, the junction of *YE* and *YF* is always positive with respect to earth. Rectifier *MRA* is therefore non-conducting and relay *L* cannot operate.

The limit of 1,060 Ω imposes a restriction on the ohmic length of station lines. In practice, however, this is not unduly restrictive since transmission reasons also impose a limit on the length of lines and it is found that, in general, transmission considerations are the more critical.

Self Drive Battery Testing Element. To permit the selection of a free first group selector, on originated calls, the bank of the uniselector is connected to the group selectors and, on receipt of the calling signal, the wipers of the uniselector rotate until a free group selector is found. To indicate whether a group selector is free, a third wire known as the Private (*P*) wire is associated with the pair of wires carrying the line signals. The principle of using a *P* wire to indicate the availability for traffic of a switch or relay set is employed at all stages of switching within the switching centre.

To indicate the free condition, the *P* wire is connected to battery via a 550 Ω resistor. The absence of battery potential (or the presence of an earth) indicates that the outlet is busy. This method of *P*

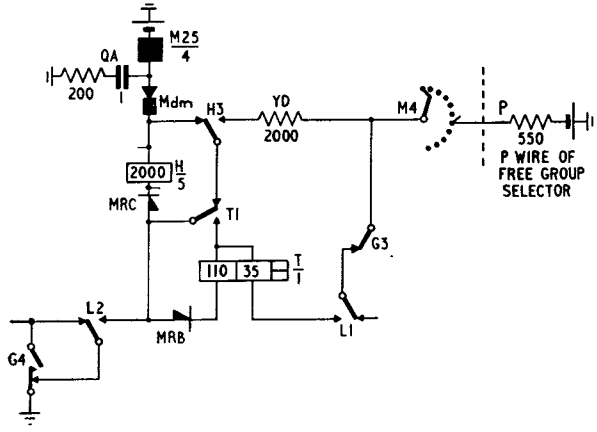


FIG. 9.22. STATION LINE CIRCUIT: SELF DRIVE AND BATTERY TESTING ELEMENT

wire testing is known as battery testing. (There is another form of testing widely used in telephone practice in which the convention is earth to indicate busy and absence of earth to indicate the free condition. This is known as earth testing and it is not used in the teleprinter automatic switching system.)

The circuit elements used to self drive and search for a free outlet are given in Fig. 9.22.

On the receipt of the calling signal, relay *L* operates to complete the self drive circuit of the uniselector from battery, uniselector magnet *M*,

interrupter springs *Mdm*, *H*3, *T*1, *L*2, *G*4 to earth.

The interaction between the uniselector interrupter springs and magnet drives the wipers over the bank contacts of the uniselector. As the wipers pass over the bank contacts, each outlet is tested to ascertain whether it is free and to do this the *P* wires which are connected to arc *M*4 are extended in turn to relay *T* over the path, wiper *M*4, *G*3, *L*1, both windings of relay *T* in series, *MRB*, *L*2 and *G*4 to earth. When a free outlet is found, relay *T* operates to the battery connected via the 550 Ω

The time available for stopping the uniselector is sufficient to permit the use of a suitably designed 3,000 type relay, and the short operating time of the high speed relay is of more importance in securing immunity from double connexion than in preventing overshooting of the seized outlet.

The rectifier element *MRB* assists the performance of the testing relay circuit by virtue of its non-linear resistance/voltage characteristic. When the voltage across the rectifier in the forward direction is high the resistance is low, so that for the normal

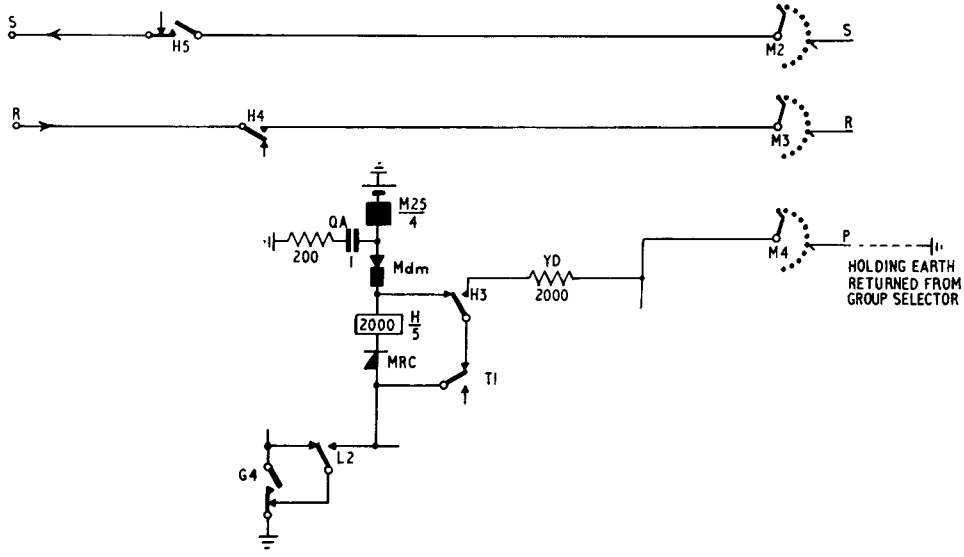


FIG. 9.23. STATION LINE CIRCUIT: SWITCHING AND HOLDING ELEMENT

resistor on the *P* wire of the group selector. The *T* relay operates quickly in order to prevent the uniselector overshooting the outlet. Contact *T*1 breaks the self drive circuit of the uniselector, the resistance of relay *H* being too great to allow the uniselector magnet to operate.

Relay *T* in operating, short-circuits its own high resistance winding by contact *T*1. This reduces the potential of the *P* wire to approximately three volts with respect to earth, and a second station line circuit testing the *P* wire would interpret the outlet as being busy since its *T* relay would not operate to such a low potential.

For obvious reasons it is important to avoid double connexions, i.e. two uniselectors switching simultaneously to one group selector. Exhaustive tests have shown that the high speed relay battery testing element described is, for all practical purposes, immune from liability to double connexion. It is for this reason that this element has been used at all stages of selection in the teleprinter switching system.

operating condition of relay *T* the series resistance of *MRB* is small and maximum current is available for the operation of the relay. If, however, the potential on the *P* wire is reduced, the voltage across *MRB* is reduced and therefore its resistance is increased. The current flowing in the coils of relay *T* is therefore reduced by a greater ratio than the ratio of *P* wire potentials. This ensures that a second testing relay receives insufficient current to operate in parallel with a relay which has already operated and, in addition, the shunting effect of the second relay on the holding relay is considerably reduced.

Switching and Holding Element. Once a free outlet has been found it is necessary to extend the line wires forward to the group selector and to disconnect relay *L* and resistor *YG* in the S.L.C. to avoid attenuating line signals. It is also necessary for the uniselector wipers to retain their position on the selected outlet. The circuit elements which permit this to be done are shown in Fig. 9.23.

When relay *T* operates, *T*1 removes the short-circuit from relay *H* which operates over the following circuit: battery, uniselector magnet *M*, interrupter springs *Mdm*, relay *H*, *MRC*, *L*2, *G*4 to earth. Contacts *H*4 and *H*5 extend the *S* and *R* wires to the group selector via the uniselector wipers *M*2 and *M*3. *L* relay releases when the *R* wire is switched through and it is necessary to arrange a holding circuit for relay *H*. This is provided by arranging that the group selector, on receiving the calling signal on the *R* wire, replaces the 550 Ω battery connected resistor on the *P* wire, by an earth. This causes the release of relay *T* and provides a holding circuit for relay *H* via battery, uniselector magnet *M*, interrupter springs *Mdm*, relay *H*, *MRC*, *T*1, *H*3, *YD*, wiper *M*4, to earth on the *P* wire. It is important that the operate circuit for relay *H* via contact *L*2, should not be broken before the holding circuit is established over the *P* wire. This is ensured by arranging that relay *L* has a release lag sufficient to cover the time required by the group selector to return the holding earth over the *P* wire. *L* relay, it will be noted, is made slow to operate to ensure that it is fluxed sufficiently to give its full release lag when the first choice outlet is seized.

The uniselector will remain switched to the outlet as long as the earth is returned from the group selector over the *P* wire. This method of holding is known as backward holding since the holding earth is fed over the *P* wire against the direction in which the chain of switches is being extended. It will be noted that a 2,000 Ω resistor is included in the holding circuit of relay *H*. This is necessary because on the release of the connexion, the holding earth from the group selector is removed to allow relay *H* to release and, during the period relay *H* is releasing, battery potential is connected to the *P* wire from the uniselector magnet *M*, interrupter springs *Mdm*, relay *H*, *MRC*, *T*1, *H*3 and *YD*. This might be interpreted by a searching station line circuit as a free condition but for the inclusion of *YD*, which limits the current to a value which is insufficient to operate relay *T* in the hunting S.L.C.

Incoming Call. It is convenient to consider next the circuit element which enables the station line to be seized from the final selector multiple. This is shown in Fig. 9.24.

The connexions to the final selector multiple include a *P* wire, the potential of which is used to indicate whether the station is busy or available for traffic. The free condition of the station line is indicated by battery, resistor *YA* (550 Ω), *L*1, *G*3, *M*4 home contact to the final selector multiple. When a final selector offering a call tests the station line circuit, it connects earth via its testing relay to the *P* wire and thence via *G*6, relay *H*, interrupter springs *Mdm*, uniselector magnet *M* to battery, to operate relay *H*.

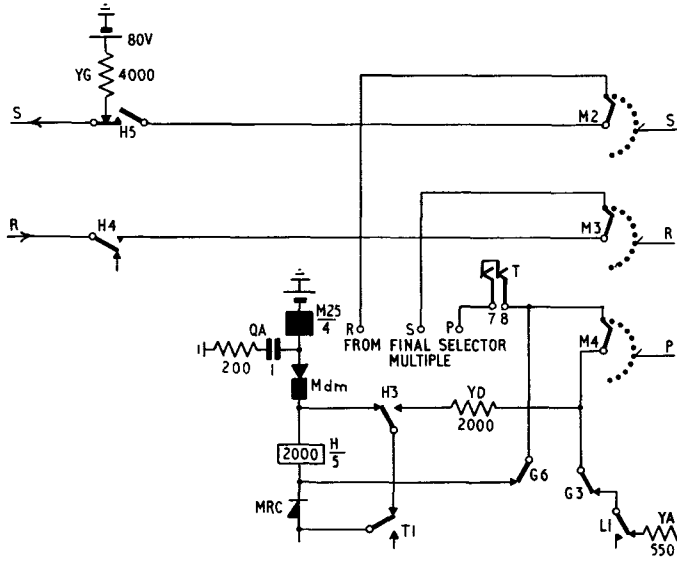


FIG. 9.24. STATION LINE CIRCUIT: CIRCUIT ELEMENT FOR INCOMING CALL

Relay *H* operates and holds via *H*3, *YD*, *M*4 home contact, to the earth on the *P* wire. Operation of the contacts *H*4 and *H*5 connects the station line to the final selector multiple via the home contacts of arcs *M*2 and *M*3.

Relay *H* is held by the earth on the *P* wire from the final selector, in a similar way to that in which it is held from the group selector in the case of an originated call. There is one important difference, however, in that the final selector applies forward holding conditions since the holding earth is fed in the direction in which the chain of switches is being extended.

Release Guarding and Homing. When the station line is in use for a call it is necessary to prevent a final selector from switching to it. This is achieved by disconnecting the battery potential from the *P* wire, to busy it. On the release of the connexion it is necessary for this busy condition to be maintained until the relays at the teleprinter station have fully restored and the station line circuit

uniselector has driven to the home position. The circuit element which enables this to be done is shown in Fig. 9.25.

When the call is set up, relay H operates and in so doing completes the circuit for relay G, from earth, YC, $\underline{H2}$, relay G to battery. Contact $\underline{G3}$ disconnects the 550 Ω battery connected resistor YA, from the P wire.

Assuming that the call was originated by the station; the wipers are standing in the bank and

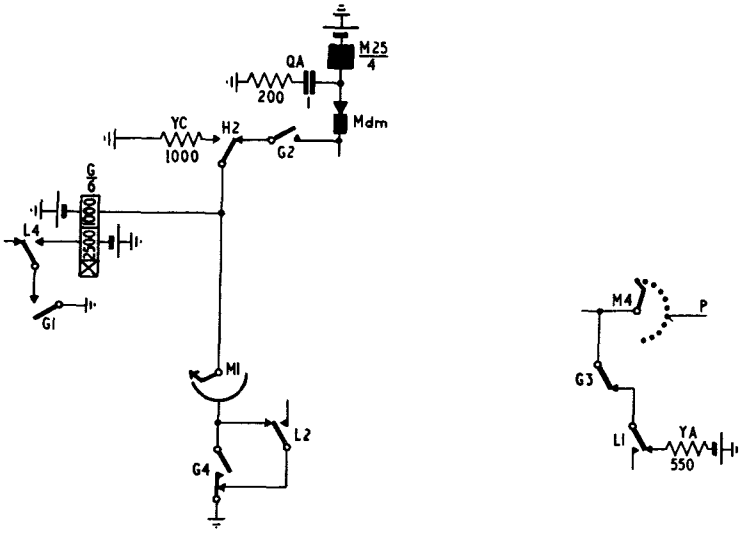


FIG. 9.25. STATION LINE CIRCUIT: RELEASE GUARDING AND HOMING ELEMENT

relay G is held over the circuit, $\underline{G4}$, $M1$ arc, G relay to battery. On the release of the connexion, the holding earth is removed from the P wire and relay H releases. A circuit for self driving the uniselector is completed from $\underline{G4}$, $M1$ arc, $H2$, $\underline{G2}$, interrupter springs Mdm, uniselector magnet M to battery. The uniselector self drives until the wipers reach the home position. The wipers are then brought to rest since the drive circuit is cut at $M1$. $M1$ also breaks the holding circuit of relay G which releases slowly. The release lag of relay G is chosen so that before the connexion of battery potential to the P wire at $G3$, sufficient time elapses to ensure that the equipment at the teleprinter station is fully restored.

The circuit operation for the release of a received call is similar to that for an originated call except that homing of the uniselector is not necessary.

Out of Service Condition. In the description of the calling relay element it was stated that the line signal for the out of service condition is a disconnexion. This is used only when a metallic pair exists between the station and the switching centre. In cases in which it is necessary to use a V.F. channel, the out of service signal is the same as the calling signal, the absence of dial pulses being used to differentiate between a normal calling condition and the out of service condition.

In considering the operation of the circuit elements, the case of the V.F. station line will be dealt with first. Reference should be made to Fig. 9.26 which shows the complete circuit of the S.L.C.

When the marking signal is received from the teleprinter station the uniselector hunts for, and finds, a free group selector which returns an earth over the P wire to hold relay H in the S.L.C. Relay H operates and holds relay G at $\underline{H2}$. After a period of 12–24 sec if dial pulses are not received, the group selector removes the holding earth from the P wire. Relay H releases and the uniselector homes as already described. On the release of relay H, relay L is reconnected to the R wire at $H4$. Relay L operates to the marking signal still connected at the teleprinter station. Relay L in operating holds relay G from earth, $\underline{G1}$, $\underline{L4}$, G relay to battery. The out of service signal results, therefore, in relays L and G in the S.L.C. being operated.

In those cases in which a disconnexion of the R wire is used to signal the out of service condition, it is not necessary to wait 12–24 sec, to interpret the signal. When the $\underline{H4}$ and $\underline{H5}$ contacts operate and extend the station line to the group selector, the absence of a marking signal on the R wire results in the group selector not returning a holding earth on the P wire. Therefore when relay L releases, because of the operation of contacts $\underline{H4}$ and $\underline{H1}$, the operate circuit of relay H is broken at $L2$ and relay H releases. In the meantime, however, relay G has operated from earth, YC, $\underline{H2}$, coil of G to battery. On the release of relay H, relay L is reconnected to the line at $H4$ and relay L reoperates. Relay L in operating provides a holding circuit for relay G at $\underline{G1}$, $\underline{L4}$, relay G to battery.

Thus regardless of whether the out of service condition is signalled by a disconnexion or a negative battery, the result is to cause relays L and G in the S.L.C. to be operated. The operation of relay G and the release of relay H, provide a circuit to home the uniselector as already described. Contacts $\underline{G3}$ and $\underline{G6}$ busy the P wire on the final selector multiple.

In order to indicate to the suspense relay set whether the station line is

(*a*) free
(*b*) busy
or (*c*) out of service

three leads, designated *X*, *Y* and *Z*, are used to connect the S.L.C. to the suspense relay set. The

Contacts *T*1 and *L*2, both of which break the uniselector magnet circuit, are made of platinum, because silver contacts would not give a satisfactory life with the relatively heavy currents which have to be carried.

So that the correct functioning of the S.L.C. can be checked, the test jack springs *T*3 and *T*4 enable resistor *YF* to be short-circuited to operate relay

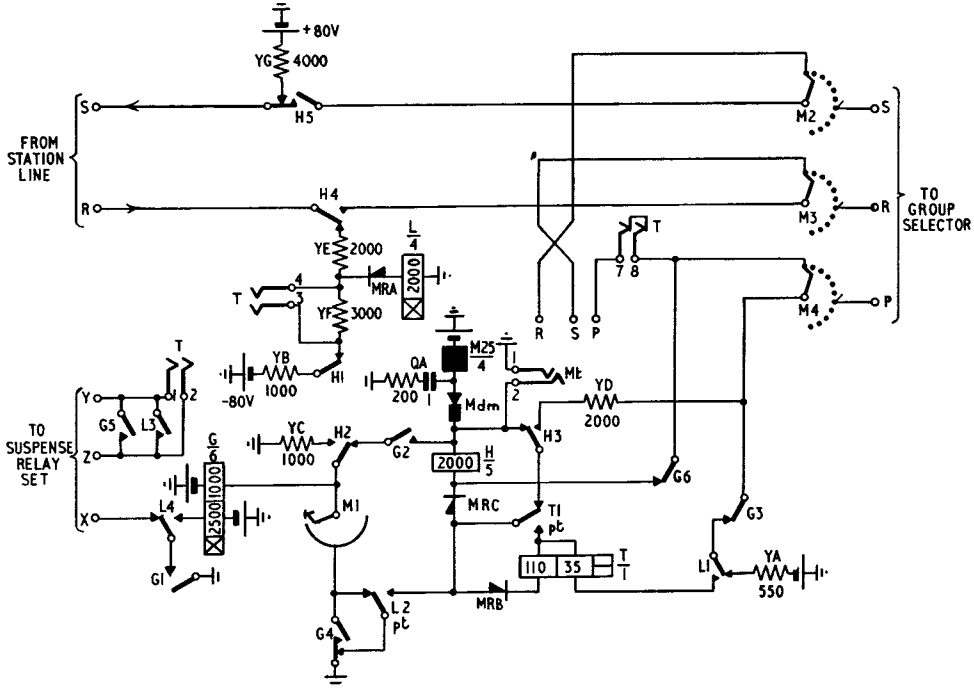


FIG. 9.26. COMPLETE CIRCUIT DIAGRAM OF STATION LINE CIRCUIT

conditions set up on these three leads are scheduled below.

Condition	Relays Operated	Connections of *X*, *Y* and *Z* leads within the S.L.C.
Free	Nil	All leads are disconnected.
Busy	G. H.	*X* is earthed at *G*1. *Y* and *Z* are connected together at *G*5.
Out of Service	G. L.	*X* is disconnected at *L*4. *Y* and *Z* are connected together at *G*5.

Notes on the Station Line Circuit. The spark quench capacitor *QA* is used to absorb the inductive energy stored in the uniselector magnet when its circuit is broken. This avoids excessive sparking at the contacts breaking the circuit, in particular those of the interrupter springs.

L. This causes the uniselector to drive and set up the out of service condition.

By removing the test link from between springs *T*7 and *T*8 and inserting it between springs *T*1 and *T*2, the *P* wire is busied and the out of service indication is given to the suspense relay set. This provides a simple means of busying a station line against received traffic for maintenance or other purposes. Test jack springs *Mt*1 and *Mt*2 enable a resistor of 30 Ω to be connected in series with the self drive circuit of the uniselector so that the electrical performance of the uniselector can be checked.

Rectifier *MRC* is provided so that when the final selector seizes the station line and connects an earth to the *P* wire, the uniselector is not stepped via *T*1 and *H*3. Relay *G* is made slow to operate to ensure that, for originated calls, the holding earth is returned from the group selector before the operating circuit for relay *H* is broken at *G*4.

The relays of the S.L.C. are mounted in plug-in relay sets, on the basis of two circuits per relay set. The wiring of the shelf jacks is so arranged that when a relay set is removed, the *P* wire is disconnected and busied, and the shelf jack springs connected to the *Y* and *Z* leads make contact to apply out of service indications to the suspense relay set. A photograph of S.L.C. relay sets and uniselectors is given in Fig. 9.27.

Group Selector. The group selector uses the 2,000 type mechanism described earlier and is arranged to accept only one digit of the pulse train. This steps the wipers vertically, to the required level, and then by self drive action the wipers are rotated automatically over the bank contacts to find a free outlet.

The group selector banks have a total of 600 contacts, so that by means of wiper switching relays, to be explained later, it is possible to provide 20 outlets per level, each outlet comprising an *S* wire, an *R* wire and a *P* wire. The bank capacity of the switch is therefore 200 outlets.

To simplify maintenance and to provide flexibility in provisioning a single design of group selector is used throughout the system, simple variations in shelf wiring being used to provide the small differences in facilities of switches used as first, second, or trunk selectors.

The facilities included in the circuit provide for—

(*a*) Recognizing an incoming calling signal and returning a marking pulse of 25 msec duration. Where this pulse is returned over station lines it is the "proceed to select" signal, and over trunk lines it is the "call confirmation" signal.

(*b*) Guarding the selector against seizure by another call until the selector has restored to normal.

(*c*) Stepping vertically to the required level under the control of dialled pulses.

(*d*) Hunting over the selected level to find a free outlet.

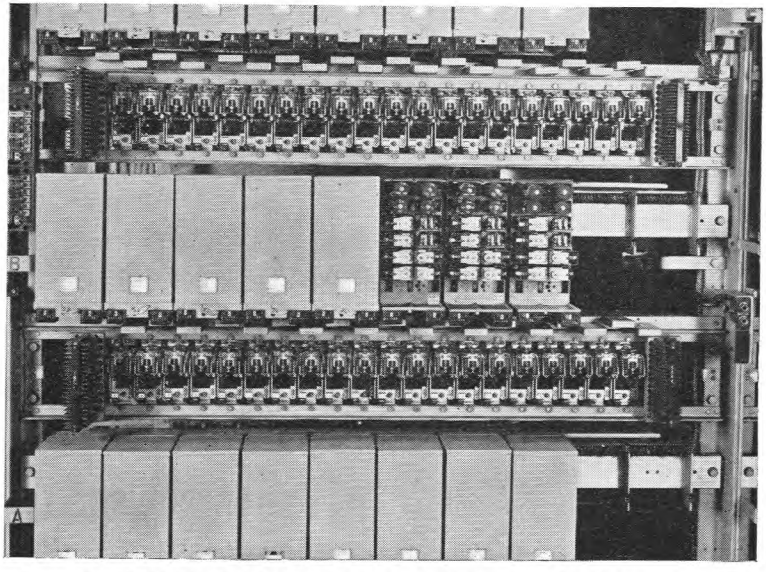


FIG. 9.27. RACK ARRANGEMENT OF STATION LINE CIRCUITS

(By courtesy of H.M. Postmaster-General)

(*e*) Testing two outlets at each rotary step.

(*f*) Seizing a free outlet and extending the line wires forward to the next stage.

(*g*) Holding the preceding stage.

(*h*) Driving to the eleventh rotary step if no free outlet is found, and returning a service signal to the caller to indicate that no circuits are available.

(*i*) Driving to the eleventh rotary step if the level is spare, and returning the *IR* signal to immediately release the connexion.

(*j*) Operating an overflow call count meter whenever a selector finds all outlets to be busy. The overflow meter is connected to the eleventh rotary step position and may be commoned to more than one level.

(*k*) Extending an earth to the appropriate service signal start lead whenever the selector is stepped to the eleventh rotary step position.

(*l*) Indicating by means of a lamp that the selector is seized but not switched to a working outlet.

(*m*) Releasing the connexion automatically, if the selector is seized but not stepped within 12–24 sec (first selectors only).

(*n*) Indicating by means of a "test buzzer" whether the wipers are switched to an odd or even outlet.

(*o*) Giving an alarm if the selector fails to release due to a mechanical fault.

In considering the circuit arrangements which are used to provide these facilities it is convenient to examine the separate elements into which the circuit may be divided.

The A Relay Element. The A relay responds to

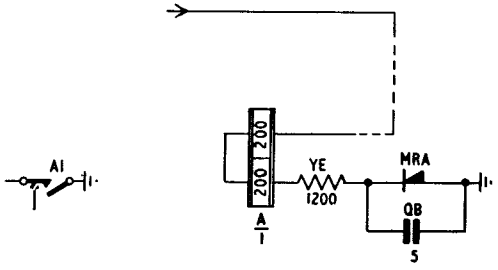


FIG. 9.28. GROUP SELECTOR: CIRCUIT ELEMENT FOR RELAY A

the calling and dial pulse signals received on the *R* wire. The circuit element is shown in Fig. 9.28.

Relay *A* is of the 3,000 type and is polarized by rectifier *MRA* so that it is operated only when negative battery is connected to the *R* wire. Resistor *YE* limits the line current to a safe value and *QB* is a wave shaping capacitor to steepen the front of negative going signals. The relay is required to respond to the dial pulse signals and to ensure low distortion its armature is of the isthmus type. For the same reason the relay core is fitted with nickel iron sleeves and the contact load is limited to one make-before-break contact unit.

"Proceed to Select" Signal Element. On being seized, a first selector returns to the calling station a 25 msec pulse of negative battery as the "proceed to select" signal. Trunk selectors are required to return a similar pulse as the "call confirmation" signal. The circuit elements which provide this facility are shown in Fig. 9.29.

On the operation of relay *A* a circuit is completed to operate relay *B* from earth, *N*1, *A*1, relay *B*, *YB* vertical magnet to battery. *B*7 completes a circuit for relay *BA* which operates with a lag of approximately 25 msec. Successive operation of contacts *B*6 and *BA*5 connects negative battery to the *S* wire for approximately 25 msec.

For group selectors acting as second selectors this facility is not required and is removed by disconnecting contacts *B*6 and *BA*5 from the *S* wire by strapping on the selector shelf jacks.

Controlled Vertical Stepping. The next element to be considered is that which provides the facility

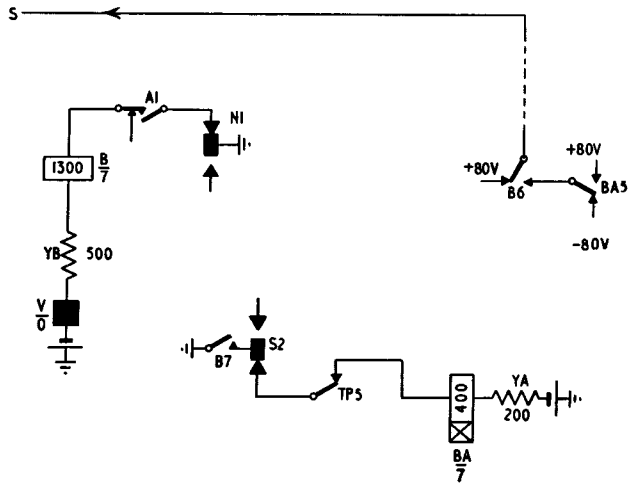


FIG. 9.29. GROUP SELECTOR: CIRCUIT ELEMENT FOR GENERATION OF "PROCEED TO SELECT" OR "CALL CONFIRMATION" SIGNAL

of stepping the selector vertically under the control of the dialled pulses. The circuit element is shown in Fig. 9.30.

The operation of relay *A* by the calling signal, completes the operating circuit for relay *B* from

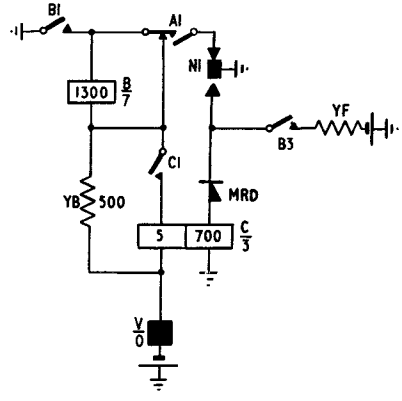


FIG. 9.30. GROUP SELECTOR: CIRCUIT ELEMENT FOR VERTICAL STEPPING

earth, *N*1, *A*1, relay *B*, resistor *YB*, and vertical magnet to battery. The current which flows is sufficient to operate relay *B* but not the selector magnet. Relay *B* operates and contact *B*1 completes a holding circuit for relay *B*. *B*3 connects

battery from resistor YF to rectifier MRD to operate relay C. $\underline{C1}$ connects the low resistance winding of relay C across resistor YB and in series with the vertical magnet of the selector. When the first pulse of the train is received relay A releases and $A1$ short-circuits relay B, thereby increasing the current in the selector vertical magnet which operates.

Relay A responds to the dial pulses, the release of A corresponding to the break of the dial pulse contact. The selector magnet is operated by the release of $A1$, and is therefore energized for $66\frac{2}{3}$ msec at 100 msec intervals (nominal). The vertical magnet repeatedly operates to step the wipers to the level corresponding to the digit dialled.

The short-circuit across the coil of relay B by contact $A1$ allows an induced current to flow which results in a release lag for relay B of approximately 200 msec. $A1$ short-circuits relay B for a nominal $66\frac{2}{3}$ msec per pulse and this is short enough to ensure that relay B holds during pulsing. As soon as the selector is stepped off normal the $N1$ spring-set operates and short-circuits the 700 Ω winding of relay C. The holding of this relay is then dependent upon the current in the 5 Ω winding. The current which flows in this winding when $A1$ is operated, is insufficient to hold relay C, but the pulses of current which flow when the $A1$ contact responds to dial pulses, hold relay C operated. The shunting action of the $N1$ contacts ensures that the release lag of relay C is sufficient for the relay to hold during the "make" period between successive pulses of the digit pulse train.

At the end of the digit pulse train, relay A remains operated for the duration of the interdigit pause and this is sufficiently long to permit relay C to release.

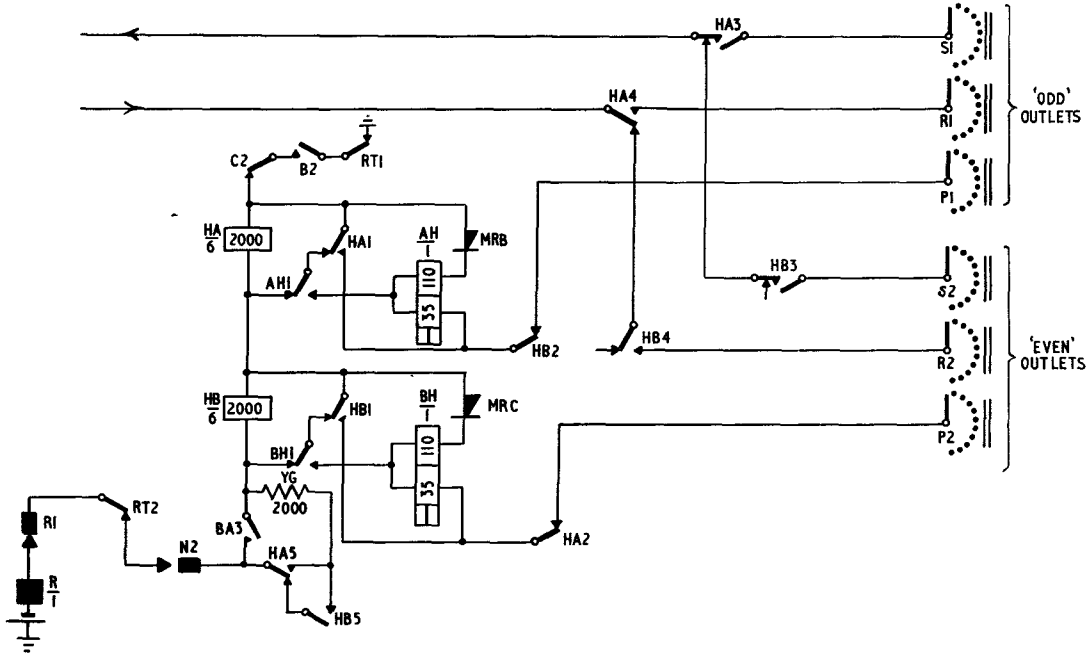


FIG. 9.31. GROUP SELECTOR: CIRCUIT ELEMENT FOR ROTARY HUNTING AND TESTING

Rotary Hunting. On the release of relay C following vertical stepping, the wipers are self driven over the selected level to find a free outlet. The relevant circuit elements are shown in Fig. 9.31.

It will be noted that the bank contacts are arranged in six arcs, so that for each rotary position of the wiper assembly there are two outlets, each comprising an S, R and P wire. To enable each outlet of the pair to be tested two testing relays are provided. These are of the high speed type similar to the testing relay used in the S.L.C. and are arranged to test for a free condition represented by battery via 550 Ω.

On the release of the C relay following vertical stepping, earth is connected via $RT1$, $\underline{B2}$, $C2$, $HA1$, $AH1$, $HB1$, $BH1$, $\underline{BA3}$, $\underline{N2}$, $RT2$, $R1$ to rotary magnet and battery. The rotary magnet

and rotary interrupters interact and self-drive the wipers over the bank contacts. Each *P*1 contact is tested in turn over the circuit *P*1 wiper, *HB*2, two windings of *AH* in series, *MRB*, *C*2, *B*2, *RT*1 to earth. Similarly each *P*2 contact is tested by relay *BH*. As soon as a free outlet is found the appropriate test relay operates. Assume that an odd outlet is found to be free so that relay *AH* operates. *AH*1 disconnects full earth from the self drive circuit of the rotary magnet and short-circuits the

Relay *H* in the S.L.C. is held by the earth connected to the *P* wire, first by *B*4 and later by *HA*6 (or *HB*6). Initially *B*4 provides the holding earth following seizure and later, when a free outlet is found, relay *HA* or *HB* operates and relays *A*, *B* and *BA* are released, and it is necessary for contact *HA*6 (or *HB*6) to maintain the holding earth to the S.L.C.

Considering the first selector, relay *HA* holds to the earth returned from the next stage over the

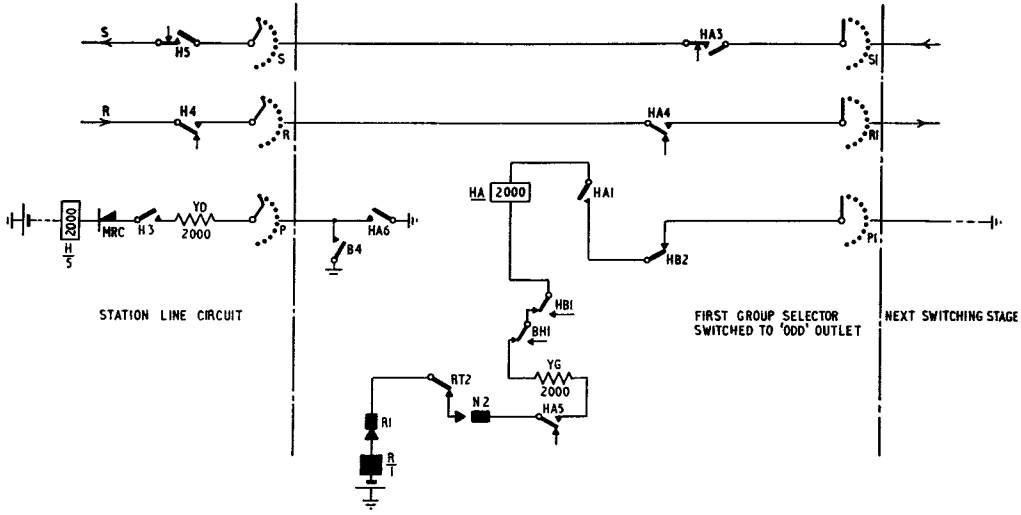


FIG. 9.32. GROUP SELECTOR: CIRCUIT ELEMENT FOR HOLDING

110 Ω winding of relay *AH* to busy the *P*1 contact. In addition *AH*1 removes the short-circuit from relay *HA* which operates over the circuit *RT*1, *B*2, *C*2 relay *HA*, *HB*1, *BH*1, *BA*3, *N*2, *RT*2, *R*1 to rotary magnet.

*HA*1 connects full earth to maintain the busy condition on the *P*1 lead, and contacts *HA*3 and *HA*4 disconnect the *A* relay and extend the *S* and *R* wires forward to the odd outlet. If the even outlet is free, relays *BH* and *HB* operate, contact *HB*3 and *HB*4 extending the *S* and *R* wires forward to the even outlet. If both the associated odd and even outlets are free, the odd outlet is seized because *AH*1 disconnects full earth from the testing circuit of relay *BH*, so preventing switching to the even outlet.

Holding. In order to maintain the switch on its selected outlet the circuit is arranged to hold to an earth returned over the *P* wire from the next switching stage. In addition an earth is returned over the *P* wire to the preceding stage so that the preceding switch is also held. The circuit elements are shown in Fig. 9.32.

path *P*1, *HB*2, *HA*1, relay *HA*, *HB*1, *BH*1, *YG*, *HA*5, *N*2, *RT*2, *R*1 rotary magnet to battery. The *HA* relay continues to hold as long as the earth is maintained on the *P* wire by the next switching stage, which may be either a second selector, final selector, trunk relay set or a relay set outgoing from group selector levels.

If an even outlet is seized, relay *HB* is held in a similar manner to that already described for relay *HA*. The operation of contacts *HA*3 and *HA*4 (or *HB*3 and *HB*4) extends the *S* and *R* wires forward to the next stage.

Wipers Stepped to Eleventh Rotary Step. If a free outlet is not found the wipers are self driven until the eleventh rotary position is reached. The rotary drive is then cut and the wipers are brought to rest for the appropriate service signal to be returned to the caller, and the level overflow meter to be operated. The circuit elements are shown in Fig. 9.33.

On reaching the eleventh step the *S* springs operate and a circuit is completed to operate relay *AH* over the path, earth, *RT*1, *B*2, *C*2, *MRB*,

relay *AH*, *HB*2, *P*1, eleventh contact of the bank, *BA*2, resistor *YC* to battery. Relays *AH* and *HA* operate as already described.

The overflow meter is operated over the circuit, earth, *B*7, *S*2, *P*2 arc to the overflow meter. Earth is connected via *B*7, *S*2, *S*1, *R*2 arc to the service signal start lead. The service signal is connected to the eleventh contact of arc *S*1 and is returned to the caller via *HA*3 over the *S* wire. Contact *S*3 ensures that relay *A* remains under the control of more than nine seconds so that attention is quickly drawn to a selector which, because of a mechanical fault or other reasons, has failed to release correctly.

Force Release. To minimize the effects of line faults which would incorrectly engage first selectors, and thereby degrade the service available to other lines, first selectors are provided with a facility which ensures that if a calling signal is not followed by dial pulses within 12–24 sec the selector is

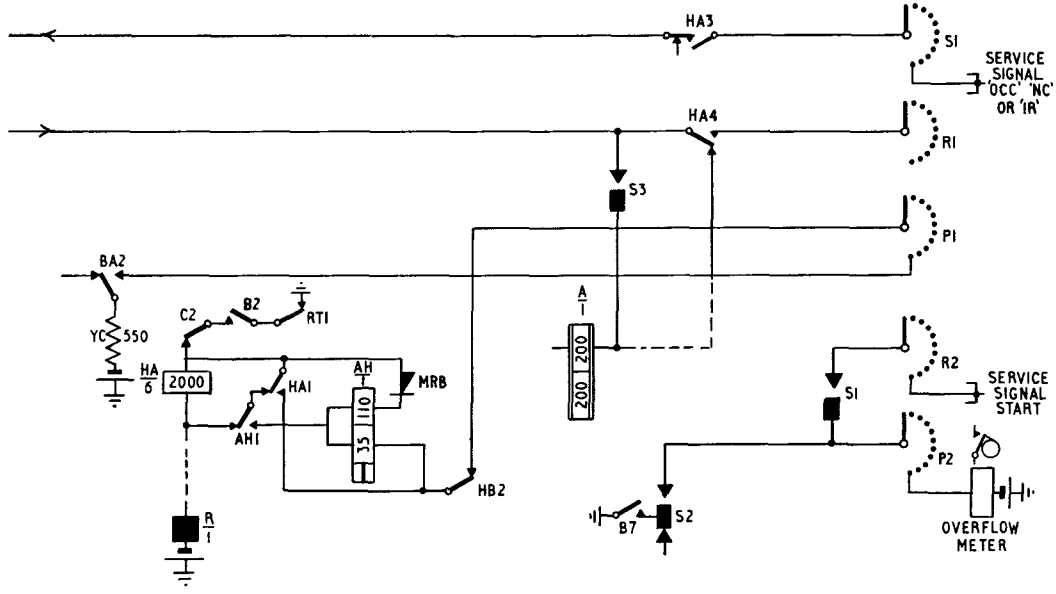


FIG. 9.33. GROUP SELECTOR: CIRCUIT ELEMENT FOR 11TH ROTARY STEP

the caller even though its operating circuit has been broken at *HA*4.

Release of Selector. On clearing the call, the selector is restored to normal by first driving to the end of the level to disengage the wipers from the bank. Reference should be made to Fig. 9.34 which shows the complete circuit of the selector.

The release of the selector is initiated by the removal of the holding earth from the *P* wire. This releases relay *HA* (or *HB*) and a circuit is completed via earth, *BA*1, *TP*4, *HB*5, *HA*5, *N*2, *RT*2, *R*1 and rotary magnet to battery to self drive the wipers. As soon as the wipers reach the twelfth rotary position, the rotary disc disengages from the comb plate and the carriage assembly drops and returns to its normal position. Contact *N*2 opens and disconnects the self drive circuit. The earth for the drive circuit is connected via a low resistance shelf relay which operates when the drive circuit of a selector is completed. A common time delay relay raises an alarm if the shelf relay is energized for forcibly released. This facility also enables the out of service condition to be signalled over V.F. channels. Reference should be made to Fig. 9.34.

The *B* relay is operated when the selector is seized and is released when either the call is extended to the next switching stage or is cleared. The continued operation of the *B* relay is therefore an indication that the selector is seized but not switched. The operation of relay *B* operates relays *BA* and *C* as already described. A 350 msec earth pulse is connected to the *S* pulse lead at 12 sec intervals, and the first pulse to arrive operates relay *TP* via *C*3 and *BA*7. Relay *TP* operates and locks via earth, *B*7, *S*2, *TP*1 to coil of relay *TP*. After an interval of 12 sec, an earth pulse is applied from the *Z* pulse lead via *TP*2 to short-circuit relay *BA*, which releases slowly. *BA*4 disconnects relay *A* which releases, in turn releasing relay *B*. *B*7 disconnects the holding circuit for relay *TP* which also releases. The release of relays *BA* and *B* in sequence connects a negative pulse to the *S* wire by the

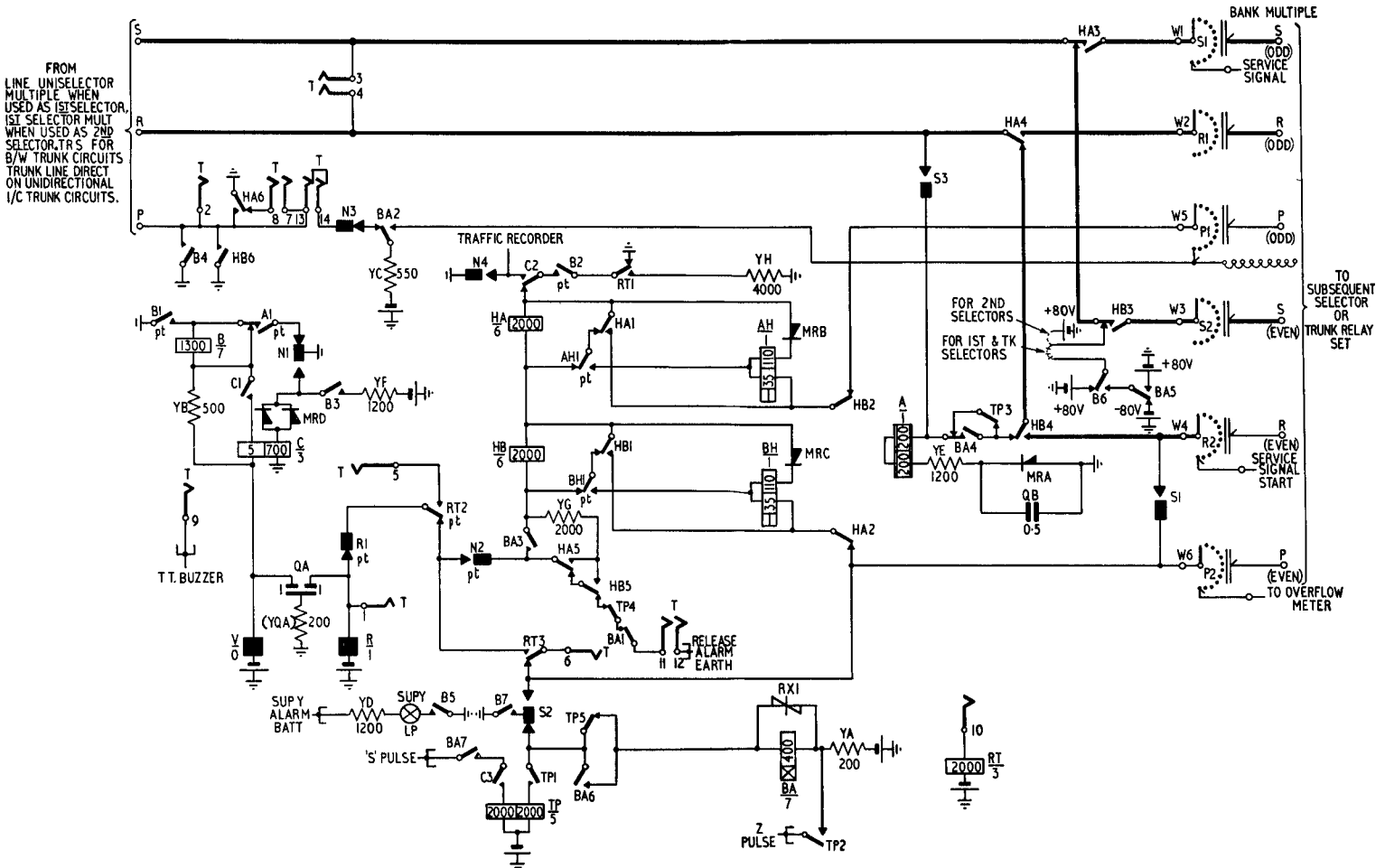


FIG. 9.34. COMPLETE CIRCUIT DIAGRAM OF GROUP SELECTOR

successive restoration of contacts *BA*5 and *B*6. This pulse is returned to the calling station to reset the position equipment, if the calling signal is due to the operation of the DIAL key at the teleprinter position.

As soon as relay *TP* releases, the rotary drive circuit is completed via earth, *BA*1, *TP*4, *HB*5, *HA*5, *N*2, *RT*2, *R*1 to rotary magnet, to restore the selector to normal.

The period which elapses before the force release is effected depends upon the timing of the arrival of the calling signal and the *S* and *Z* pulse cycle, and the period may vary from 12–24 sec. Force release is not provided on either second or trunk selectors.

Guarding. The selector is guarded against unwanted seizure by either earthing the *P* wire or disconnecting the battery potential normally connected via resistor *YC*.

During a call, the earth applied to the *P* wire by contacts *B*4, *HA*6 or *HB*6, in addition to holding the preceding stage also busies the selector. During release, contact *N*3 is operated until the switch is restored to normal, the battery potential which indicates the free condition is therefore not connected to the *P* wire until the selector is fully restored.

To busy a selector for maintenance purposes the *P* wire is earthed by transferring the test peg from *T*13/14 to *T*8/7.

Test Trunk Buzzer. In order that the maintenance staff can check whether the selector is switched to the odd or even outlet without having to remove the cover, a test trunk buzzer is provided. By inserting a test peg between *T*8/9, the buzzer operates if an even outlet has been selected because of the earth connected to *T*8 from contact *HA*6.

Supervisory Alarm. In addition to the forced release facility provided on first selectors, all group selectors are provided with a supervisory alarm. Each selector is fitted with a supervisory alarm lamp which is lit by the operation of contact *B*5. The battery supply for the lamp is drawn via a common shelf relay which operates to extend the alarm condition to a common delayed alarm relay set. This energizes the rack alarm lamp and floor alarms if the selector alarm persists for 6–12 min.

Notes on the Selector Circuit. The non-linear resistor *RX*1 is fitted across the coil of relay *BA* to quench the spark which would otherwise appear at contact *B*7 when it opens the circuit of relay *BA*. The electrical characteristic of *RX*1 is such that its resistance falls rapidly as the potential across it rises. It therefore heavily damps the induced voltage which appears across relay *BA* when its circuit is broken and so reduces the tendency to spark at contact *B*7. *RX*1 does not affect the normal functioning of relay *BA*.

Resistor *YG* is included in the holding circuit of relay *HA* (or *HB*) so that when the selector is being released, a spurious free condition is not connected to the *P* wire of the following stage. This spurious free condition could occur during the release of *HA* (or *HB*) by the connexion of the *P*1 wire via *HB*2, *HA*1, relay *HA*, *HB*1, *BH*1, *YG*, *HA*5, *N*2, *RT*2, *R*1 and rotary magnet to battery. The inclusion of *YG* in this path, however, limits the current to prevent the operation of any testing relay connected to the *P* wire of the next stage at this instant.

Rectifier *MRD* is included to improve the performance of the *C* relay. The sense of polarization of *MRD* is such as to oppose the eddy currents in the 700 Ω winding of *C* when current is connected to the 5 Ω winding, but not to oppose the eddy currents when the 5 Ω circuit is broken. This results in a rapid build up of flux in *C* during the release periods of contact *A*1, consequently during pulsing the flux density in the relay core is maintained at a higher value than would be so in the absence of the rectifier. The risk of relay *C* prematurely releasing during a train of distorted pulses is therefore considerably reduced.

The *RT* relay is provided to facilitate routine testing of the selector. The relay can be operated from the routine tester via the test cord which is plugged into the selector test jack. The contacts of the *RT* relay enable electrical access to be gained to the selector rotary magnet so that the mechanical condition of the selector can be checked by observing the response to trains of test pulses.

Mounting of Group Selectors. Group selectors are mounted on shelves which are fitted with jacks so that the selectors can be readily removed for maintenance. A photograph of group selectors is given in Fig. 9.35.

Final Selector. The final selector, which is reached from the group selector multiple, accepts two digits of the pulse train, the first digit stepping the wipers vertically and the second rotating them into the selected level.

The final selector bank multiple is connected to station line circuits and a multiple capacity of 200 lines is achieved by the use of wiper switching relays. The station line circuits to a given telegraph office are arranged as a group of consecutive outlets and it is possible for a station line group of up to 20 lines to be accommodated on one level of the final selector multiple.

To gain access to an office the number dialled corresponds to the first line in the group and by automatic hunting the selector self drives to find a

free line in the group. If there is no free line available, waiting facilities are provided so that instead of self driving the selector is held on a waiting contact at the beginning of the office group. As soon as a line becomes free the selector self drives to find the free outlet. If, however, a line does not become free within a predetermined period, the selector is released from the waiting contact and the selector self drives to the twelfth rotary step and restores to the normal position. It then automatically steps vertically to a specified level (normally level 1) and automatically hunts over this level to find a free line to connect the call to the overflow centre.

The detailed facilities provided are as follows—

(*a*) Accepting a calling signal and returning an earth on the *P* wire to hold the preceding group selector and to busy the final selector.

(*b*) Stepping vertically under the control of the dialled pulses on the receipt of the tens digit.

(*c*) Rotating the wipers into the required level under the control of the dialled pulses on receipt of the units digit.

(*d*) Hunting, automatically, to seize a free line in the group of lines to which the selector has been stepped.

(*e*) Switching to a disengaged line in the selected group of lines.

(*f*) Connecting the *WRU* signal to the called line.

(*g*) Recognizing the return of answer-back signals from the called station and thereupon connecting the calling teleprinter to the called teleprinter.

(*h*) Connecting the *DER S* signal to the calling teleprinter if the answer-back signals are not received from the called teleprinter within two seconds of connecting the *WRU* signal. The faulty line is busied, and the selector remains locked to the line independently of the calling teleprinter which can be released from the connexion under the control of the calling telegraphist.

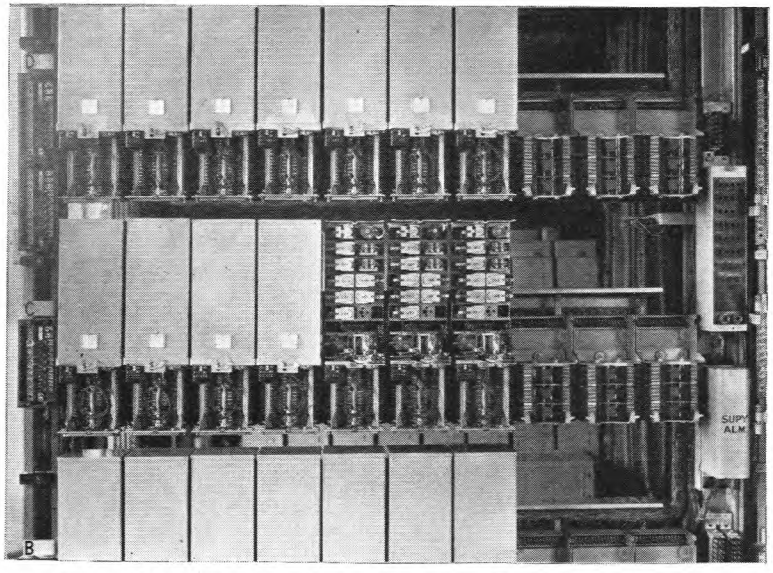


FIG. 9.35. DETAILS OF GROUP SELECTOR RACK ARRANGEMENTS
(*By courtesy of H.M. Postmaster-General*)

(*i*) Giving audible and visual alarms when the selector is locked to a faulty line.

(*j*) Permitting manual retest of a faulty line by the insertion of a test plug in the selector test jack.

(*k*) Releasing the selector and the called station line when the test plug is removed after a satisfactory retest.

(*l*) Immediately releasing the connexion if a spare number is dialled.

(*m*) Waiting on a wait contact at the beginning of the office group, under the control of the suspense relay set, if all the lines in the required group are engaged. The waiting condition is signalled to the calling telegraphist by the return of the *MOM* signal.

(*n*) Releasing the selector from the waiting contact under the control of the suspense relay set, and allowing the selector to hunt for and seize a line becoming free in the required group.

(*o*) Releasing a waiting selector after a predetermined time, and if it fails to find a free line in the

required office group, causing the selector to step automatically to an overflow level and hunt for a disengaged line to the overflow centre.

(*p*) Returning *OCC* signal to a calling teleprinter failing to find a free outlet.

(*q*) Releasing the selector and other switches in the connexion on the receipt of a spacing signal of duration longer than 300 msec.

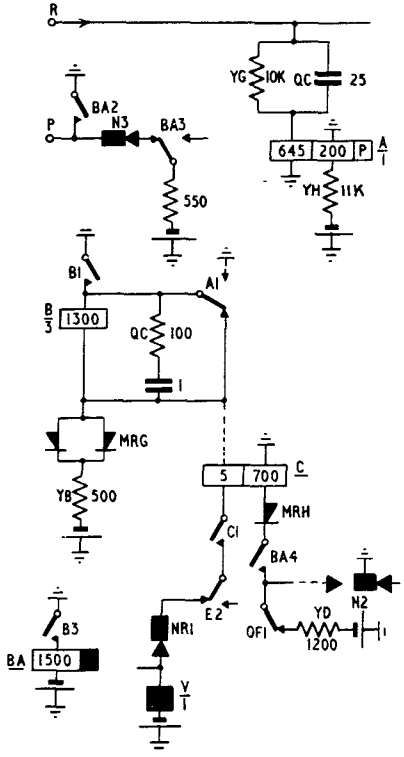


FIG. 9.36. FINAL SELECTOR: CIRCUIT ELEMENT FOR CONTROLLED VERTICAL STEPPING

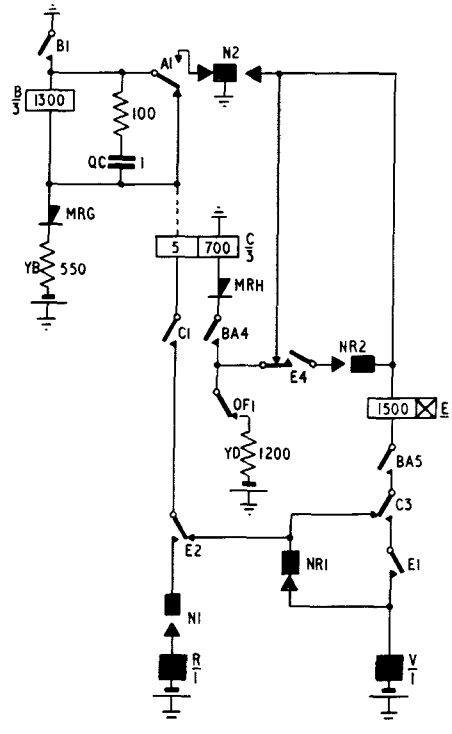


FIG. 9.37. FINAL SELECTOR: CIRCUIT ELEMENT FOR CONTROLLED ROTARY STEPPING

(*r*) Guarding the selector against premature seizure during release.

(*s*) Giving audible and visual alarms if the selector fails to release due to a mechanical fault.

(*t*) Connecting a start earth to the signal start wires as necessary.

(*u*) Giving audible and lamp alarms if the selector is seized but not stepped, or is standing on the eleventh rotary step.

In considering the circuit arrangements of the final selector, it is convenient to examine the separate circuit elements into which the circuit may be divided, as was done with the group selector.

Controlled Vertical Stepping. The first digit train received by the selector steps the wipers to the required level, followed by the next digit train which steps the wipers into the level. The circuit element for the pulse controlled vertical stepping is shown in Fig. 9.36 and it will be noted that it is similar in principle to the element already described for the group selector. The most important difference is the use of a polarized relay as the *A* relay. The reason for this is explained later.

On seizure of the selector, relays *A*, *B*, *BA* and *C* operate in sequence as for the group selector. During the receipt of the first digit the vertical magnet is pulsed to step the switch to the required level and after the switch has stepped off normal, relay *C* is dependent upon the current in its 5 Ω winding for holding, since the 700 Ω winding is short circuited. During the interdigit pause relay *C* releases. As in the case of the group selector, the action of contact *A*1 in short-circuiting relay *B* during pulsing ensures that the release lag of relay *B* is sufficiently long for the relay to remain operated during the receipt of a digit pulse train.

Controlled Rotary Stepping. The units digit is used to step the wipers into the level selected by the tens digit. The circuit elements are shown in Fig. 9.37.

On the release of relay C following vertical stepping, relay E operates over the path, earth, $\underline{N2}$, E relay, $\underline{BA5}$, $C3$, $NR1$, vertical magnet to battery. Relay E in operating completes a circuit for the re-operation of relay C by removing the short-circuit across the 700 Ω winding of C at $\underline{E4}$.

Relay C operates and contact $\underline{C3}$ disconnects the operating circuit of relay E, but completes a holding circuit via $\underline{E1}$. To ensure that relay E does not release during the transit time of $C3$, relay E is fitted with a slug which ensures that the release lag exceeds the transit time of contact $C3$.

On receipt of the units digit, the rotary magnet is pulsed via the circuit, earth, $\underline{B1}$, $A1$, 5 Ω winding of relay C, $\underline{C1}$, $\underline{E2}$, $\underline{N1}$ to rotary magnet. The wipers are stepped into the bank and on the first rotary step the rotary off normal springs (NR) operate. $\underline{NR2}$ short-circuits the operating circuit for relay C and as in the case of vertical stepping, relay C is dependent for holding on the pulsing current in the 5 Ω winding. At the conclusion of the digit, relay C releases and $C3$ disconnects the holding circuit for relay E which also releases. The wipers are now standing on the bank contacts corresponding to the two digits dialled into the selector.

Automatic Rotary Hunting and Testing. The selector is arranged to hunt automatically for a free line in the office group. The circuit element is shown in Fig. 9.38 and it will be noted that it is very similar to the circuit element used in the group selector.

On release of relay E, contact $E3$ completes the driving and testing circuit which functions as described for the group selector. The free condition of the station line circuit is indicated by battery connected to the PA or PB leads via a 550 Ω resistor. The circuit is so arranged that, as in the group selector, if the two outlets which are being tested together are both free the HA relay operates to seize the odd choice.

Holding and Release of the Selector. Fig. 9.39 shows the circuit elements which enable the final selector to be held switched to the selected line.

In addition, the final selector holds the remaining switches in the chain within the switching centre. To enable this facility to be provided it is necessary for the relay A to be connected in leak with the R wire during the call, in readiness to detect the clearing signal. In order to minimize the attenuation of the signalling currents by the shunting effect of relay A, a polarized relay is used because of its high sensitivity which permits a higher leak impedance than would be possible with a 3,000 type relay. The shunted capacitor combination QD and YG ensures that the repetition distortion of relay A is kept to a minimum.

The release of relay B is effected by the short-circuit from contact $A1$ which provides a release lag of approximately 300 msec. This is long enough to ensure that relay B does not release to dial pulses or teleprinter signals but when a clearing signal is received relay B releases. (The second winding on relay A is used to provide a small electrical spacing bias so that line disconnexions

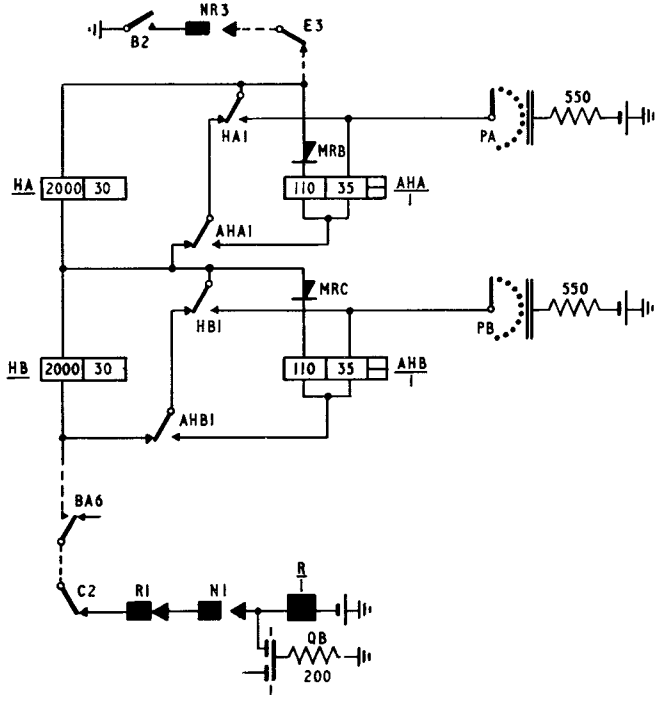


FIG. 9.38. FINAL SELECTOR: CIRCUIT ELEMENTS FOR AUTOMATIC HUNTING AND TESTING

cause relay A to space and so produce a clearing signal. The bias also ensures that relay A spaces when the selector is disengaged.)

Relays B and BA are, therefore, operated for the duration of the call and it is possible to use contact $\underline{BA2}$ to connect an earth to the P wire to hold the preceding group selector and to busy the final selector.

Contact $\underline{B2}$ connects an earth to hold relay HA (or HB) in series with the rotary magnet. The earth from contact $\underline{B2}$ is extended via $\underline{HA1}$, $HB2$ to the PA wiper, to operate relay H in the station line circuit.

When a clearing signal is received, contact $A1$ short-circuits relay B long enough for relay B to release. $B3$ releases relay BA.

*B*2 disconnects relay *HA* which releases and in turn releases relay *HR*. *HR*2 completes the drive circuit for the rotary magnet from earth, *BA*6, *HR*2, *R*1, N1 to rotary magnet. The selector then drives out of the bank and restores to the normal position. The free condition on the *P* wire is not connected until the selector has fully restored and contact *N*3 made.

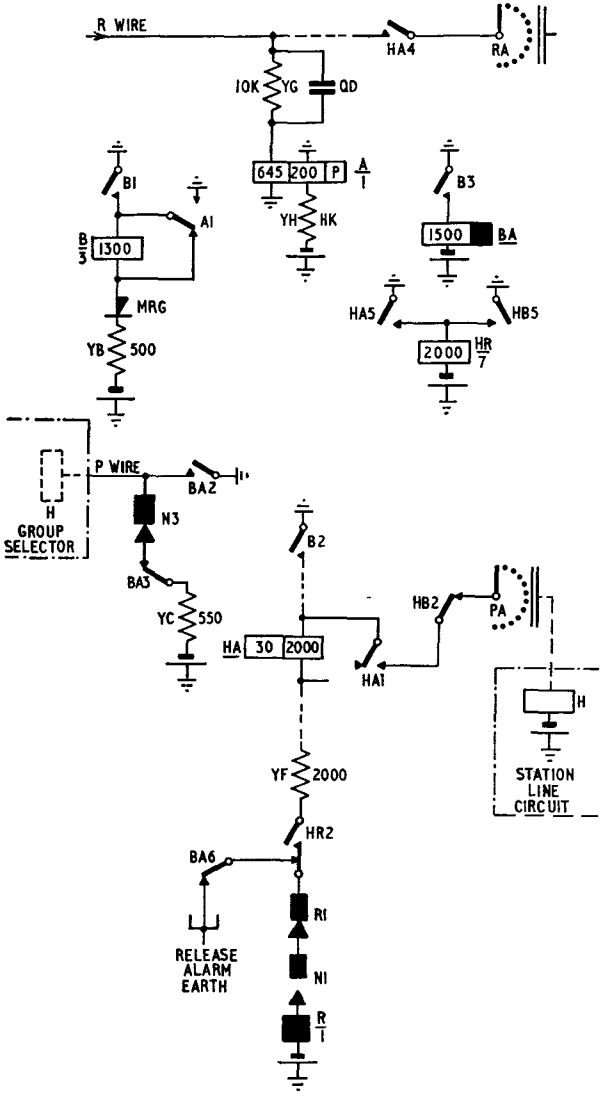


FIG. 9.39. FINAL SELECTOR: CIRCUIT ELEMENTS FOR HOLDING AND RELEASE

Automatic Taking of the Answer-back and Station Fault Alarm. As soon as the final selector switches to the free line, the final selector automatically transmits signals to trip the answer-back drum of the called teleprinter. If teleprinter signals are not returned within two seconds, the station line is regarded as faulty and the *DER S* signal is returned to the caller.

The circuit elements are shown in Fig. 9.40.

To measure the time interval in which the answer-back signals are expected to be returned from the calling teleprinter, two phasing pulses, the WRU phasing pulse (WRUPP), and station fault pulse (SFP) are associated with the WRU signal.

For the purpose of describing the functioning of the circuit element it will be assumed that an odd choice has been selected by the operation of relay *HA*.

HA4 connects negative battery to the *RA* wiper to start the teleprinter motor at the called position. The called position relay set returns negative battery as the call connected signal, via the *SA* wiper, HA3, *SF*3 and thence to the calling station. Earth is connected to the WRU Signal Start Lead from NR4, *F*1 and *MRE*. This energizes the circuits distributing the WRU signal and associated phasing pulses, and on receipt of the 50 msec earth pulse on the WRU Phasing Pulse lead, via HR1, *F*2, *P*4 and *SF*2, relay *P* operates. P4 locks relay *P* to earth via NR4, *F*1, P4, *SF*2 to relay *P*. P2 connects the WRU signal to the called teleprinter. P3 connects the *F* relay element to the *S* wire in readiness to recognize the return of the answer-back signals.

The WRU signal consists of the sequence of teleprinter characters shown in Fig. 9.41 which also shows the relative timings of the phasing pulses.

As soon as the teleprinter motor at the called station has run up to the correct speed the WRU signal trips the answer-back drum to return the station code set up on the answer-back drum. The start element of the first teleprinter character reaching the final selector operates the F relay in the following manner.

Prior to the operation of contact *P*3, capacitor *QA* was positively charged via *YK* and *YJ* to + 80 V. On the operation of relay *P*, *QA* charges negatively via *YK* to the negative battery on the *S* wire. The direction of the charging current is such that *MRF* is non-conducting and thus the current has to pass via resistor *YK* and is too small to operate relay *F*. The time constant of the charging circuit is approximately 200 msec. The first teleprinter character of the answer-back code is received at least 600 msec after the operation of relay *P* and therefore capacitor *QA* will have acquired a large negative charge. On the receipt of the first character, the change of potential on the

S wire causes a surge of current via *QA* in the conducting direction of *MRF*. Because *MRF* is conducting the current is large enough to operate relay *F* which locks at *F*1 to earth at *NR*4.

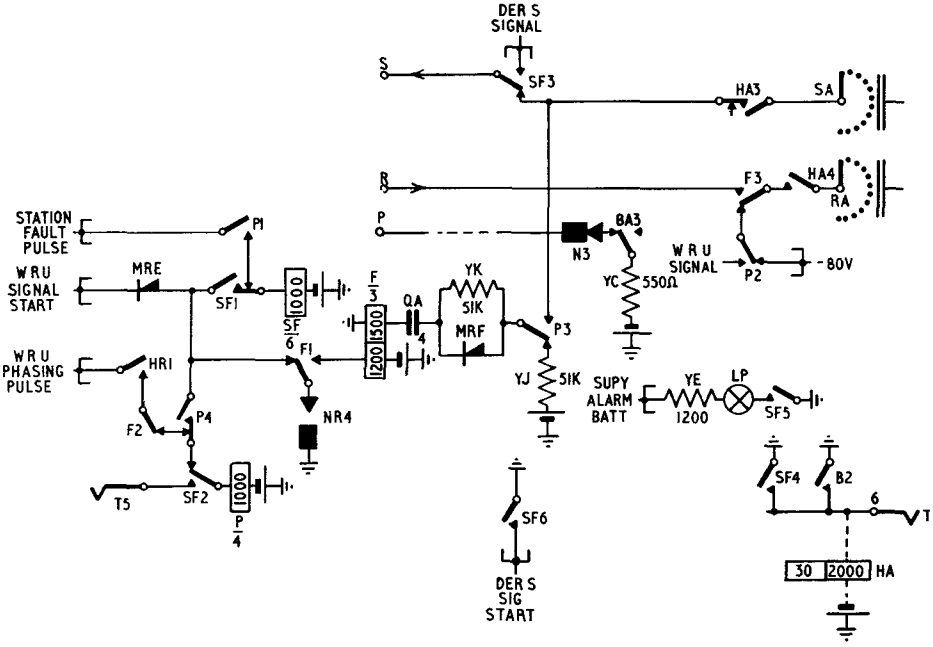


FIG. 9.40. FINAL SELECTOR: CIRCUIT ELEMENTS FOR AUTOMATIC TAKING OF THE CALLED STATION'S ANSWER-BACK CODE

*F*1 disconnects the holding circuit of relay *P* which releases.

*F*2 prevents the re-operation of relay *P* to further phasing pulses.

*F*3 connects the calling teleprinter transmitter through to the teleprinter receiver at the called station.

*P*3 on restoring disconnects the *F* relay element from the line.

If the station line is faulty the answer-back signals are not returned and *F* relay is not operated. Therefore on the receipt of the station fault pulse at the end of the cycle, relay *SF* operates via *SF*1, *P*1, to earth on the phasing pulse lead. Relay *SF* locks via *SF*1, *F*1, *NR*4, to earth. *SF*2 releases relay *P*.

*SF*3 connects the *DER S* signal to the caller to indicate that a faulty line has been selected.

*SF*4 applies a holding earth to the *HA* relay so that when the caller clears and releases relay *B*, the selector is held on the faulty outlet which is then busied against seizure by further callers.

*SF*5 lights the selector supervisory alarm to draw attention to the fault condition.

*SF*6 connects an earth to the *DER S* signal start lead.

To attend to the fault the maintenance staff are provided with a test plug which is inserted into the

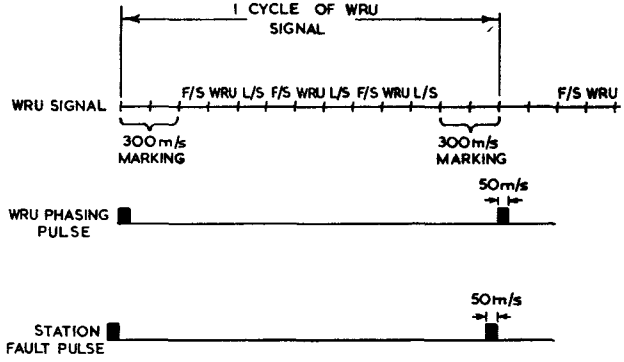


FIG. 9.41. W.R.U. SIGNAL, W.R.U. PHASING PULSE AND STATION FAULT PULSE

selector test jack to connect earth to springs *T*5 and *T*6. The earth on *T*5 operates relay *P* which connects the WRU signal to the line at *P*2. By looping the line at the Engineering Control Board (ECB) the fault can be proved to be in or out of the switching centre equipment, since the WRU

signal should return via the loop to operate the *F* relay and so release relay *SF* at *F*1 and relay *P* at *SF*2. If the fault is proved to be outside the switching centre, the final selector remains busied as long as the test plug is inserted in the selector test jack, to maintain relay *HA* (or *HB*) operated by the earth connected via *T*6. This prevents the selector from releasing and *N*3 busies the *P* wire

*AW*1 in addition to busying the *TA* contact to further selectors, also permits relay *W* to operate in series with the rotary magnet. *W*2 connects earth to the MOM signal start lead and *W*1 connects MOM signal to the calling teleprinter. The selector continues to wait as long as the battery potential is connected to the *TA* bank contact by the suspense relay set. As soon as this potential is

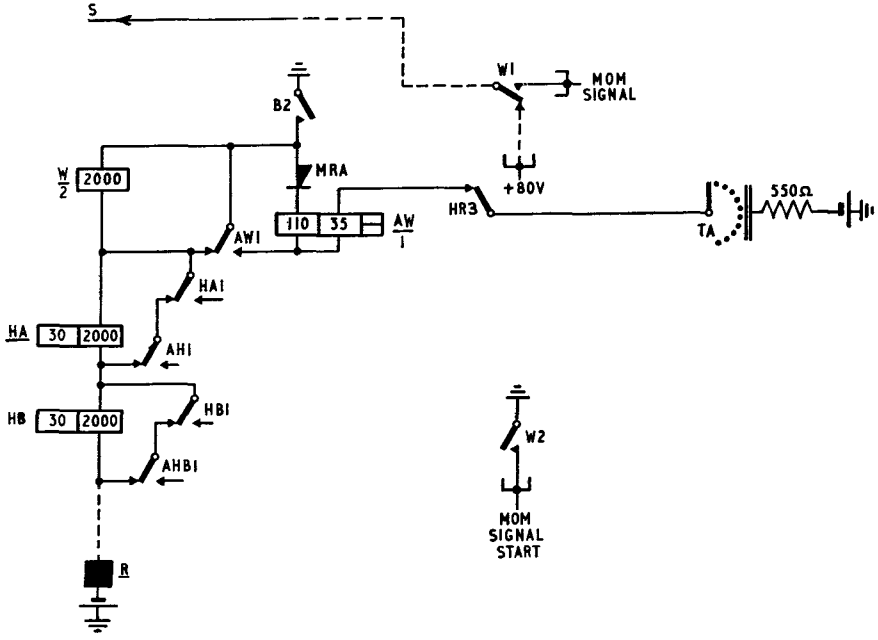


FIG. 9.42. FINAL SELECTOR: CIRCUIT ELEMENT FOR WAITING FACILITY

and so prevents another call interfering with the testing.

Waiting Facility. As already explained, in order to increase the traffic efficiency of station lines, a suspense facility is provided so that if all lines to the required office are busy, the final selector waits until a line becomes free, the waiting condition being indicated to the calling telegraphist by the return of the MOM signal.

The circuit elements are shown in Fig. 9.42.

To enable the waiting facility to be provided, the final selector is fitted with a fourth bank (designated *T*) cabled away to the suspense relay sets. To indicate that the next call should wait, the suspense relay set connects battery via a 550 Ω resistor to the *TA* contact at the beginning of the office group. The selector, before commencing to hunt over the office group, tests the *TA* lead with the *AW* relay which operates if battery via 550 Ω is present.

removed, relay *AW* releases and *AW*1 completes the rotary drive and testing circuits for the selector to drive in search of a free line.

Normally, for an office with one waiting contact, the waiting battery potential is connected to the *TA* contact corresponding to the digit dialled. When, however, two waiting contacts are provided it is necessary to use two consecutive *TA* contacts having two separate waiting battery supplies from the suspense relay set. The first selector to wait arrives at the position determined by the digits dialled, takes one step and is then held by the battery potential connected to the *TA* bank contact. The suspense relay set then connects battery potential to the preceding *TA* bank contact so that the next selector calling is held on the contact corresponding to the digit dialled. The waiting contacts occupied by the first and second selectors to wait are known as the first waiting contact, and second waiting contact respectively.

Overflow Facilities. A facility is provided so that a final selector failing to find a free line to the wanted office is automatically routed to a group of lines to an overflow centre. This augments the waiting facility by enabling the message to be routed to the overflow centre if the predetermined waiting period is exceeded. This ensures that the message is dropped at an office as close to the receiving office as possible and so avoids the need for the originating telegraphist to engage trunk lines in further attempts to dispose of the message. A further use for the overflow facility is the ability to close small offices during periods of light traffic. In such cases the wait facility is automatically withdrawn and all calls to the office are immediately routed to the overflow centre without requiring the use of special dialling codes.

The circuit elements are shown in Fig. 9.43.

The *TB* contact corresponding to the last line in the office group is connected to battery potential via a 250 Ω resistor. If there are no free lines in the group the selector drives to the last contact in the group and relay *AOF* operates to battery, *TB* arc, relay *AOF*, *YA*, *MRD*, *AHB*1, *HB*1, *AHA*1, *HA*1, *AW*1, *E*3, *NR*3, *OF*2, *B*2 to earth.

*AOF*1 removes the short-circuit from *OF* relay which operates in series with the rotary magnet.

OF relay locks via *OF*4, *NR*2, *N*2 to earth.

*OF*2 operates relay *VS* to earth via *B*2. *OF*3 connects earth to the rotary magnet drive circuit to drive the selector to the twelfth rotary position. The selector then drops and returns to the normal position. The off normal springs restore and *N*1 breaks the rotary magnet circuit and *N*2 releases relay *OF*.

*OF*1 connects battery via *BA*4 and *MRH* to operate relay *C*. *C*1 completes the circuit of the vertical magnet from release alarm earth, *V*1, *VS*2, 5 Ω winding of relay *C*, *C*1, *E*2, *NR*1 to vertical magnet. The selector steps vertically by self-drive action until the overflow level is reached. This is normally level 1 and is reserved for circuits to the overflow centre. The normal post springs *NPA* are set to operate when the overflow level is reached and *NPA*1 connects earth to hold the vertical magnet operated, and so prevent further stepping. Relay *C* which has been held operated by the current in its 5 Ω winding now releases and *C*1 disconnects the vertical magnet. A circuit is completed for rotary drive over the following circuit, earth, *B*2, *OF*2, *VS*4, *E*3, *AW*1, *HA*1, *AHA*1, *HB*1, *AHB*1, *AOF*1, *OF*3, *C*2, *R*1, *N*1 to rotary magnet. The selector then self drives into the overflow level testing the outlets in the manner already described. On switching to a free outlet relay *VS* is released by *HR*4.

Eleventh Rotary Step. If a selector hunting over the overflow level fails to find a free outlet, it drives to the eleventh rotary step position and returns the

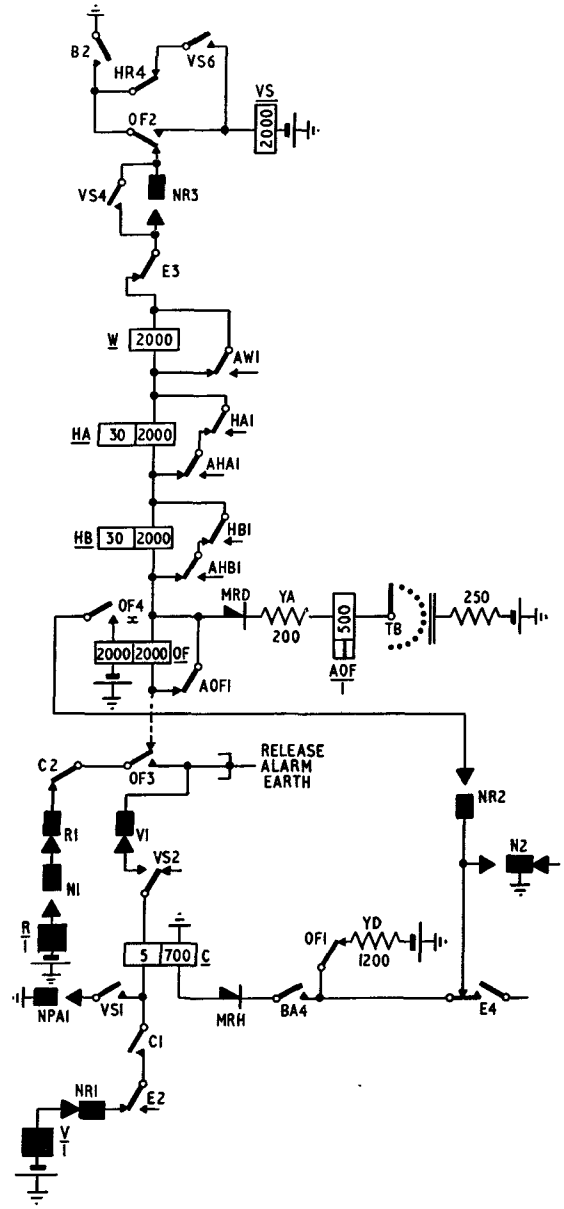


FIG. 9.43. FINAL SELECTOR: CIRCUIT ELEMENTS FOR OVERFLOW FACILITY

OCC signal to the caller. Similarly, when it is required to provide a group of lines within the final selector multiple but without overflow facilities, e.g. duplex or inquiry circuits, the busy condition

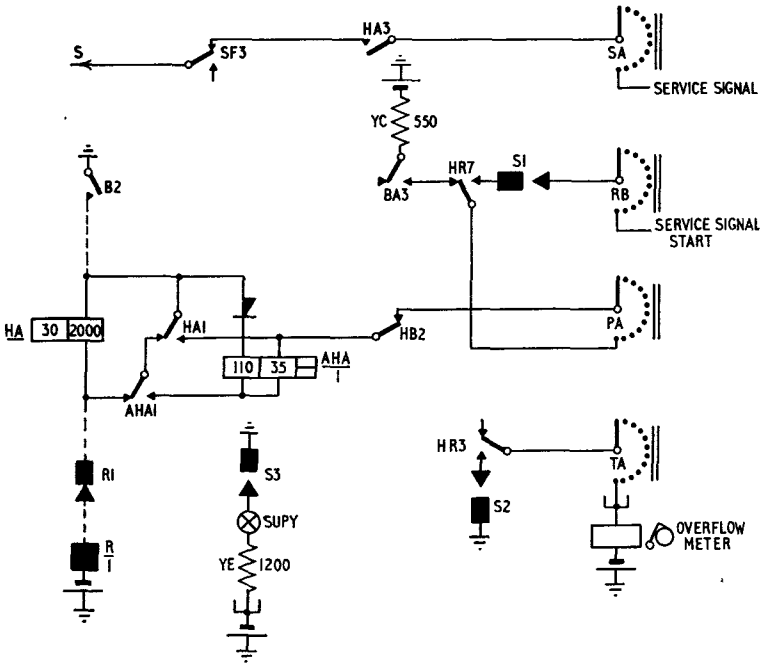


FIG. 9.44. FINAL SELECTOR: CIRCUIT ELEMENT FOR 11TH ROTARY STEP

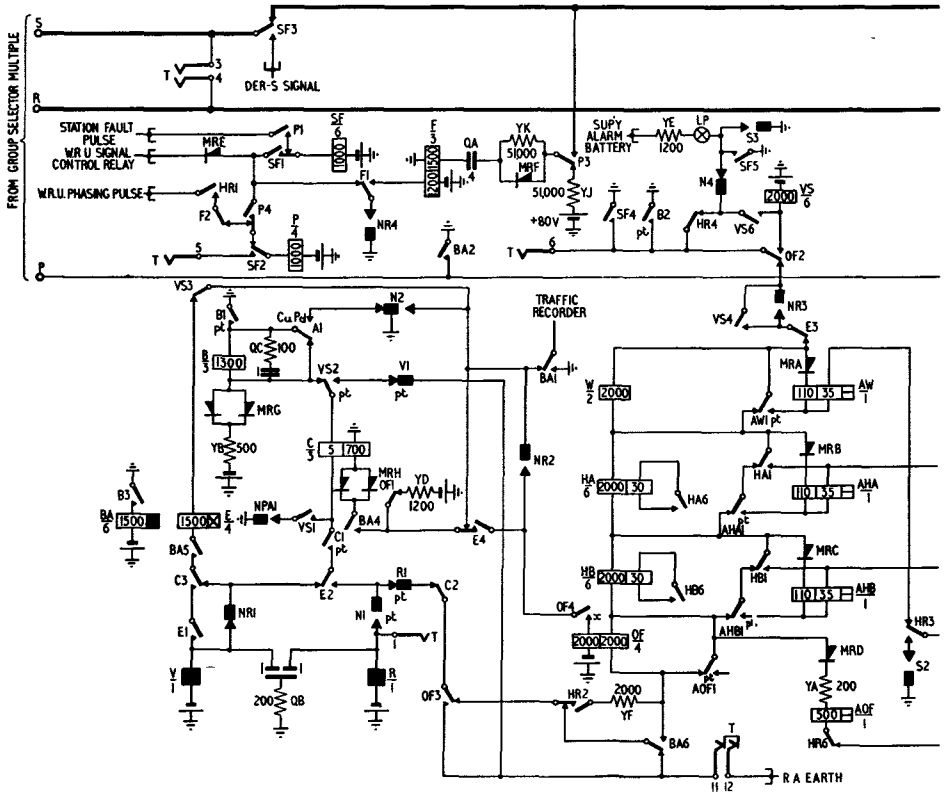


FIG. 9.45. COMPLETE CIRCUIT

is indicated by the selector stepping to the eleventh rotary step position. To enable this to be done, the group of circuits is accommodated at the end of the level and the battery normally connected to the *TB* contact at the end of the group is omitted. On failing to find a free outlet the selector drives to the eleventh rotary step position and stops. The circuit element is shown in Fig. 9.44.

On reaching the eleventh rotary step battery is connected via *YC*, *BA*3, *HR*7, eleventh step bank contact of *PA* arc, *PA* wiper to operate relay *AHA*. *AHA*1 cuts the rotary drive and operates relays *HA* and *HR* as already described. The *S* springs are operated whilst the selector is standing on the eleventh rotary step. Earth is connected from *B*2 etc., *HA*1, *PA* wiper and arc, *HR*7, *S*1, *RB* wiper to the service signal start wire. The service signal is returned over the *SA* wiper via *HA*3 to the calling subscriber. *S*3 connects earth to energize the selector supervisory alarm. To operate the overflow meter an earth is extended via *S*2, *HR*3, *TA* wiper to the overflow meter connected to the *TA* bank eleventh outlet.

The service signal connected to the eleventh rotary step of the final selectors is either *OCC* for working levels or *IR* for spare levels.

Spare Lines. The *IR* signal is returned to the calling station to release the connexion whenever a spare number is dialled. To provide this facility, the last outlet in each group of spare lines is connected to the *IR* signal for spare lines. This connects battery via a 550 Ω resistor to the *PA* arc to cause the selector to switch. The *IR* signal is connected to the *SA* contact and is thus returned to the caller via contact *HA*3 and *SF*3. If the number dialled corresponds with an early outlet in a group of spare lines, the selector drives to the last outlet in the group to return the *IR* signal.

Release Alarm. The release alarm provided on final selectors is similar to that provided for group selectors.

Complete Final Selector Circuit. A complete circuit diagram of the final selector is shown in Fig. 9.45 and it will be noted that the circuit includes a few minor facilities not already described.

These include a test trunk buzzer to indicate whether the selector has switched to an odd or even choice outlet, and a wait bell to indicate that the selector is waiting.

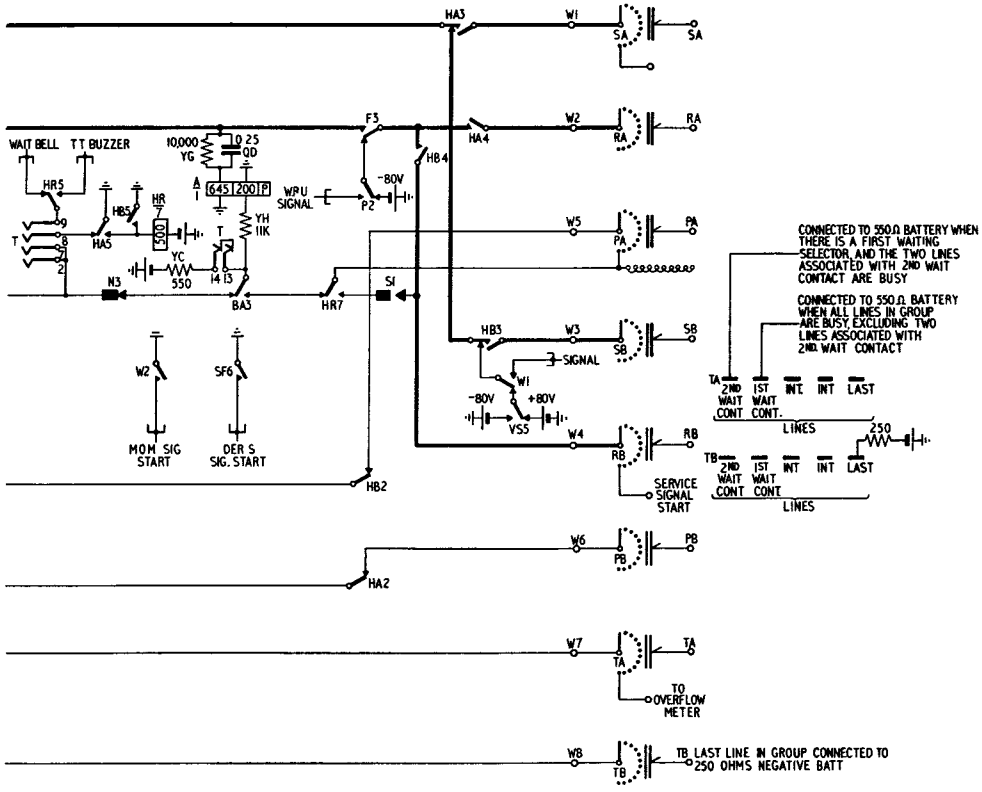


DIAGRAM OF THE FINAL SELECTOR

19—(T.421)

Supervisory Alarm. The final selector is provided with a supervisory alarm which is operated to indicate either the seized but not stepped condition, a station fault alarm or the selector standing on the eleventh rotary step. The delay period is 3–6 min.

A photograph of a partially-equipped final selector shelf is shown in Fig. 9.46.

Suspense Relay Set. The suspense relay set is provided on the basis of one per office group. It receives from each station line in the group an indication whether the line is busy, free, or out of service, and in response to this information, the suspense relay set applies marking conditions to the final selector multiple to determine whether calls shall wait.

The facilities of the suspense relay set provide for—

(*a*) Connecting a battery potential to the first wait contact of the office group when all working lines are busy.

(*b*) Connecting a battery potential to the second wait contact when the first wait contact is occupied by a waiting final selector. (This facility is not used on small office groups.)

(*c*) Releasing a final selector from the first wait contact when a line in the group becomes free.

(*d*) Releasing a final selector from the second wait contact when the first wait contact becomes free.

(*e*) Releasing a final selector from a wait contact after waiting a period of 30–60 sec.

(*f*) Routing a call immediately to overflow if all lines in the group are out of service or if the wait contacts are occupied.

Group Control Wire. To determine whether each station line is free, busy, or out of service, a group control wire is used. The circuit element is shown in Fig. 9.47.

A free station line is indicated by the released condition of relays L and G; the out of service condition by L and G operated; and the busy condition by L released and G operated. Relay PT can only operate therefore, when at least one station line is engaged on a call, and the remaining station lines are either busy or out of service.

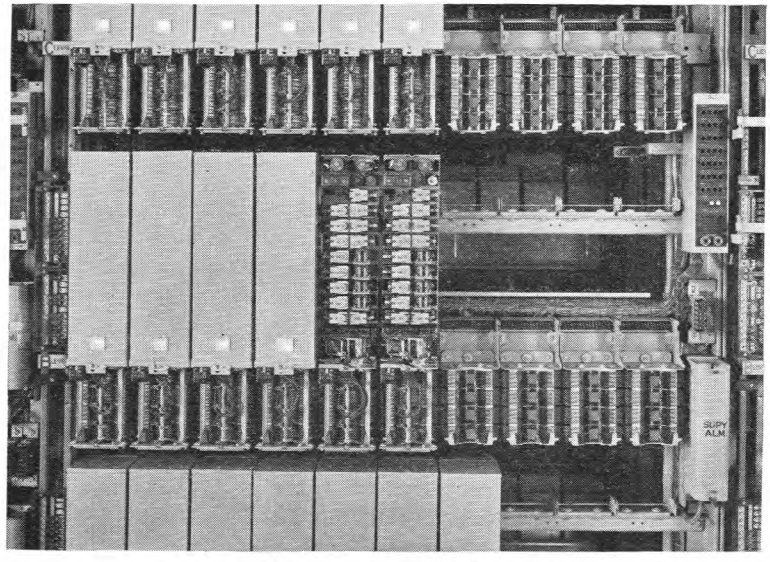


FIG. 9.46. VIEW OF FINAL SELECTORS
(*By courtesy of H.M. Postmaster-General*)

Office Group with One Waiting Contact. The circuit elements for one wait contact are shown in Fig. 9.48.

When all the lines in the group are free or out of service, relay PT is unoperated and the TA bank contact is disconnected. When, however, there is no free line, but some lines are busy, relay PT operates and connects battery via YD, $\underline{PT1}$, $M3$ to the TA bank to cause the next final selector testing the office group to wait. The final selector connects earth via its AW relay to operate relay S. If a line becomes free, relay PT releases and $PT1$ disconnects the battery from the TA bank to release the selector which drives and switches to the free line. However, if a line does not become free within 30–60 sec the selector is discharged from the

wait contact by the following sequence of operations.

S4 connects relay *TP* to the 30 sec *S* pulse lead and on the arrival of the first earth pulse relay *TP* operates and is locked to earth via S5, TP1, M2 to coil of *TP*. After 30 sec an earth pulse is applied over the *Z* pulse lead via TP2 to operate relay *M*. Contact M1 locks relay *M* to the *Z* lead for the duration of the pulse, independently of TP2. M3 disconnects the battery from the *TA* bank to free, relay *PT* is released and *PT*1 discharges the final selector standing on the first wait contact and also releases relay *S*. Relay *S* in releasing disconnects the battery from the second wait contact at *S*3 and the final selector steps on to the first wait contact where it finds a marking battery via resistor *YC* and relay *X* in parallel, SA1, *S*2, *PT*1, *M*3 and *TA* bank contact. This circuit is maintained at *SA*1 during the slow release period of relay *SA*, the circuit of which is broken at *S*5. The release lag of

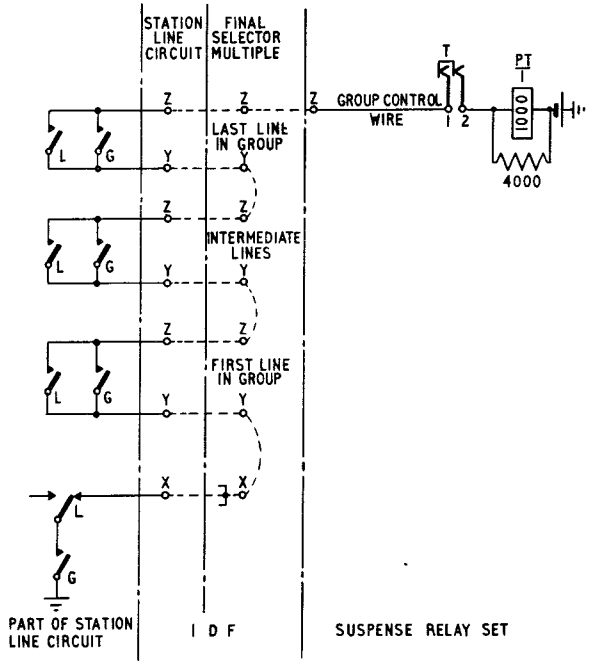


FIG. 9.47. SUSPENSE RELAY SET: CIRCUIT ELEMENTS OF GROUP CONTROL WIRE

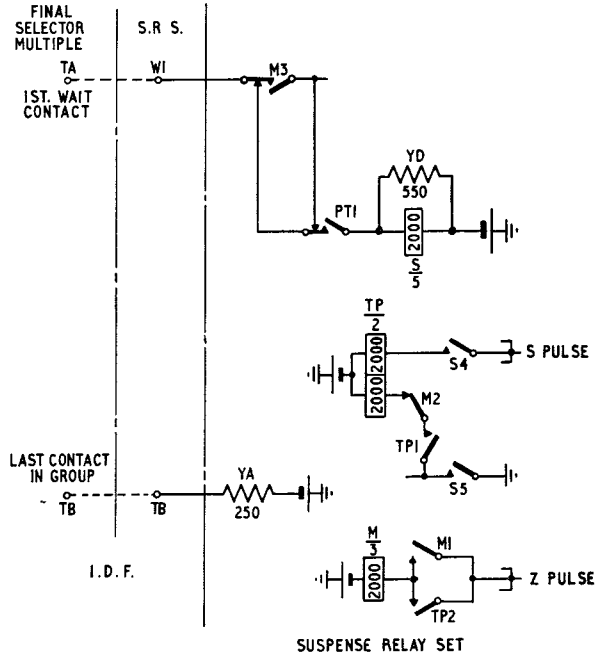


FIG. 9.48. SUSPENSE RELAY SET: CIRCUIT ELEMENT TO PROVIDE ONE WAITING CONTACT

release the final selector from the wait contact. The final selector drives and finding no free outlet, reaches the *TB* battery on the last contact in the group and the call is routed to overflow.

Following the operation of *M*3 and the discharge of the call to overflow, relay *S* releases, relay *TP* having meanwhile released since its hold circuit is broken at M2. Relay *M* remains held to the *Z* pulse via *M*1 and releases when the pulse terminates.

Office Group with Two Waiting Contacts. Fig. 9.49 shows the additional circuit elements for office groups with a second wait contact.

When the first wait contact is occupied by a waiting final selector, relay *S* operates. S5 operates relay *SA* and S3 connects battery via *YB* to the second waiting contact to cause the next final selector arriving to wait. As soon as a line becomes *SA* is long enough to cover the time required for the selector discharged from the first wait contact to drive and switch to the free station line and reoperate relay *PT*. This is necessary to prevent the incorrect release of two waiting calls when only one line becomes free.

Whilst relay *SA* is releasing, relay *X* is operated by the selector standing on the first wait contact. X1 connects battery to the second wait contact in readiness for a further call.

If the selector standing on the first wait contact is forcibly released by the time pulse, the selector on the second wait contact is passed forward to the first wait contact as already described.

Working Lines Associated with the Second Wait Contact. Reference should be made to the full circuit of the suspense relay set shown in Fig. 9.50.

When a working line is associated with the second wait contact, a complication arises because a final selector cannot step backwards, therefore a final selector standing on the first wait contact cannot seize a line associated with the second wait contact. To overcome this difficulty the circuit is arranged so that the group control wire does not include the S.L.C.s of the lines associated with the second wait contact. These are connected instead to relay *PTA*, the contact of which controls the battery

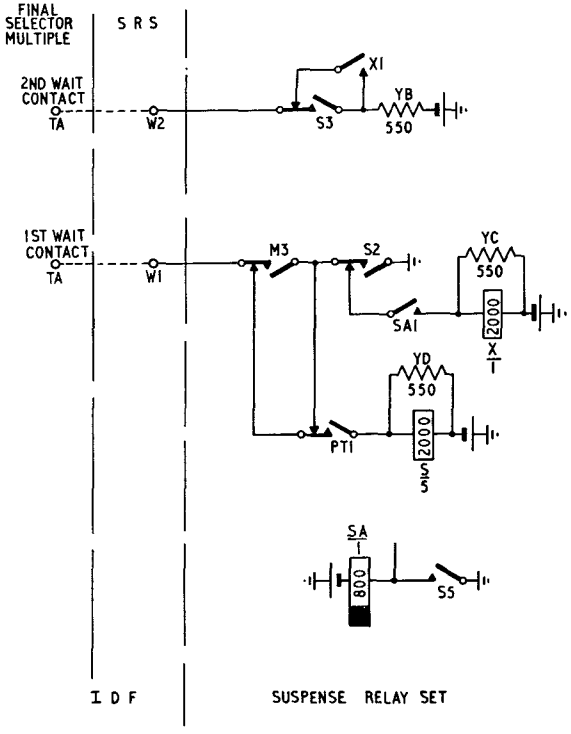


FIG. 9.49. SUSPENSE RELAY SET: CIRCUIT ELEMENT FOR SECOND WAIT CONTACT

connected to the second wait contact, so that if one of the associated lines becomes free the selector standing on the second wait contact is allowed to switch to the line, whilst the selector standing on the first wait contact is unaffected.

Suspense Without Overflow. For some services such as Duplex, or Enquiry, it is required to provide delayed hunting without overflow. This is achieved by omitting the connexion to the TB tag and by arranging that there are no other working lines after the last line of the group in the final selector multiple, so that calls which would otherwise overflow are switched to the service signal on the eleventh rotary step position of the final selector.

Contact S1. Contact *S1* is included in the circuit to avoid possible difficulties with single line offices, since during the release of a connexion the relay *L* in the S.L.C. may be operated for a short period. Contact *S1* ensures that relay *PT* is not released until relay *G* in the S.L.C. has restored, indicating that the station line is free.

Relays in Parallel with Test Battery Resistors. Relays *X* and *S* are connected in parallel with the 550 Ω resistors through which battery potential is connected to mark the *TA* bank contacts. At first it might be thought that the presence of the relays would interfere with the operation of the high speed testing relays in the final selector, by allowing increased current to flow in the testing circuit thereby increasing the risk of double connexion. In practice, however, the inductance of the coils is such that, having regard to the operate times of the high speed relays, the rate of growth of current in the *X* and *S* relay coils is too slow to produce any double connexions.

Release Lags of Relays PT and PTA. Relay *PT* and *PTA* are both made slow to release by shunting with resistors. This ensures that when a line in the group becomes free, the S.L.C. has sufficient time to connect the free condition to the *P* wire before relay *PT* (or *PTA*) discharges the final selector from the waiting contact.

Bothway Trunk Relay Set. To permit trunk lines to be connected to the bank contacts of the group selector levels for outgoing calls, it is necessary to employ relay sets which mark the *P* wires of the group selector multiple free or busy according to the condition of the trunk lines. The main function of the relay set is, therefore, to determine from the signals passing over the line the condition to be applied to the *P* wire of the group selector multiple. In addition, it also allows the trunk line to be connected to an incoming trunk selector for incoming calls and for this reason is known as a Bothway Trunk Relay Set.

The detailed facilities provided by the relay set are as follows—

(*a*) Giving access to the trunk line from group selector levels for outgoing calls.

(*b*) Giving access to the trunk selector for incoming calls.

(*c*) Connecting an earth to the *P* wire of the group selector multiple to hold the selectors within the switching centre during an outgoing call.

(*d*) Guarding the trunk line against premature seizure on release, to ensure that the selectors at the distant end of the trunk line have fully restored.

(*e*) Automatically checking the transmission path of the trunk line on seizure for an outgoing call.

(*f*) Returning the *DER T* signal to the caller if the trunk line tests faulty when seized for an outgoing call.

(*h*) Returning the trunk line to service if it responds satisfactorily to a retest during the $2\frac{1}{2}$ min period and the caller has meanwhile cleared.

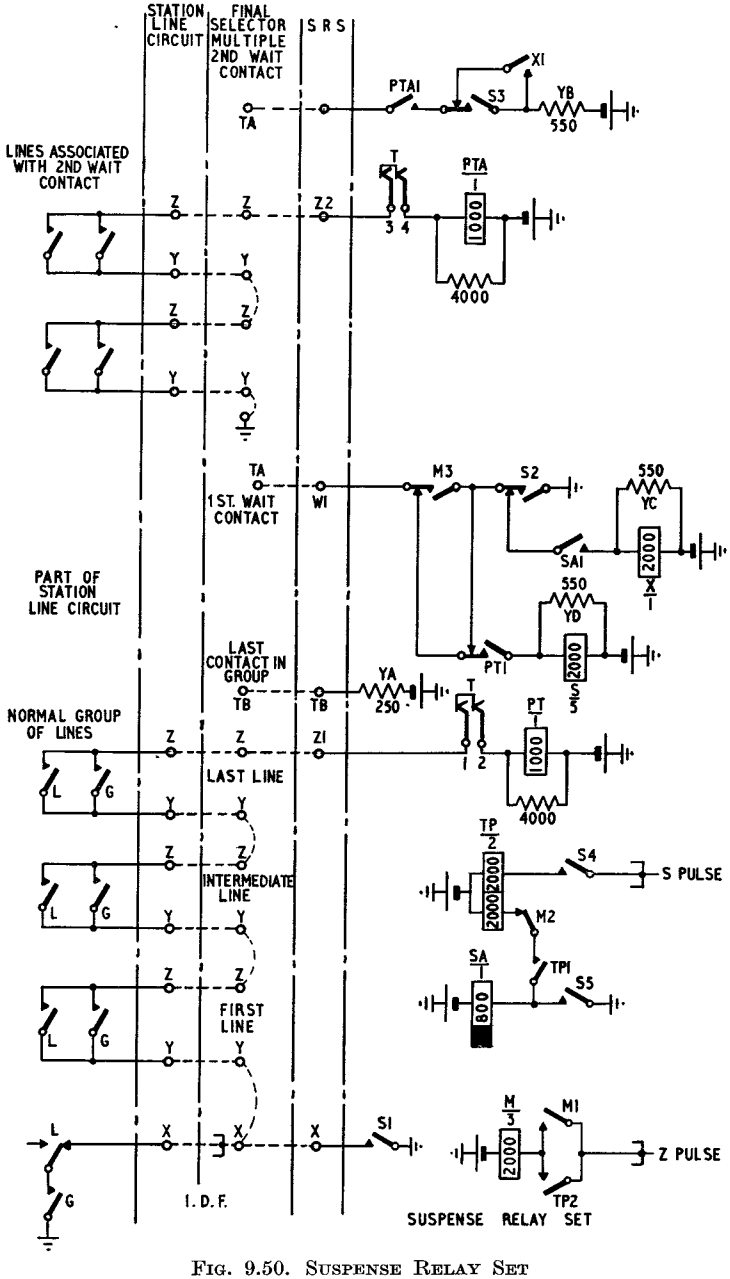


FIG. 9.50. SUSPENSE RELAY SET

(*g*) Automatically retesting the faulty trunk line at 30 sec intervals for a period up to $2\frac{1}{2}$ min, the trunk line meanwhile being busied against seizure for further traffic.

(*i*) Locking the trunk line out of service and operating an alarm if a satisfactory test is not made during the $2\frac{1}{2}$ min period.

(*j*) Forcibly releasing the connexion after $2\frac{1}{2}$ min

if the trunk line has tested faulty and the caller has not cleared.

(*k*) Disconnecting the associated incoming trunk selector on outgoing calls.

(*l*) Recognizing a clearing signal on outgoing calls, and thereupon removing the holding earth from the *P* wire to release the switches in the switching centre.

(*m*) Busying the trunk line against seizure for an outgoing call when it is in use for an incoming call.

(*n*) Busying the trunk line at both ends during routine testing.

The circuit elements of the trunk relay set will now be considered.

A, B and H Relay Element. This element, shown in Fig. 9.51, enables the trunk line to be seized from a group selector level and also provides facilities for holding the switches engaged in the connexion within the same switching centre. The free condition of the trunk line is indicated by battery connected to the *P* wire via the 550 Ω resistor *YB*. When a searching group selector tests the trunk relay set and finds it free, it connects earth to the *P* wire to operate relay *H*. *H3* and *H5* disconnect the associated trunk selector from the trunk line. As soon as relay *HA* (or *HB*) operates in the outgoing group selector, the calling signal is extended forward to cause relay *A* to mark. Relay *B* is operated at *A1*. *B1* connects earth to the *P* wire to hold the *HA* (or *HB*) relay in the group selector. *B2* operates relay *G* and *B3* provides a holding earth for relay *H* via *H1*. Relay *A* is similar to the final selector *A* relay already described and it responds to all signals subsequently sent by the calling station. The circuit of relay *B* is also similar to that of the *B* relay in the final selector in that the short-circuit applied via contact *H4* when *A*1 spaces, produces a

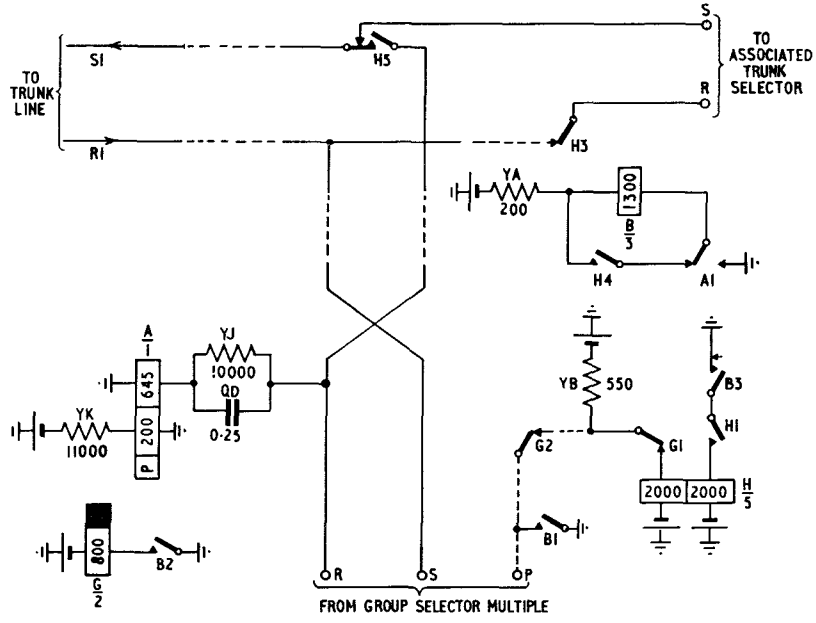


FIG. 9.51. BOTHWAY TRUNK RELAY SET: A, B, AND H RELAYS, CIRCUIT ELEMENTS

release lag of approximately 300 msec and this feature is therefore used to enable the clearing signal to be recognized.

"Call Confirmation" Signal Recognition. When the calling signal is extended to the trunk line by the group selector it is transmitted to the trunk selector at the distant end of the trunk line. This selector responds by returning a negative pulse of approximately 25 msec duration as the "call confirmation" signal and the correct receipt of this signal at the outgoing end of the circuit is used as an indication that the trunk line is fault free and may be used for traffic. The circuit elements which enable the call confirmation signal to be recognized are shown in Fig. 9.52.

Relay *X* is polarized by two rectifiers and while a spacing signal is received from the trunk line, *MRB* is non-conducting and relay *X* is not operated. On receipt of the negative pulse, however, relay

X operates and $\underline{X1}$ connects battery via YB, relay Y, $\underline{H2}$ to earth, to operate relay Y which locks at $\underline{Y1}$ to earth via $\underline{B3}$ and $\underline{H1}$.

The operation of relay Y is therefore an indication of the correct receipt of the call confirmation signal.

The operating circuit of relay X includes the shunted capacitor combination YH and QB to shape the signal applied to relay X, which is of the high speed type, to ensure a satisfactory response to the call confirmation signal. Rectifier MRA and resistor YF assist the shaping of the signal and also ensure equal attenuation of both marking and spacing signals which prevents bias distortion to teleprinter signals at a later stage in the connexion.

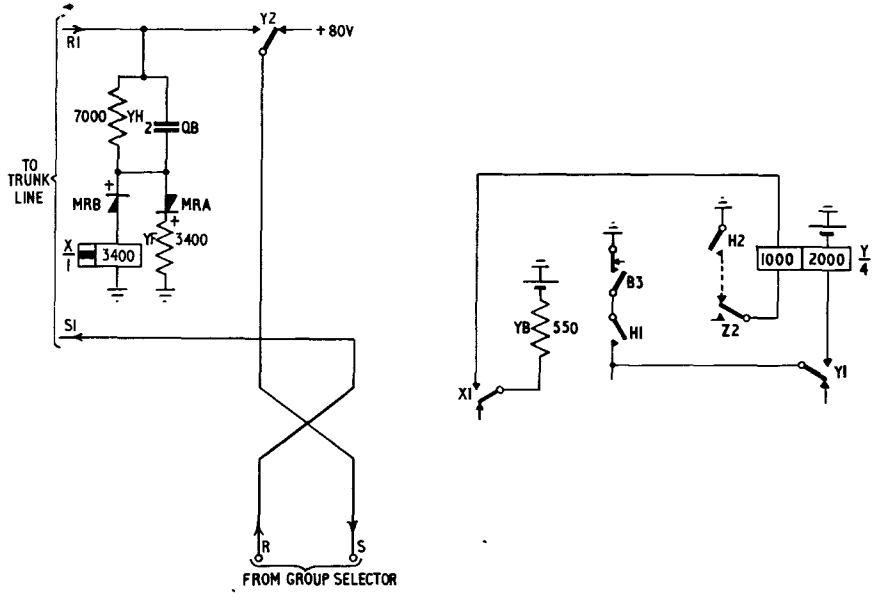


FIG. 9.52. BOTHWAY TRUNK RELAY SET: CIRCUIT ELEMENT FOR RECOGNIZING THE "CALL CONFIRMATION SIGNAL"

Trunk Line Testing Faulty. The circuit element concerned is shown in Fig. 9.53.

The trunk line is regarded as faulty if the call confirmation signal is not received within 200 msec of the application of the calling signal.

When the trunk relay set is seized relays B and H operate as already described and a circuit is completed to operate relay AZ from earth, $\underline{B3}$, $\underline{H1}$, $Y1$ to relay AZ. $\underline{AZ1}$ and $\underline{AZ2}$ complete the operating circuit for relay Z which has an operate lag of at least 200 msec. This operate lag is achieved by arranging that the two windings are differentially connected so that when contact $\underline{AZ1}$ closes, the flux due to the current surge into capacitor QA opposes the flux due to the current in the other winding. The resultant flux is insufficient to operate the relay, until the current surge into capacitor QA has decayed sufficiently for the flux due to the current in the 1000 Ω winding to predominate and operate the relay. Contact $AZ2$ is provided to ensure that on the release of relay AZ, the discharge path of capacitor QA does not include the windings of relay Z. This ensures that release of relay Z is not delayed.

If relay Z operates before relay Y, $\underline{Z2}$ prevents relay Y operating (Fig. 9.52): the trunk line is regarded as faulty and the DER T signal is returned via $\underline{Z3}$, $Y2$, over the S wire to the calling station. $\underline{Z1}$ connects start battery via the RT relay coil, $RT1$, $\underline{Z1}$ to the signal and alarm control relays, one of which operates to start the DER T and TCHR signal distribution circuits, and to energize a group of timing relays which control the timing of the automatic retesting of the trunk line. At this stage the resistance in the lead to the signal and alarm control relays is too great to permit the operation of relay RT.

Contact $\underline{Z6}$ connects the Trunk Circuit Hold and Retest Signal (TCHR signal) to the trunk line. This signal consists of marking signal interrupted by 500 msec spacing pulses at 29·5 sec intervals. The effect of this signal is to cause the release and reseizure of the distant trunk selector at 30 sec intervals, the reseizure being accompanied by the return of the call confirmation signal if the trunk line is no longer faulty.

Meanwhile Z4 provides a holding circuit for relays *H* and *AZ* independent of *B*3 which restores when the caller clears on receipt of the *DER T* signal. Z5 disconnects the battery potential from the *P* wire, thereby busying the trunk relay set to further callers.

If on retest the call confirmation signal is received, relays *X* and *Y* operate if *B*3 is normal (i.e. if the caller has cleared) and Y1 disconnects the circuit for relay *AZ* which releases, *AZ*1 in turn

Release Guard. After releasing an outgoing trunk call it is important to ensure that the selector at the distant end has fully restored before the trunk is made available for further outgoing traffic. If this safeguard were not provided it would be possible to pick up the trunk selector during release and mis-routed calls would result.

The circuit element concerned with providing the necessary guard is shown in Fig. 9.54.

On the receipt of the clearing signal from the

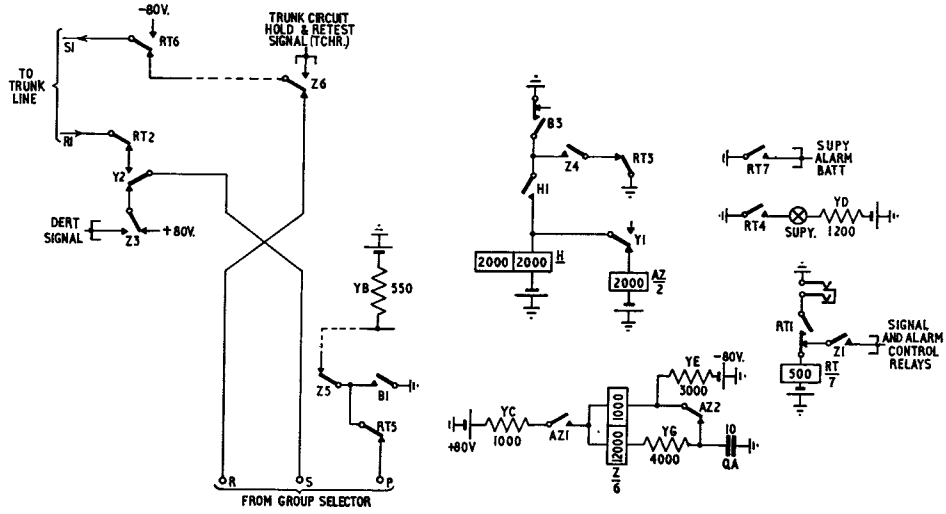


FIG. 9.53. BOTHWAY TRUNK RELAY SET: CIRCUIT ELEMENT FOR TRUNK LINE FAULT INDICATION

releasing relay *Z*. *Z*4 disconnects the holding circuit for relays *H* and *Y*, and the trunk relay set is restored to normal and is able to accept further calls.

If, however, a satisfactory response is not received to the automatic retesting, after 2½ min the signal and alarm control relays apply full earth to the signal and alarm control lead. This allows relay *RT* to operate and lock via RT1. RT4 and RT7 energize the supervisory alarms. RT6 connects a negative battery to the trunk line to busy the trunk relay set at the distant end. RT2 disconnects the incoming *R* wire and RT5 disconnects the *P* wire to force release the connexion if the caller has not already cleared and to busy the trunk relay set to outgoing traffic. RT3 disconnects relays *H* and *AZ* which release, in turn releasing relay *Z*.

This method of automatically testing the trunk line ensures that short duration faults do not produce an alarm. This avoids wasting the time of the maintenance staff in attending to transient fault conditions. At the same time by temporarily busying the circuit it cannot be taken for service whilst the fault condition persists.

calling station, relay *B* releases as already described. *B*3 disconnects one coil of relay *Y* but relay *Y* holds via *B*3, AG2, *Z*2, X1 until relay *X* releases on return of the clearing signal from the distant switching centre. *Y*4 and *AG*1 release relays *AG* and *G* in sequence. The release lags of relays *AG* and *G* total 600–900 msec, thus the *P* wire is not marked free at *G*2 until 600–900 msec after the recognition of the clearing signal at both switching centres. This is sufficient to ensure that the distant trunk selector is fully restored, even allowing for adverse tolerances on the timings of the *B* relays detecting the clearing signal at the two switching centres.

Incoming Call. To consider the functioning of the relay set on an incoming call reference should be made to Fig. 9.55 which shows the complete circuit of the trunk relay set.

It will be noted that in the disengaged condition the trunk line is connected through to the *S* and *R* wires of the trunk selector.

On receipt of the calling signal, the high speed relay *X* operates and X1 disconnects the *P* wire to

busy the trunk relay set to outgoing calls. Since relay X is of the high speed type, the busying action is carried out very quickly so as to reduce the possibility of "head on collision," i.e. simultaneous seizure from both ends of the circuit. This danger, Thus on any one trunk line the traffic in one direction is greater than in the other and this reduces considerably the chance of head-on collisions.

On receipt of the calling signal, relay A and B in the trunk selector operate and return an earth over

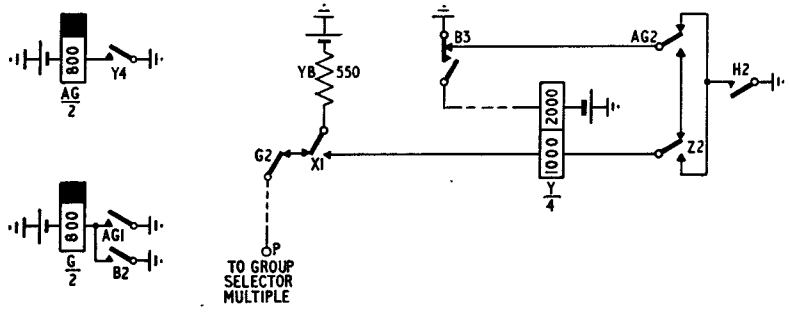


FIG. 9.54. BOTHWAY TRUNK RELAY SET: CIRCUIT ELEMENT FOR RELEASE GUARDING ON OUTGOING CALLS

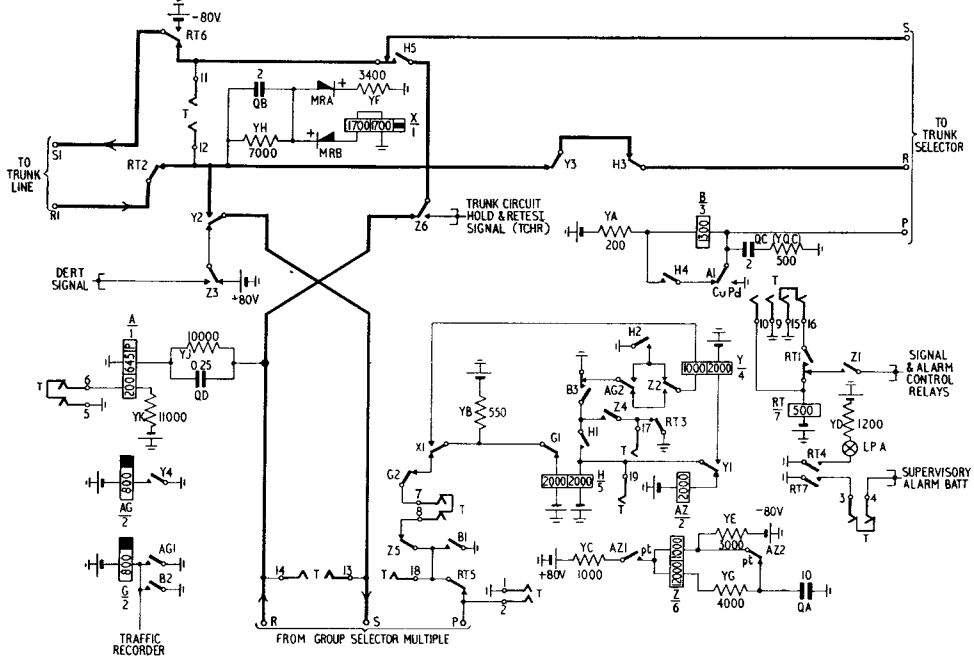


FIG. 9.55. COMPLETE CIRCUIT DIAGRAM OF BOTHWAY TRUNK RELAY SET

inherent in simple bothway working, is also minimized by arranging the connexions to the group selector bank contacts so that the order of search is reversed at opposite ends of the trunk route. This ensures that early choice circuits (which carry most of the outgoing traffic) at one end are the late choice circuits at the other end.

the P wire from the trunk selector to operate relay B in the trunk relay set. $\underline{B2}$ operates relay G. $\underline{B1}$ busies the trunk relay set to outgoing traffic independently of $X1$ (since relay X responds to line signals). On the release of the connexion the trunk selector removes the holding earth from the P wire to release relay B which is now fast to

release, and $B2$ releases relay G. $G2$ and $B1$ apply free conditions to the P wire. Relay G has a release lag long enough to ensure that the trunk relay set is not opened for traffic before the distant trunk relay set has restored. This is necessary to allow for differences in timing of the B relays recognizing the clearing signal in the two switching centres. The G relay release lag also provides a guard to prevent the trunk circuit being seized for an outgoing call at the incoming end when the

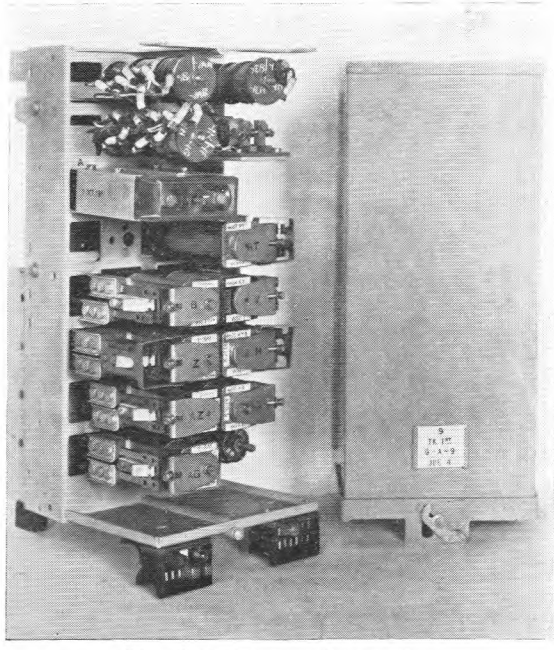


FIG. 9.56. TRUNK RELAY SET
(By courtesy of H.M. Postmaster-General)

automatic retest is being applied by the *TCHR* signal following a fault.

Uni-directional Trunk Circuits. For uni-directional trunk circuits the relay set is provided at the outgoing end only, the incoming end being terminated directly on the S and R wires of the trunk selector. At the outgoing end, in the absence of the trunk selector, a positive battery is connected to the lead which would normally be connected to the trunk selector S wire. This is necessary to maintain standard line signals during the disengaged condition.

Miscellaneous Features. The RT relay, in addition to its function under trunk fault conditions, is also used when the trunk relay set is being tested by the trunk relay set routine tester. The relay is operated from the tester and contacts $\underline{RT6}$ and $\underline{RT2}$ disconnect the line from the relay set and busy the trunk relay set at the distant end. This enables the relay set to be tested without interfering with traffic, and without assistance from the distant maintenance staff.

The relay sets are mounted on plug-in plates and the standard rack accommodates 10 relay sets on each of 7 shelves. A view of a trunk relay set is given in Fig. 9.56.

The trunk relay set can be readily removed from the rack for maintenance, the appropriate shelf jack springs being arranged to make contact so that the trunk selector S and R wires are connected through to the trunk line. This allows incoming calls to be completed even though the relay set is removed from the rack. Similarly, the trunk is busied to outgoing traffic by means of a pair of shelf jack springs which make contact, on removal of the relay set, to connect an earth to the P wire to the group selector multiple.

At the bottom of the relay set are mounted test jacks. These are primarily to allow the routine tester to be connected to the relay set, but they also allow the P wire to the group selector multiple to be earthed by inserting the test peg between the appropriate springs. This allows the trunk line to be busied to outgoing traffic for maintenance purposes. In addition the test jack mounting accommodates the supervisory alarm lamp.

Signal and Alarm Control Relays for Trunk Relay Sets. The circuit arrangements for the signal and alarm control relays for trunk relay sets are shown in Fig. 9.57.

The shelf relay SA, is operated when the battery connected RT relay is connected to it by the operation of the Z relay in the trunk relay set. The resistance of the SA relay is too high to permit the RT relay to operate. $\underline{SA1}$ connects a start earth to the distribution circuits for the *DER T* and TCHR signals, $\underline{SA2}$ connects earth to operate relay ST.

On receipt of the next 30 sec Z pulse, relay A operates, relay ST meanwhile holding in series with relay A to the earth pulse. On the removal of the earth from the pulse lead, relay ST releases. By similar action on the receipt of the next pulse, 30 sec later, relay B operates followed by the release of relay A, and the receipt of the next three pulses results in the successive operation of relays C, D and E.

$\underline{E1}$ connects full earth to operate relay RT in the trunk relay set and so raise the alarm. The $2\frac{1}{2}$ minutes taken to progressively operate relays A, B, C, D, and E is the period during which the faulty trunk line is retested.

To ensure that each retest of the faulty trunk line is allowed to be completed, the relative timings of the 30 sec Z pulses and the spacing signals of the

TCHR signal are arranged so that there is a 15 seconds separation between the two signals. This ensures that the operation of the *RT* relay does not occur whilst a retest is in progress.

Relay Set Outgoing from Group Selector Levels. As already explained it is often cheaper to serve large offices direct from group selector levels rather than from the final selector multiple. It is necessary, however, to provide suitable relay sets to permit the station lines to be seized from the group selector levels to apply holding conditions for those group selectors and to enable the answer back codes to be taken automatically.

The detailed facilities provided by the relay sets are as follows—

(*a*) Giving access to the station line from a group selector level.

(*b*) Applying an earth to the *P* wire to hold the selectors in the switching centre during a call.

(*c*) Recognizing the clearing signal and thereupon releasing the selectors within the switching centre.

(*d*) Automatically connecting the WRU signal to the station line at the beginning of each call incoming to the station.

(*e*) Recognizing the return of the answer-back code signals from the station and then completing the connexion between the calling and called teleprinters.

(*f*) Returning the *DER S* signal to the calling station if the answer-back code is not received from the called station in response to the WRU signals.

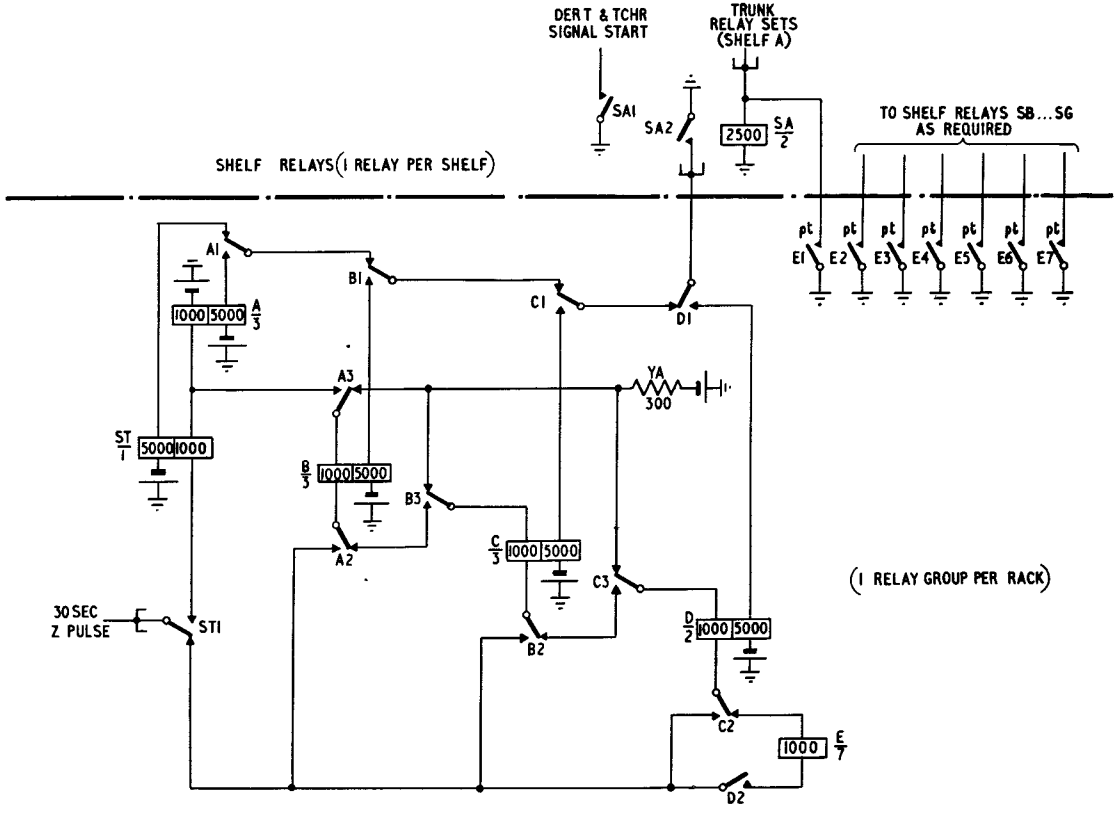


FIG. 9.57. SIGNAL AND ALARM CONTROL RELAYS FOR TRUNK RELAY SETS

(*g*) Allowing the caller to clear after returning the *DER S* signal, meanwhile busying the station line against seizure for further traffic.

(*h*) Giving bell and lamp alarms in the switching centre when a station fault condition arises.

(*i*) Permitting an automatic retest of the station line by the insertion of a test plug in the outgoing relay set test jack.

(*j*) Restoring the station line to service on withdrawal of the test plug if the station line responds correctly on retest.

(*k*) Connecting start earths to the WRU and *DER S* signal start leads.

The circuit of the relay set is given in Fig. 9.58.

The functioning of the circuit is very similar to the corresponding elements already described for the final selector, and therefore a detailed description is not necessary.

It will be noted that the battery potential which marks the free condition of the *P* wire is obtained from the associated station line circuit. A further feature to note is that for overflow circuits it is sometimes necessary to have joint access from both group selector levels and the final selector multiple, and in such cases the *S*, *R*, and *P* connexions to the station line circuit are also connected to the appropriate outlets on the final selector multiple. Under these conditions it is necessary that when the relay set outgoing from the group selector levels encounters a station fault condition, the final selector multiple outlet should be busied. This is effected by contact *SF3* which connects earth towards the final selector multiple but does not prevent the release of the group selector concerned in the call.

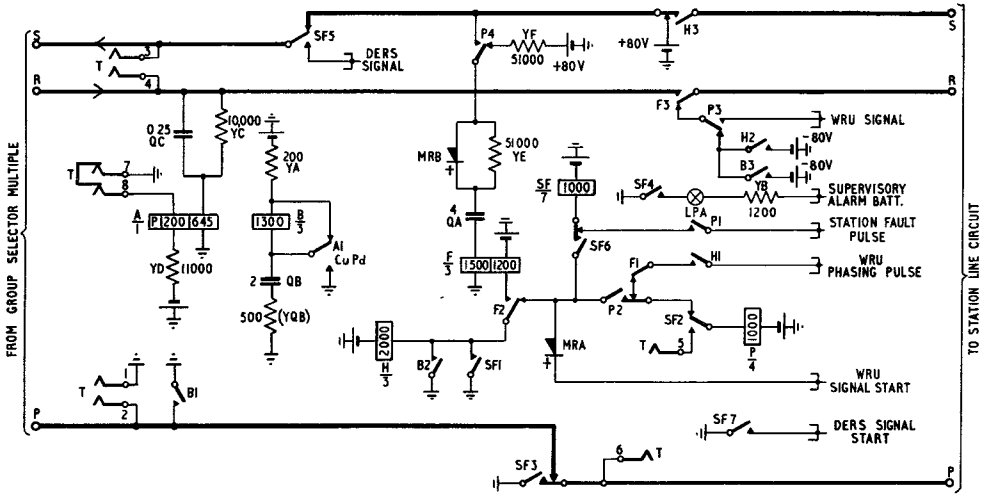


FIG. 9.58. RELAY SET OUTGOING FROM GROUP SELECTOR LEVELS

Special Services Final Selector. The special services final selector differs somewhat from the regular final selector because instead of giving access to teleprinter station lines it connects to circuits such as test desk station lines, speak and test sets, and relay sets distributing test message signals and teleprinter speed test signals.

It is simpler than the regular final selector because it does not provide facilities for waiting, overflow, or automatic transmission of the *WRU* signal and the associated station fault alarm.

The facilities of the special services final selector provide for—

(*a*) Returning holding conditions to the other switches in the connexion within the switching centre.

(*b*) Vertical and rotary stepping under the control of dialled pulses.

(*c*) Hunting for a free outlet in the required group.

(*d*) Returning *OCC* signal to the caller if all outlets in the required group are busy.

(*e*) Operating an overflow meter if the selector fails to find a free outlet in the required group.

(*f*) Releasing the selector and the switching train if a clearing signal is received on the *R* wire.

(*g*) Guarding the selector against seizure during release.

(*h*) Giving audible and visual alarms if a selector is held and not stepped vertically.

(*i*) Giving audible and visual alarms if a selector is held on the eleventh rotary step.

(*j*) Giving audible and visual alarms if the selector fails to release due to a mechanical defect.

(*k*) Returning the *IR* signal to release the connexion forcibly if a spare number is dialled.

(*l*) Connecting an earth to the start lead associated with the OCC and IR signals as required.

Fig. 9.59 shows the circuit of the special services final selector.

Its operation is very similar to that of the regular final selector apart from the absence of the *P*, *F*, *SF*, *AW*, *W* and *VS* relays and a detailed circuit description is therefore not necessary. One difference, however, is that when the special services final selector encounters battery on the *TB* arc to indicate the end of the group, relays *AGE* and *GE* operate to drive the selector to the eleventh rotary step to return the OCC signal to the caller

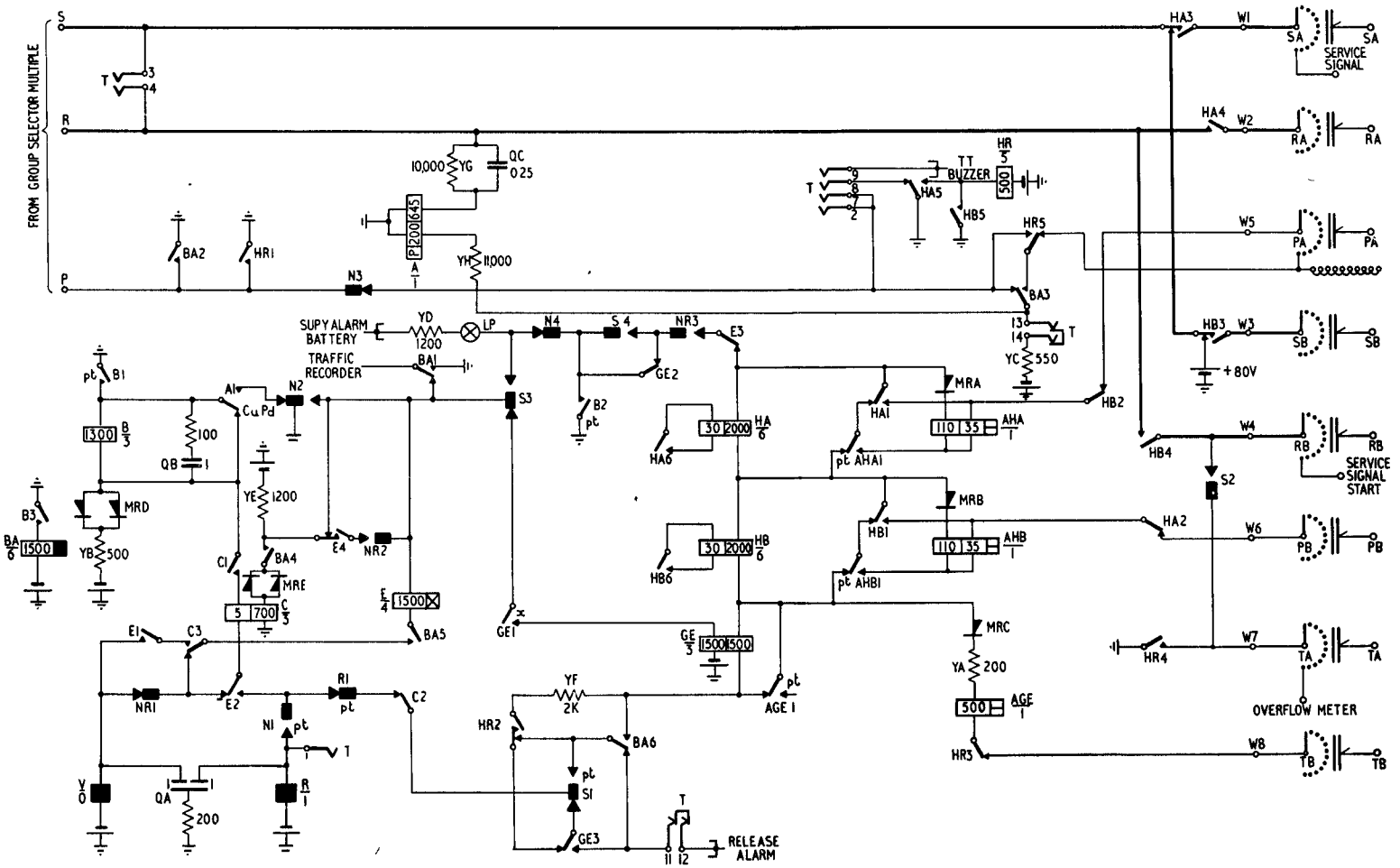


FIG. 9.59. SPECIAL SERVICES FINAL SELECTOR

and to operate the overflow meter, whereas the regular final selector on encountering battery on the *TB* arc is routed to the overflow level.

Teleprinter Speed Test Signal and Access Relay Set. To enable faultsmen to check the speed of teleprinter motors against a central speed standard, a teleprinter speed test signal is generated at each switching centre. Access to this signal is gained by dialling to relay sets arranged as a group in the special services final selector multiple.

The speed test signal consists of 20 c/s reversals

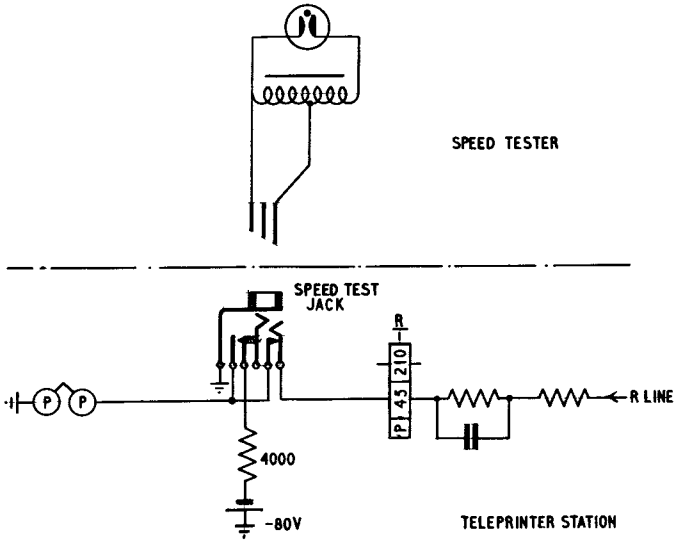


FIG. 9.60. CIRCUIT ARRANGEMENT AT TELEPRINTER STATIONS FOR USING TELEPRINTER SPEED TEST SIGNAL

interrupted at 10 sec intervals by marking current for 150 msec. At the teleprinter station this signal is used to flash a neon lamp illuminating a segmented disc fitted to the end of the shaft of the teleprinter transmitter cam. The circuit arrangements at the teleprinter station are shown in Fig. 9.60.

The neon lamp is connected to the line by means of the plug which is inserted into the special jack fitted on the dialling unit. Auxiliary springs on the jack hold the teleprinter magnet to mark and the incoming signals are received on the auto-transformer which steps up the voltage to ensure that the lamp flashes at each signal transition, i.e. at 25 msec intervals.

The segmented disc has six pairs of black and white segments and rotates at a nominal speed of 400 r.p.m. Thus when a disc running at the correct speed is illuminated stroboscopically by the signal the pattern appears stationary. If, however, the motor speed is incorrect, the pattern appears to rotate and the speed of rotation is proportional to the speed error. The 150 msec marking intervals in the speed test signal cause the illumination to be blacked out at 10 sec intervals. The maximum speed error permitted for teleprinter motors ($\pm$ 0·5 per cent) corresponds to a drift of two black and two white segments of the disc pattern between successive blackouts of the display.

The lamp and transformer are fitted in a small portable case illustrated in Fig. 9.61.

At the switching centre the facilities of the teleprinter speed test relay set are—

(*a*) Giving access to the teleprinter speed test signal from a special services final selector number.

(*b*) Connecting an earth to the teleprinter speed test signal start lead.

(*c*) Returning a "call connected" signal to the calling station before connecting the teleprinter speed test signal.

(*d*) Returning a clearing signal on the send wire when the relay set is released by the special services final selector.

The circuit of the relay set is shown in Fig. 9.62.

The free condition of the relay set is indicated by battery potential connected to the *P* wire via *YA*, *G*2, *H*1, *T*7, and *T*8. On being seized relay *H* operates to negative battery received on the *R* wire. *H*1 completes a circuit to hold relay *H* to the earth extended forward on the *P* wire by the special services final selector. *H*2 connects negative battery from *G*1 to the *S* wire to send the "call connected" signal to the calling station. *H*3 applies earth to the teleprinter speed test signal start lead and *H*4 connects earth to the circuit of relay *G*. Relay *G* is differentially connected and because of the action of capacitor *QA*, it has an operate lag of approximately 150 msec. This operate lag ensures that a steady negative signal of sufficient duration to ensure satisfactory switching of the calling position relay set, is transmitted before the teleprinter speed test signal is connected at *G*1.

When the connexion is cleared at the calling station, the clearing signal is received by the special services final selector and the holding earth is removed from the *P* wire to release relay *H*. *H*2 connects positive battery to the *S* wire to acknowledge the clearing signal and *H*4 releases relay *G* for *G*2 to reconnect the free condition to the *P* wire. Rectifier *MRA* is included in the circuit to prevent the release of relay *H* by differential action if teleprinter signals are sent from the calling station.

Teleprinter Test Message Signals and Access Relay Sets. To enable the receiving margin of teleprinters to be checked, test message signals having a predetermined distortion are generated at each switching centre. These signals are also used for checking the transmission performance of T.A.S. trunk lines.

The test message is in the form of a standard text, viz. THE QUICK BROWN FOX JUMPS OVER THE LAZY DOG SQSPSO, and distortion is introduced by lengthening or shortening the start element of each character. Four signals, with fixed distortions of 0, 20, 25, and 30 per cent are produced, alternate sequences of the test message having the start elements either lengthened or shortened. A fifth signal, the switched test message, consists of two consecutive sequences of 0 per cent, two of 20 per cent, two of 25 per cent, and two of

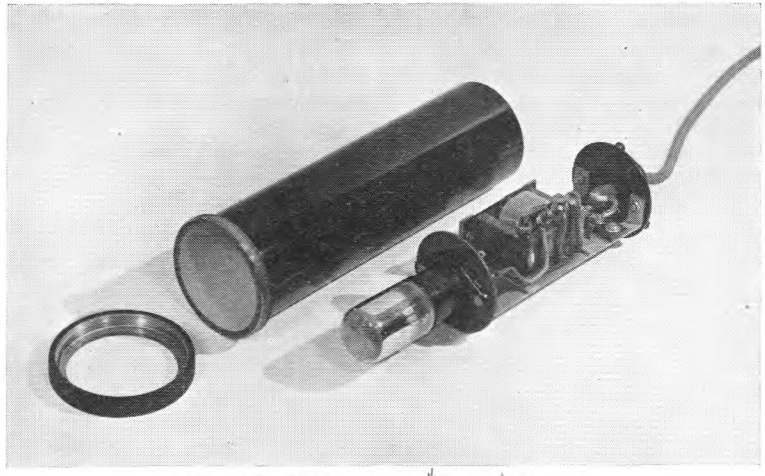


FIG. 9.61. TELEPRINTER SPEED TESTER
(By courtesy of H.M. Postmaster-General)

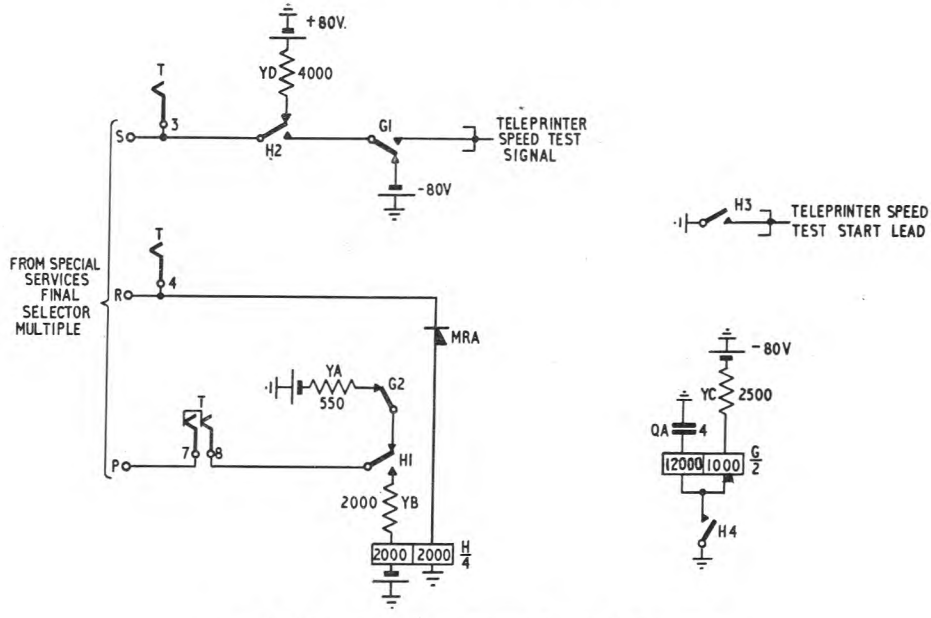


FIG. 9.62. TELEPRINTER SPEED TEST, RELAY SET

30 per cent, continuously repeated. Each message sequence is preceded by an announcement (transmitted without distortion) indicating the degree of distortion of the following sequence. Dialled access to the test message signals is provided by means of access relay sets terminated on the special services final selector multiple. Separate groups of relay sets, each with its own dialling code, are provided for each of the five signals.

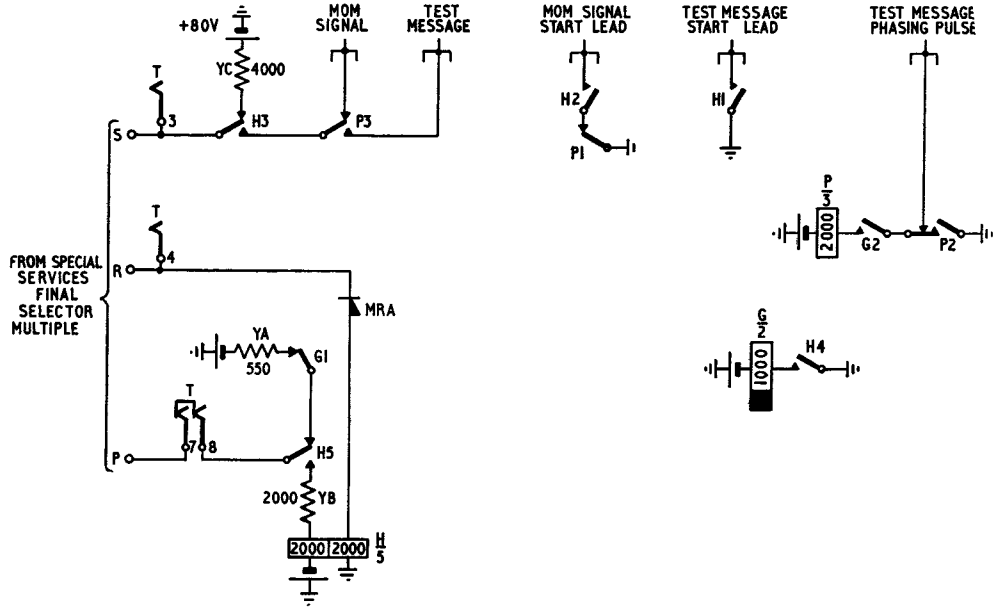


FIG. 9.63. TELEPRINTER TEST MESSAGE, RELAY SET

The circuit of the relay set is given in Fig. 9.63 and the following facilities are provided.

(*a*) Giving access to the teleprinter test message from a special services final selector number.

(*b*) Returning MOM (wait) signal to the caller until the commencement of the next test message cycle.

(*c*) Connecting an earth to the start wires of the test message and MOM signals.

(*d*) Holding to an earth on the *P* wire from the special services final selector.

(*e*) Returning a clear signal on the send wire when the relay set is released by the special services final selector.

The free condition of the relay set is indicated by the battery potential connected to the *P* wire via *YA*, *G*1, and *H*5, *T*7, and *T*8. On being seized, relay *H* operates to the negative battery on the *R* wire. *H*1 connects earth to the test message signal start lead. *H*2 connects earth to the MOM signal start lead. *H*3 returns the MOM signal to the caller. *H*4 operates relay *G* and *H*5 locks relay *H* to the holding earth connected to the *P* wire by the special services final selector.

The calling line is first connected to the MOM signal because random switching to the test message would produce spurious characters on the teleprinter tape, if the switching occurs in the middle of a character. To avoid this difficulty, the MOM signal is returned until the beginning of the next test message sequence, when an earth pulse is extended over the test message phasing pulse lead to operate relay *P* via *P*2 and *G*2. Relay *P* locks to *P*2 via *G*2. *P*1 disconnects the earth from the MOM signal start lead and *P*3 connects the test message signal to the calling station.

When the calling station clears, the clearing signal is received by the special services final selector which removes the holding earth from the *P* wire. Relay *H* releases. *H*3 connects positive battery to the *S* wire to acknowledge the clearing signal and *H*4 releases relay *G*. *G*2 releases relay *P* and *G*1 restores the free condition to the *P* wire.

Rectifier *MRA* is included in the circuit to prevent relay *H* releasing by differential action if teleprinter signals are received from the calling station.

Signal Generation, Control and Distribution

In earlier sections of this chapter reference has been made to service signals. The methods employed for the generation of these signals and their

distribution to the switching equipment will now be described.

The required service signals are produced at each switching centre by three pairs of signal generators. Each signal generator consists of a motor running at a closely controlled speed, rotating a set of brushes around a group of concentric segmented brass rings and in addition operating a group of cam springs. The segments of the brass distributor rings are connected to appropriate potentials via the cam-springs and the sequence of cam operation is so arranged that the resultant distributor brush potentials correspond to the required teleprinter signals. In addition to double-current signals, the signal generators produce earth pulses for a variety of switching purposes.

Three signal generators are required to produce the full range of signals and the six generators provided at each switching centre include duplicate machines for standby and maintenance purposes. The six signal generators (mounted in enclosed compartments to reduce noise) are accommodated on a 4 ft 6 in. Signal Generator Rack, see Fig. 9.64, together with the associated control and alarm equipment. The generator control keys and lamps are, however, fitted on the adjacent Signal Distribution Rack, see Fig. 9.65. The generator compartments are fitted with transparent door panels to permit observation of the generators under operating conditions. The generators rest on shelves supported upon runners which permit the machines to be withdrawn to the front of the rack for maintenance purposes.

The signals produced by the signal generators

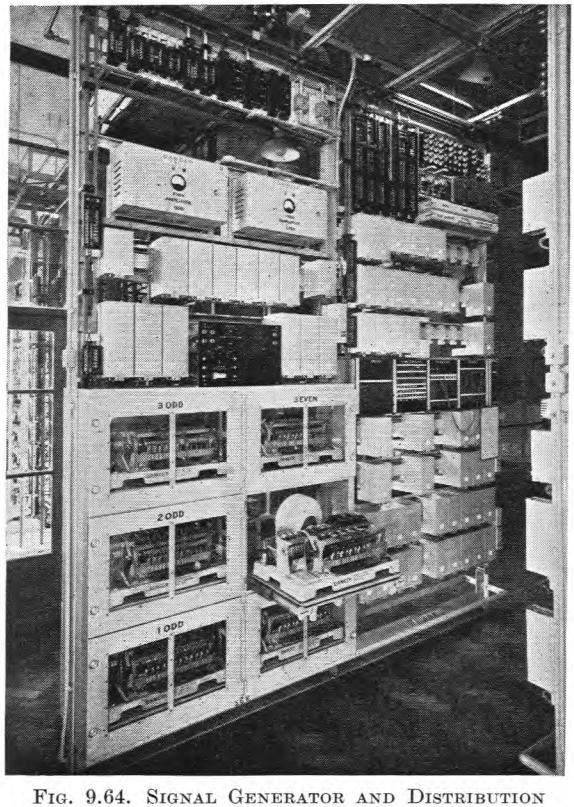


FIG. 9.64. SIGNAL GENERATOR AND DISTRIBUTION
(By courtesy of H.M. Postmaster-General)

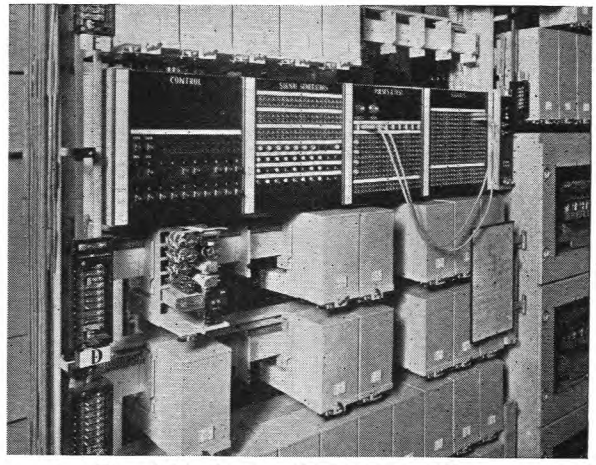


FIG. 9.65. SIGNAL DISTRIBUTION RACK: GENERATOR CONTROL PANEL
(By courtesy of H.M. Postmaster-General)

Generator D.C. Signalling No. 1

Signal	Type of Signal	Use
TM 0 per cent	T	Test message for transmission testing and check of teleprinter margin.
TM 20 per cent	T	Test message for transmission testing and check of teleprinter margin.
TM 25 per cent	T	Test message for transmission testing and check of teleprinter margin.
TM 30 per cent	T	Test message for transmission testing and check of teleprinter margin.
TM Switched	T	Test message for transmission testing and check of teleprinter margin.
TM P.P.	E	Phasing pulses to ensure connexion to TM signal at beginning of TM cycle.

Generator D.C. Signalling No. 2

Signal	Type of Signal	Use
WRU	T	"Who are You" signal for tripping the answer-back drum at a called teleprinter station.
OCC	T	Station busy signal.
MOM	T	Wait signal.
WRU P.P.	E	Phasing pulses controlling the application of the WRU signal.
S.F.P.	E	Station Fault Pulse for controlling the return of the DER S signal
I.R.	D	Immediate Release signal providing forced release from spare levels and numbers.
12 sec. S & Z 30 sec. S & Z	E	Timed pulses for miscellaneous switching functions.
T.C.H.R.	D	Trunk Circuit Hold and Retest signal controlling the automatic re-testing of faulty trunk circuits.
H.R.T.	D	Holding Relay Test signal for testing 'B' relays in switching circuits.

Generator D.C. Signalling No. 3

Signal	Type of Signal	Use
DER S	T	Fault Signal indicating that a faulty station line has been selected.
DER T	T	Fault signal indicating that a faulty trunk circuit has been selected.
NC	T	Trunk Busy signal.
T.S.T.	D	For checking teleprinter motor speed.
20 c/s.	D	20 c.s signal for miscellaneous test purposes.

are enumerated above and the type of signal is indicated as follows—

Teleprinter Signals: T
Double Current Pulses: D
Earth Pulses: E

Signal Generators

General Description. The three types of signal generating machine are of the same basic design, each consisting of a main base casting upon which are mounted the driving motor, message and pulse cam units, contact spring sets, friction brake and distributor. The machines are illustrated in Figs. 9.66, 9.67, and 9.68.

Connexions. Power supplies and external circuits are connected to the generators via 3-way and 25-way plugs and sockets respectively. Duplicate sockets, wired in parallel, are provided so that generators may be operated when withdrawn from the rack on their sliding shelves for maintenance purposes.

Driving Motor. Each signal generator is driven by a 160 V d.c. shunt wound motor.

Cam Assemblies and Gearing. Generation of the various signals and pulses is effected by means of 3,000-type spring sets operated by cams, the peripheries of which are notched to provide the required sequences of operation. Where accuracy of timing is required, e.g. teleprinter code combinations and certain pulses, the outputs are routed via the segments of a distributor. In other cases, the cam-operated contact springs are directly connected to the output socket. For some pulses, accuracy of timing is achieved by a "gate" circuit. The signal is wired via two contact spring sets in series, the spring sets being operated by cams rotating at different speeds. Typical arrangements for obtaining signals are shown in Fig. 9.69.

The various groups of cams are mounted on shafts driven through reduction gears from the main shaft. Details of the gears and shaft speeds are shown in Fig. 9.70.

Cams for Teleprinter Signals. These are mounted on the main camshaft which is designed to accommodate six sets of five cams. Each cam controls one element of the five unit code and each set of five cams represents a group of 80 characters, the angular division of the notches in the cams for operating the contact spring sets being arranged in accordance with the character sequence required. The main camshaft rotates at 5 r.p.m. as the time required for one revolution $= 80 \times 150$ msec $= 12$ sec.

If the whole 80 characters are not required, the balance is made up with "all marking," "letter-shift," "line-feed" or "carriage return" signals.

Pulse Cams. Each auxiliary camshaft is capable of accommodating five cams and the cams are cut according to the length of the pulses required.

Distributor. Each machine is fitted with a distributor to ensure the correct formation and timing

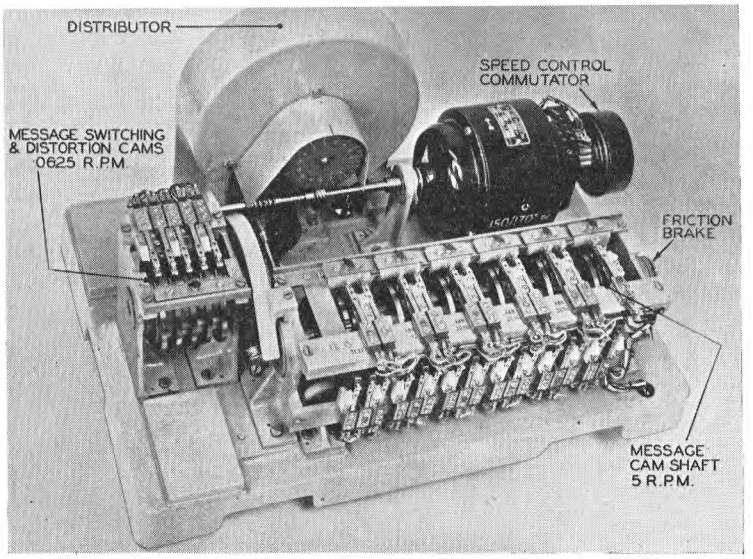


FIG. 9.66. GENERATOR D.C. SIGNALLING NO. 1A
(By courtesy of H.M. Postmaster-General)

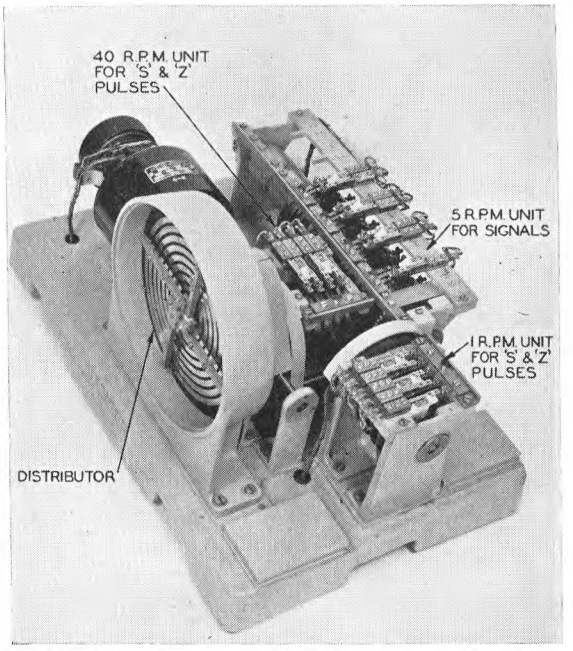


FIG. 9.67. GENERATOR D.C. SIGNALLING NO. 2A
(By courtesy of H.M. Postmaster-General)

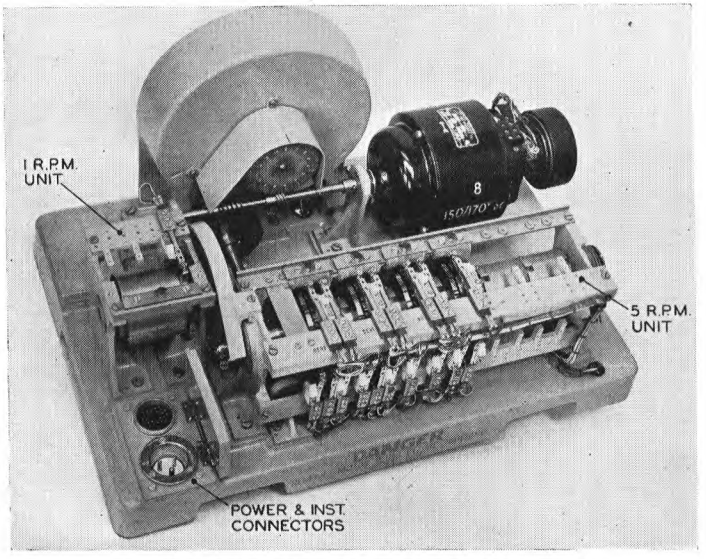


FIG. 9.68. GENERATOR D.C. SIGNALLING NO. 3B
(By courtesy of H.M. Postmaster-General)

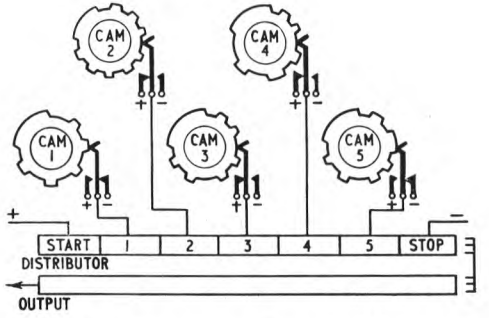


FIG. 9.69. TELEPRINTER SIGNALS, METHOD OF GENERATION

of the teleprinter combinations and certain other signals. The distributor comprises eight concentric rings, the outer four are divided into segments whose length determines the duration of the signals, the inner four being continuous. Connexion between the segmented rings and the corresponding

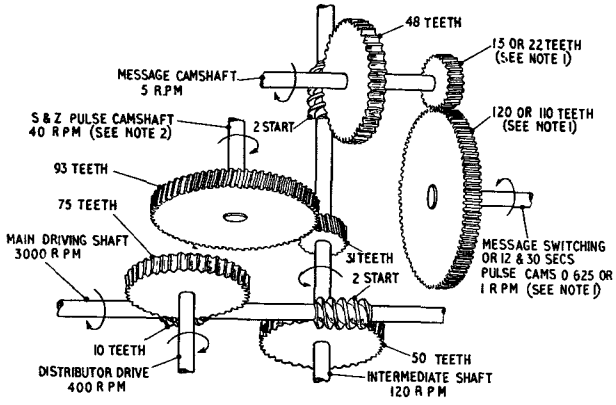


FIG. 9.70. GENERATOR D.C. SIGNALLING NOS. 1A, 2A, AND 3B: SHAFT SPEEDS AND GEAR RATIOS

solid rings is made by four brush arms carrying carbon brushes.

Friction Brake. A friction brake is provided on the main camshaft of each machine to produce a considerable constant load so as to mask any small variations in loading which may occur between different angular positions of the cams.

Generator D.C. Signalling No. 1A. This machine, illustrated in Fig. 9.66, transmits a standard test message followed by a series of characters chosen to test the efficiency of the teleprinter typehead clutch. The complete sequence is as follows—

"THE QUICK BROWN FOX JUMPS OVER THE LAZY DOG + SQSPSO."

The complete message (comprising 57 character combinations, including four letter shift combinations after the last printed character) is transmitted eight times to form a complete switched Test Message: twice at zero distortion and twice at each of the following values of distortion: 20 per cent, 25 per cent, and 30 per cent. The required distortion is introduced by appropriately lengthening or shortening the start element of each character.

The first transmission at each value of distortion is with a lengthened start element and the second with a shortened start element. The stop element is adjusted in each case to maintain the correct character duration, i.e. 150 msec. Each of the eight transmissions forming the complete switched test message is preceded by an announcement indicating the degree of distortion thus—

Messages 1 and 2: "TEST DSTN. = 0%"
Messages 3 and 4: "TEST DSTN. = 20%"
Messages 5 and 6: "TEST DSTN. = 25%"
Messages 7 and 8: "TEST DSTN. = 30%"

A full stop is added to the 0 per cent announcement to complete the required number of 23 character combinations. In each case the announcements are transmitted without distortion and are preceded by three letter shift, line feed and carriage return signal combinations in order to prepare the paper carriage when the receiving teleprinter is of the page printing type. Each announcement is followed by three letter shifts. The transmission of the complete cycle of four announcements and eight test messages occupies 96 sec.

Test messages corresponding to each of the above values of distortion are also generated continuously.

A 300 msec marking signal (equivalent to two teleprinter characters) precedes the start of each announcement to provide a suitable interval during which lines may be connected to the signal

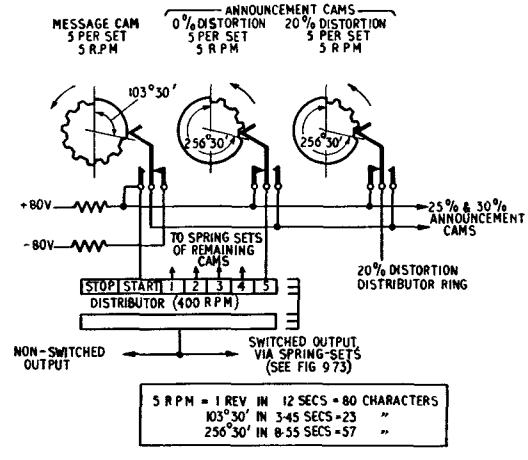


FIG. 9.71. TEST MESSAGE AND ANNOUNCEMENT

output. In conjunction with the external signal distribution equipment, the generator transmits a phasing pulse synchronized with this marking signal to ensure that callers are only switched at the appropriate instant.

Announcements and Test Messages. (Fig. 9.71 refers.) Each announcement comprises 23 character combinations and the test message 57 character combinations. One revolution of the cams is completed in 12 sec and eight revolutions

are required to complete the two transmissions of the message at each of the four values of distortion. The announcement occupies 3·5 sec and the message 8·55 sec, the blank portions of the cams being arranged so that transmission of the announcement precedes the message. One set of five cams on the 5 r.p.m. shaft is allocated to the test message and one set to each of the four values of distortion. The sixth set is used to generate phasing pulses and will be described later.

It is arranged that during the transmission of the announcement, the message spring sets are opposite the uncut portions of the message cams and the changes of potential on the distributor segments are controlled by the announcement cams. Similarly, during transmission of the message, the announcement spring sets are opposite the uncut portions of the announcement cams and the message spring sets control the transmission.

Distortion Switching Cams. (Fig. 9.72 refers.) One segmented ring of the distributor, together with the corresponding inner (solid) ring, is allocated to each value of distortion. The zero-distortion segment ring has seven segments representing the

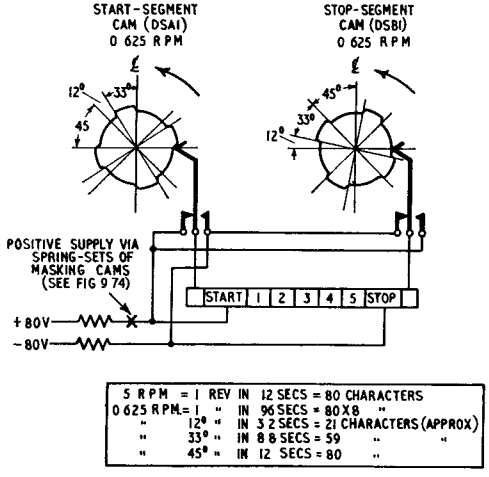


FIG. 9.72. DISTORTION SWITCHING CAMS

start element, the five code elements and the stop element.

On the other three segmented rings, two additional auxiliary segments are added between the main start and stop segments. These are used to introduce the required amount of artificial distortion. By means of distortion switching cams and spring sets, the auxiliary segments can be used to lengthen the start element and shorten the stop element or vice versa. The start and stop segments on various rings, numbered 5 to 8 counting from the centre, are allocated as follows—

Rings	*Distortion*	*Start Segment*	*Aux. Segment*	*Stop Segment*
8	0 per cent	1 (20 ms)	—	1 (30 ms)
7	20 per cent	1 (16 ms)	2 (4 ms each)	1 (26 ms)
6	25 per cent	1 (15 ms)	2 (5 ms each)	1 (25 ms)
5	30 per cent	1 (14 ms)	2 (6 ms each)	1 (24 ms)

(Abbreviation ms = milliseconds.)

The announcements are always transmitted without distortion and each distorted message is

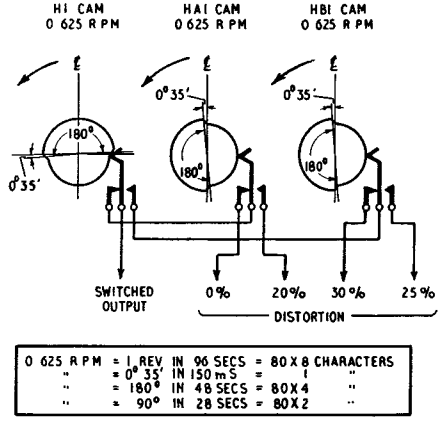


FIG. 9.73. TEST MESSAGE SWITCHING CAMS

transmitted with "late" distortion (lengthened start signal) and "early" distortion (shortened start signal) alternately. This requires the changing of the potential applied to the auxiliary segments during every 22nd and 23rd (letter shift) character of the announcement. Spring sets associated with two cams (DSA1 and DSB1) on the 0·625 r.p.m. shaft fulfil the necessary switching functions.

The angular division of these cams is identical, each consisting of four peaks and depressions arranged alternately, the peaks occupying 33° of arc and spaced 90° apart. The relative position of the cams is such that one leads the other by 45°. Thus, for an interval equal to 12° of rotation (21 characters) both spring sets will be in the operated position and for the ensuing 33° of rotation (59 characters) one spring set only will be operated. This sequence of operations results in the auxiliary segments being connected to their respective start and stop segments during announcements and both are connected to the start or the stop segment during alternate transmissions of the test message.

Test Message Switching Cams. (Fig. 9.73 refers.) The individual generator outputs corresponding to

the four distortion values are connected to the spring sets of two cams (*HA*1 and *HB*1) on the 0·625 r.p.m. shaft. These spring sets are arranged in conjunction with a third spring set (*H*1) so that each individual output is connected in turn for the duration of two message transmissions (one early and one late distortion) to the single switched test message output lead.

Start Signal Masking Cams. (Fig. 9.74 refers.) The last four letter-shift characters of the message and the first two letter-shift characters of the announcement are transmitted with the start

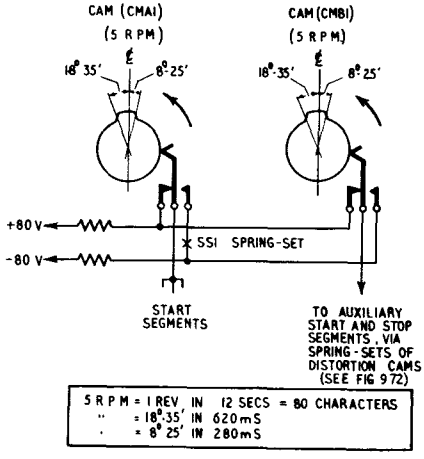


FIG. 9.74. TEST MESSAGE START SIGNAL MASKING CAMS

six repetitions of the following 13 character sequence—

1. All marking.
2. All marking.
3. Figure-shift.
4. WRU.
5. Letter-shift.
6. Figure-shift.
7. WRU.
8. Letter-shift.
9. Figure-shift.
10. WRU.
11. Letter-shift.
12. All marking.
13. All marking.

The sixth repetition is followed by two letter-shift combinations to complete the sequence of 80

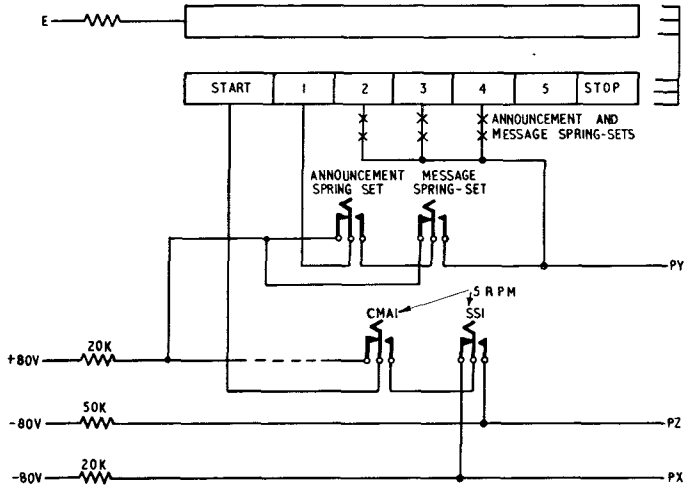


FIG. 9.75. TEST MESSAGE PHASING PULSE

element polarity reversed, thus rendering the transmission "all marking" for a period of 900 msec. The masking of the start element is achieved by spring sets operated by cams *CMA*1 and *CMB*1 mounted on the 5 r.p.m. shaft. One spring set applies — 80 V to the main start segment and the second spring set applies — 80 V to the auxiliary start segment.

Test Message Phasing Pulse. (Fig. 9.75 refers.) This is an accurate 100 msec pulse phased with the start signal of the first character of the announcement. A spring set operated by cam *SS*1 mounted on the 5 r.p.m. shaft is used to raise the potential applied to an external valve circuit from — 80 V to — 54 V, thus initiating the pulse at the appropriate instant. This is achieved via three leads, designated *PX*, *PY* and *PZ*, whose function will be described later.

Generator, D.C. Signalling No. 2A. This machine, illustrated in Fig. 9.67 supplies the following signals and pulses—

"*WHO ARE YOU*" (*WRU*) *Signal* comprises characters, i.e. the time of one revolution of the 5 r.p.m. shaft.

WRU Phasing Pulse (*WRU P.P.*) is a pulse of 50 msec duration, transmitted at the commencement of each sequence of 13 characters in the WRU signal.

Station Fault Pulse (*S.F.P.*) is a pulse similar to the WRU P.P. transmitted at the end of each WRU sequence.

Holding Relay Test (*H.R.T.*) *Signal.* This is a pulse of 15 msec duration transmitted every 150 msec.

The above three pulses are transmissions of — 80 V polarity, the "pulse-off" polarity being + 80 V.

"*OCC*" *Signal.* This comprises six repetitions of the following 13 character combinations—

1. All Marking.
2. All marking.
3. All marking.
4. Letter-shift.
5. O
6. C
7. C
8. Space.
9. Letter-shift.
10. O
11. C
12. C
13. Space.

The sixth repetition is again followed by two letter-shift combinations to make up the required total.

"MOM" Signal. This comprises six repetitions of the following 13 character combinations—

1. Letter-shift.
2. M
3. O
4. M
5. Space.
6–13. All marking.

The sixth repetition is followed by carriage return and line-feed combinations to complete the total of 80 characters.

S and Z Pulses. Two pairs of pulses are generated as follows—

(1) 12 sec *S* and *Z*. Each is an earth pulse of 350 msec duration repeated every 12 sec. The termination of the *Z* pulse precedes the commencement of the *S* pulse by an interval of 100 msec.

(2) 30 sec *S* and *Z*. These are similar to the 12 sec pulses but repeated every 30 sec.

Trunk Circuit Hold and Retest (T.C.H.R.). This is a 500 msec pulse of + 80 V potential repeated every 30 sec with — 80 V polarity for the pulse-off period. The commencement of the pulse lags 15 sec behind the start of the 30 sec *Z* pulse.

Immediate Release Signal. This comprises 1,250 msec of + 80 V potential followed by

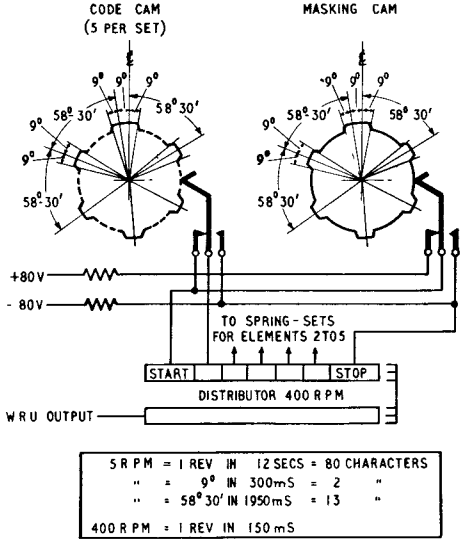


FIG. 9.76. SERVICE SIGNALS: TYPICAL ARRANGEMENT

250 msec of — 80 V potential repeated continuously.

WRU, OCC and MOM Signals. As the method of generating these three signals is similar, the *WRU* signal only will be described in detail. The cams producing the *OCC* and *MOM* signals are cut to suit the sequence of characters required.

Fig. 9.76 shows the angular division of the five

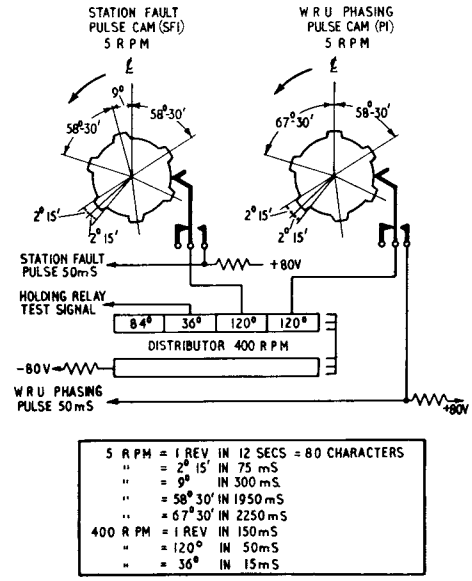


FIG. 9.77. "WRU" PHASING AND STATION FAULT PULSES, AND HOLDING RELAY TEST SIGNAL

code cams associated with the *WRU* sequence, each cam representing one code element. The outer springs of the spring sets are connected to + 80 V and — 80 V, and the moving spring is connected to the appropriate distributor ring. The distributor rings are allocated as follows—

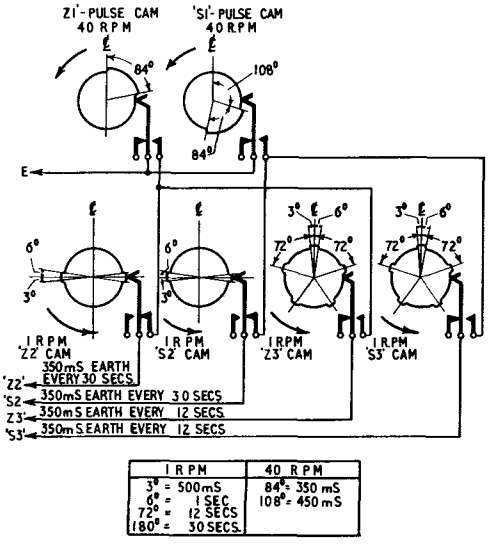
Rings 8–4 WRU.
Rings 7–3 OCC.
Rings 6–2 MOM.

The all marking elements of the sequence are produced by converting the start element of letter-shift combinations in a manner similar to that described in the preceding section.

WRU Phasing and Station Fault Pulses, HRT Signal. (Fig. 9.77 refers.) These are controlled by the remaining pair of distributor rings, in order to achieve the required degree of accuracy. In each case the signal output lead is connected to + 80 V, and the distributor brush, in passing the appropriate segment, lowers the potential on the signal lead if the spring sets are operated. An external valve circuit responds to the lowering of potential and transmits the required pulse. In the case of the S.F.P. and WRU P.P. the signals are converted to earth pulses.

The spring sets associated with the WRU P.P. and S.F.P. signals are operated by a cam on the 5 r.p.m. shaft and function as a "gate" circuit to reduce the pulses to the required periodicity.

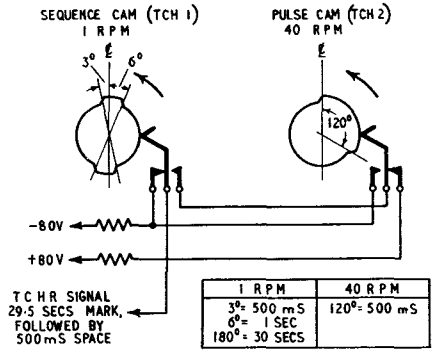
S and Z Pulses. (Fig. 9.78 refers.) Again spring



1 R P M	40 R P M
3° = 500mS	84° = 350 mS
6° = 1 SEC	108° = 450 mS
72° = 12 SECS	
180° = 30 SECS.	

FIG. 9.78. S AND Z PULSES

sets are used as a "gate" circuit. Two spring sets operated by cams (*S*1 and *Z*1) on the 40 r.p.m. shaft control the pulse length and the interval



1 R P M	40 R P M
3° = 500 mS	120° = 500 mS
6° = 1 SEC	
180° = 30 SECS	

FIG. 9.79. TRUNK CIRCUIT HOLD AND RETEST SIGNAL

between the pulses; four spring sets operated by cams (*S*2, *S*3, *Z*2 and *Z*3) on the 1 r.p.m. shaft, control the frequency of repetition of the pulses.

Trunk Circuit Hold and Retest (T.C.H.R.) Signal. (Fig. 9.79 refers.) Two cams (*TCH*1 and *TCH*2) on the 40 r.p.m. and 1 r.p.m. shafts respectively, are used to obtain the required duration and periodicity. The process is similar to the generation of *S* and *Z* pulses.

Immediate Release (IR) Signal. As shown in Fig. 9.80 a single spring set operated by a cam on the 40 r.p.m. shaft is used to generate this signal.

Generator, D.C. Signalling No. 3B. This machine, shown in Fig. 9.68, provides the following signals—

DER T Signal. This comprises seven repetitions of the following 11 character combinations—

1. Letter-shift.
2. D
3. E
4. R
5. Space.
6. T
7. Space.
8. Space.
9. Space.
10. Space.
11. Letter-shift.

The required 12 sec sequence is completed by the addition of three letter-shifts after the seventh signal repetition.

DER S Signal. This is similar to the DER T signal, except that the combination for letter *S* replaces that for letter *T*.

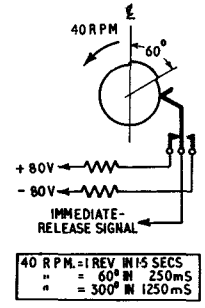
NC Signal. This comprises the following group of character combinations—

Letter-shift, *N*, *C*, Space and Letter-shift, transmitted continuously.

20 *c/s Signal.* This is a supply of continuous ± 80 V reversals transmitted at a frequency of 20 c/s.

Teleprinter Speed Test (T.S.T.) Signal. This is the 20 c/s signal, interrupted by − 80 V potential for a period of 150 msec every 10 sec.

DER S, DER T and NC Signals are generated in



40 R P M. = 1 REV IN 1·5 SECS
" = 60° IN 250mS
" = 300° IN 1250mS

FIG. 9.80. IMMEDIATE RELEASE SIGNAL

a manner similar to that described for the *WRU* signal (Fig. 9.76 refers).

The following indicates the allocation of distributor rings—

Rings 7–3	DER S
Rings 6–2	DER T
Rings 5–1	NC

20 c/s Signal and TST Signal. (Fig. 9.81 refers.) The remaining pair of distributor rings are used for the generation of the 20 c/s reversals. + 80 V and — 80 V potentials are applied alternately to the six segments comprising the outer ring. The inner ring is connected directly to the 20 c/s signal output and also via a 1 megohm resistor to the TST signal output. Operation of two spring sets by cams TST 1 and TST 2 on the 1 r.p.m. and 5 r.p.m. shafts, connects — 80 V, via 20 KΩ, to the TST signal output. This causes the continuous 20 c/s signal to be interrupted by the low impedance — 80 V pulse. The high impedance of the connexion between the two signals prevents the — 80 V pulse affecting the 20 c/s signal output.

Signal Generators—Control Arrangements. Each signal generator is associated with a Speed Control Relay Set and a Changeover and Alarm Relay Set which together provide the necessary facilities for controlling the operation of the generator. Before discussing the detailed facilities provided by these relay sets, it is convenient to consider the speed control element.

Speed Control Element. For the generation of accurate signals it is essential that the speed of the signal generator motor be controlled within very close limits about the required speed of 3,000 r.p.m. This is achieved by comparing the phase of a signal obtained from a commutator mounted on the signal generator motor shaft (50 c/s when running at 3,000 r.p.m.) with that of a standard 50 c/s signal obtained from an electrically maintained tuning fork and by correcting motor speed variations producing the change of phase relationship of the two signals.

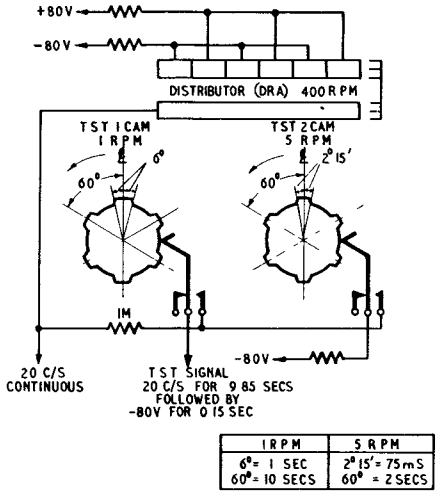


FIG. 9.81. 20 c/s AND TELEPRINTER SPEED TEST FACILITIES

Fig. 9.82 shows the elements of the speed control circuit. The anode current of $V1$ is also the field current of the signal generator driving motor and is determined by the grid/cathode potential difference. This controlling potential difference is made up of two components. One component is developed across variable resistor $RV1$ connected in the cathode circuit of $V1$ so that the potential drop across the resistor is applied between the grid and cathode of the valve. Thus an increase in the value of $RV1$ tends to decrease the anode current and vice versa.

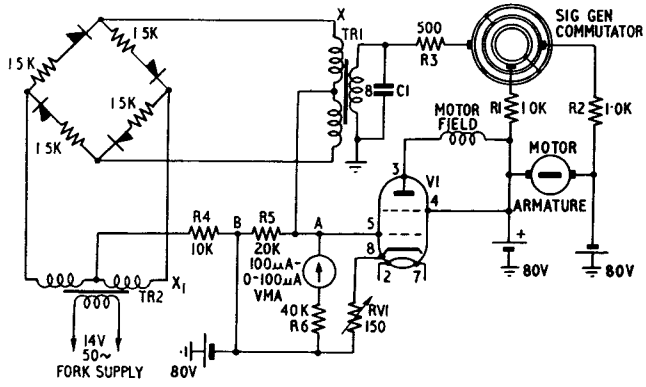


FIG. 9.82. SIGNAL GENERATOR SPEED CONTROL CIRCUIT ELEMENTS

The second component is derived from the rectifier network interconnecting transformers $TR1$ and $TR2$. Transformer $TR1$ is connected to the nominal 50 c/s signal produced by the signal generator commutator and $TR2$ is fed from the 50 c/s tuning fork controlled supply. When the two signals are in quadrature (fork supply lagging on the commutator signal) the d.c. bias produced across resistors $R4$ and $R5$ is zero.

The commutator mounted on the signal generator motor shaft (Fig. 9.66) has three concentric rings. Each of the two equal segments of the outer ring is connected to one of the two solid inner rings which in turn are connected to + 80 V and — 80 V respectively. The signal produced by the commutator therefore consists of ± 80 V reversals at a frequency proportional to the speed of rotation of the motor. Resistors $R1$ and $R2$ limit the current to a safe value should arcing occur across the commutator rings, and with $C1$ and $C2$ form a wave shaping circuit to attenuate the harmonics of the square-topped signal and produce an approximately sinusoidal output. If the speed of the motor

increases, the phase difference between the two 50 c/s supplies also increases and a d.c. component appears in the output of the rectifier network across *R5*, such that point *A* becomes positive with respect to point *B*. This potential difference, applied to the grid of *V1*, produces an increase of anode current to increase the field excitation and thus reduce the motor speed. Similarly, if the speed of the motor decreases, the phase difference between the two compared signals is reduced, the d.c. component of

It will be noted that by using the phase relationship between the two signals as the criterion for determining the magnitude of speed correction to be applied, the motor runs in synchronism with the 50 c/s fork supply. The motor thus behaves as a synchronous motor in respect of speed control but retains the superior starting characteristics of the shunt wound d.c. motor.

"Speed Control" and "Changeover and Alarm" Circuits. The complete circuits for the speed control

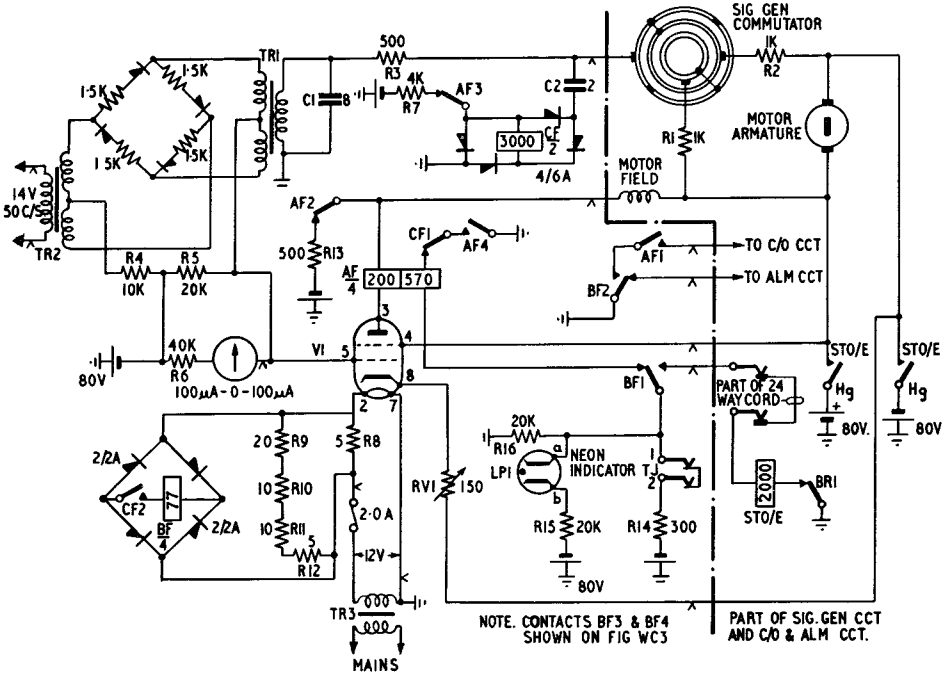


FIG. 9.83. SIGNAL GENERATOR SPEED CONTROL RELAY SET

the rectifier network output renders point *A* negative with respect to point B, the anode current of *V1* is reduced and the resulting fall in field excitation increases the motor speed.

To adjust the speed control circuit the milliameter *VMA* is connected in series with *R6* across resistor *R5* as shown. The milliameter thus behaves as a voltmeter to indicate the d.c. potential produced across *R5* by the rectifier network. *RV1* is then adjusted until the deflexion shown on *VMA* is zero. Under this condition the d.c. output of the rectifier network is zero, i.e. the two signals are in quadrature with the fork supply lagging.

Once the circuit has been set up, any tendency for the motor speed to change due to changes of mechanical load, supply voltage fluctuations, etc., is corrected as already described and the extent of the drift indicated by the deflexion of *VMA*.

and changeover and alarm relay sets are shown in Figs. 9.83 and 9.84. The speed control and changeover relay sets are interconnected so that either of the signal generators may be chosen to serve the switching equipment, whilst the second machine is kept in reserve. The circuit arrangements provide for automatic changeover in the event of failure of the motor control circuit. The keys and associated supervisory lamps are mounted on the signal distribution rack (Fig. 9.65).

The detailed facilities provided are—

(*a*) Manual nomination of either signal generator of a similar pair (designated Odd and Even) as the Main, to serve the switching centre. A lamp indication of Main nomination is provided.

(*b*) Manual transfer of nomination as Main, from Odd to Even generator and vice versa.

(*c*) Manual starting and stopping of the Reserve

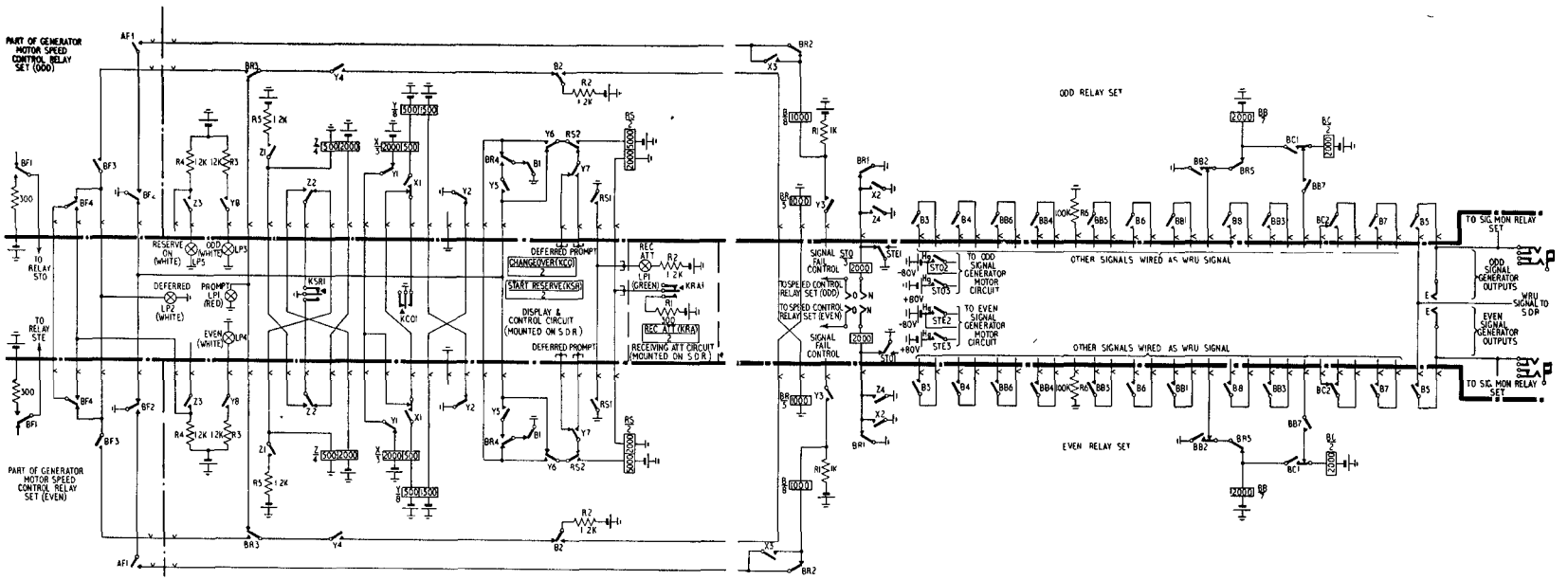


FIG. 9.84. SIGNAL GENERATOR CHANGEOVER AND ALARM RELAY SET

signal generator for maintenance purposes. A lamp indication of Reserve generator running is provided.

(*d*) Automatic control of signal generator motor speed at 3,000 r.p.m. A sensitive voltmeter is provided to facilitate the adjustment of generator speed and the observation of speed variations.

(*e*) A guard feature to prevent excessive motor speed on the failure of control valve anode current. (Relay *AF* releases and maintains motor field circuit via resistor *R*13—Fig. 9.83 refers.)

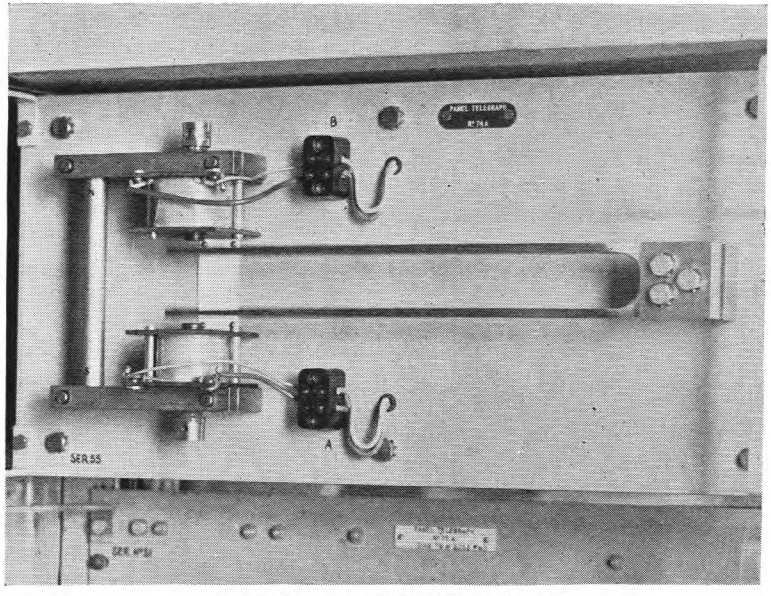


FIG. 9.85. 50 c/s TUNING FORK
(*By courtesy of H.M. Postmaster-General*)

(*f*) Disconnexion of signal generator power supplies in the event of—

1. Control valve heater current failure (relay *BF* releases).

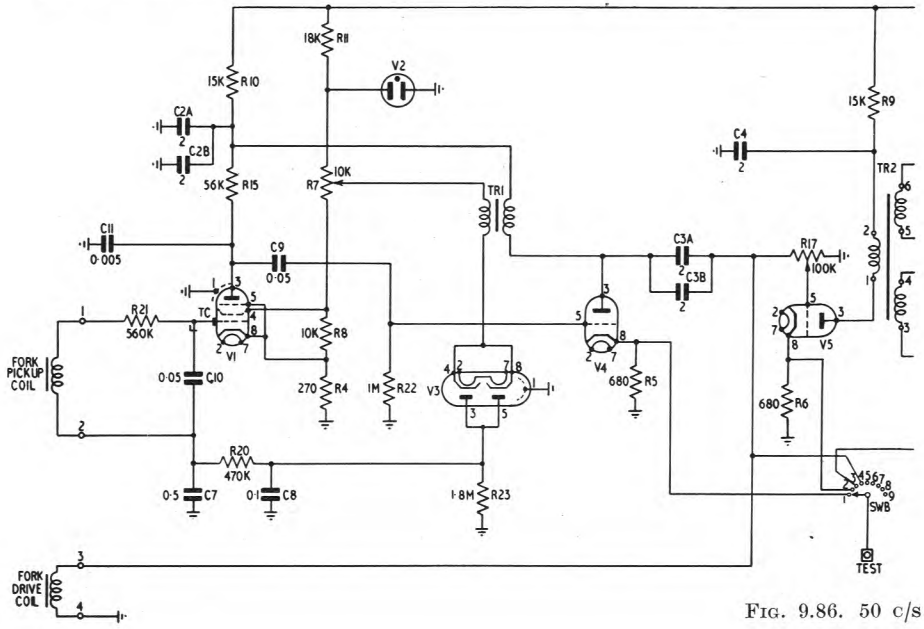


FIG. 9.86. 50 c/s

2. Stalling of generator driving motor (relay *CF* releases).

3. Removal of Speed Control Relay Set, Changeover and Alarm Relay Set or 24-way cord connecting the external control equipment to the generator.

(*g*) Automatic changeover from Main to Reserve generator on the failure of the Main generator under the conditions detailed in (*e*) and (*f*), or on the application of earth to the Signal Fail lead.

(*h*) Raising a Deferred alarm upon failure of the Main signal generator under the conditions mentioned in (*e*) and (*f*), or failure of the Reserve speed control valve heater circuit.

(*i*) Raising a Prompt alarm upon failure of both Main and Reserve generators of a similar pair.

(*j*) Cutting off the audible alarm condition whilst the fault is receiving attention.

50 c/s Fork Supply. The sub-standard 50 c/s supply used to control the signal generator speed is obtained from an electrically maintained tuning fork which is mechanically isolated from the signal generator equipment to avoid interaction due to rack vibration. A matched amplifier mounted on the signal generator rack (S.G.R.) drives the fork in addition to providing the required 50 c/s output signals. The tuning fork is illustrated in Fig. 9.85.

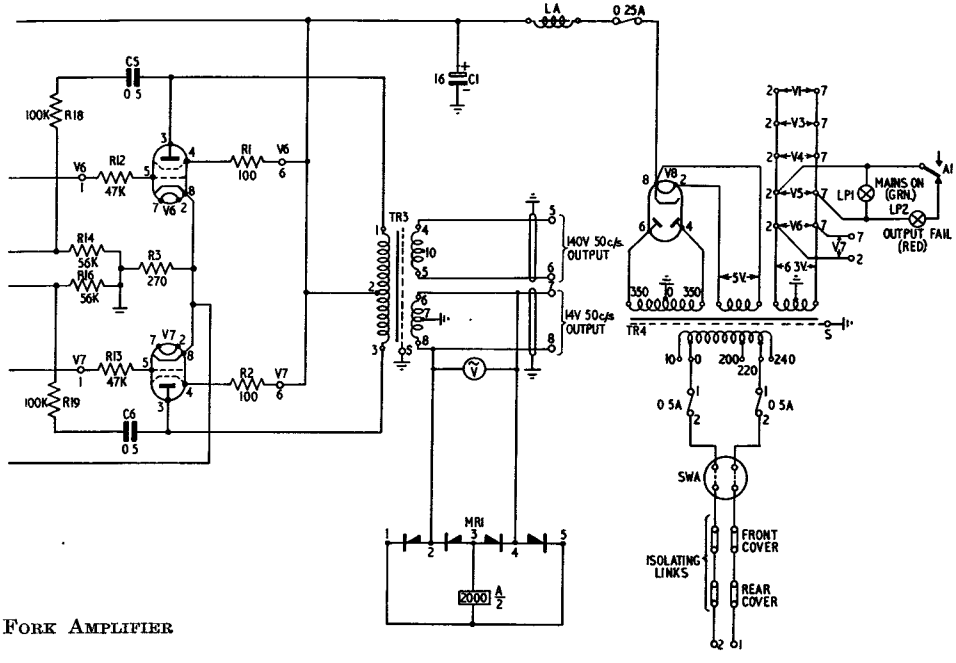
Duplicate equipment is provided so that a reserve is available for maintenance purposes. The outputs of the two sets of forks and amplifiers are controlled by a pair of interconnected Changeover and Alarm Relay Sets which provide facilities similar to those described for the control of the Signal Generators. The control keys and display lamps are mounted on the signal distribution rack (S.D.R.) control panel.

50 *c/s Tuning Fork.* This is an alloy steel tuning fork mounted rigidly on a non-ferrous plate, together with the associated drive and pick-up coils. The natural frequency of the fork, in free air, is slightly above the required frequency of 50 c/s to compensate for the slight reduction of frequency which occurs when the fork is in use, i.e. operating in a magnetic field. The "free" end of the tuning fork oscillates within a magnetic field provided by a permanent bar magnet. The drive and pick-up coils are mounted either side of the tuning fork on pole pieces, adjusted so that variations in the drive coil voltage have minimum effect on the frequency. The pole-pieces are factory pre-set as a frequency adjustment of the input signal to the amplifier.

50 *c/s Fork Amplifier.* (Fig. 9.86 refers.) This consists of a drive amplifier for maintaining the oscillation of the fork, and an output amplifier supplying a 14 V, 50 c/s signal to control the speed of the signal generators and a 140 V, 50 c/s signal for the calibration of start-stop telegraph distortion measuring sets. Both amplifiers share a common output circuit from the Fork Pick-up coil.

The circuit is designed to operate from 230/250 V a.c. mains supply.

The potential on input terminal two is determined by an automatic gain control circuit. The input voltage at terminal one from the fork pick-up coil varies sinusoidally about this potential, which



FORK AMPLIFIER

determines the amplification of the first amplifier stage, a variable—mu pentode ($V1$). The amplified signal appearing at the anode of $V1$ is fed to a second amplifying stage ($V4$).

The anode load of $V4$ is the primary winding of transformer $TR1$ which forms part of the A.G.C. circuit. The anode voltage of $V4$ is fed to the drive coil of the tuning fork to maintain the oscillation of the fork and via the gain control $RV2$ to drive $V5$. The anode load of $V5$ is transformer $TR2$ whose secondary winding is centre-tapped to supply anti-phase voltages to a class AB push-pull amplifier $V6$ and $V7$. The push-pull output transformer $TR3$ has two secondary windings, the first supplying 140 V to output terminals 5 and 6; the second supplying 14 V to terminals 7 and 8.

An a.c. voltmeter and rectifier bridge operating a supply fail relay are connected across the low voltage output. Approximately one-third of the anode voltage of $V6$ and $V7$ is fed back to the grid of each valve. The effect of this negative feed-back is to maintain the gain of the two valves at a constant value.

$V2$, a neon stabilizer, minimizes the effect of supply voltage variations and in conjunction with the input A.G.C. circuit maintains the output frequency at 50 c/s $\pm$ 0·02 per cent.

Test Message and Service Signal Distribution. To minimize wear on signal generator distributor rings and brushes, the current flowing in the brush circuit is restricted to 4 mA by 20 KΩ resistors included in the signal supply leads. The signalling current distributed to the switching equipment must, however, be sufficient to operate a number of teleprinter electromagnets in parallel, each requiring a nominal current of 20 mA.

The Signal Distribution Relay Set interposed between the signal generator and the switching centre load must, therefore, offer a high impedance to the generator and also repeat the signals to the switching equipment at low impedance to avoid adding excessive distortion.

These requirements are met by applying the signal generator output to a double triode valve and supplying the load from the contacts of a Carpenter type polarized telegraph relay included in the valve anode circuits.

By this means the impedance presented to the signal generator remains high. The small added distortion is negligible and the relay output contacts permit a maximum of 40 lines to be served simultaneously by the same distribution relay set. A suitable spark-quench and filter is included in the distribution relay output circuit to prevent excessive contact deterioration.

The number of relay sets required to supply a switching centre with each signal is determined by assessing the maximum simultaneous demand.

For the more important service signals the switching equipment to be served is divided on an Odd and Even shelf basis, or an Odd and Even rack basis. Each half of the equipment is supplied by one of a pair of coupled distribution relays sets, designated Odd and Even. The entire load may be transferred to one relay set of a pair either manually, as required, or automatically under certain fault conditions.

The less important signals are distributed on the basis of one relay set per switching centre.

The method of distribution is shown in the following table.

Signal	Distribution
WRU WRU P.P. S.F.P. DER S DER T T.C.H.R.	Odd and Even shelves served by Odd and Even coupled relay sets.
MOM OCC NC	Odd and Even racks served by Odd and Even coupled relay sets.
Test Messages H.R.T. I.R. T.S.T. 20 c/s	Switching centre served by one relay set.

Distribution Relay Set—Circuit Elements. Fig. 9.87 shows the circuit used to operate a Carpenter polarized relay from signals supplied by the signal generator.

Relay DF is the common cathode load for both triode elements of the double-triode valve. When the right hand triode conducts the potential developed across DF appears also at the left hand cathode. If the bias potential of the left hand grid is sufficiently negative with respect to the right hand grid, the left hand triode will be cut-off. By similar reasoning, if the left hand grid becomes positive with respect to the right hand grid, the left hand triode will conduct and the right hand triode will be cut-off.

From Fig. 9.87 it will be seen that the right hand grid is maintained at earth potential and that the signal generator output is connected via a potentiometer formed by resistors $R8$, $R10$, and $R5$ to the left hand grid. Approximately two-thirds of the incoming signal potential appears at the left hand grid (roughly $\pm$ 53 volts). When the incoming

signal is negative the right hand triode conducts and the left hand triode is cut-off. Current flowing in the right hand winding of relay *D* causes the relay tongue to move to Mark. Conversely, when the incoming signal is positive, current flowing in the left hand winding of relay *D* causes the relay tongue to move to Space. The input signal is

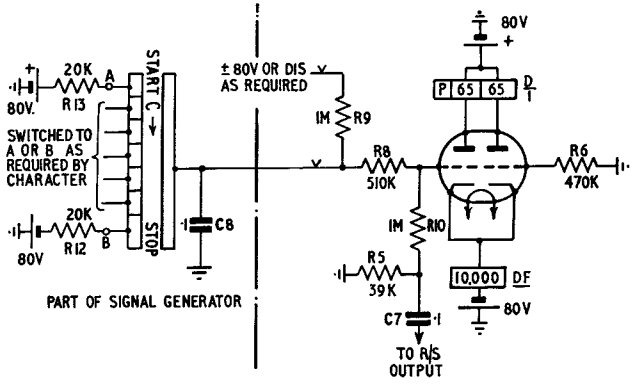


FIG. 9.87. VALVE/RELAY COMBINATION: SIGNAL DISTRIBUTION RELAY SET

therefore reproduced at the distribution relay contacts.

Resistor *R*9 provides a bias to mask discontinuities appearing in signals produced by spring sets operated by slowly revolving cams. The polarity of bias potential required depends upon the signal concerned.

It has been found that distributor brush bounce may cause brief discontinuities in the signal output. These are of insufficient duration to cause the output relay to change over but as the relay contacts break under load the consequent arcing would cause contact deterioration. Capacitor *C*8 has therefore been introduced to maintain the potential of the left hand grid during brief interruptions of the generator signal potential. The effect of *C*8 on the overall distortion introduced by the distribution circuit is negligible.

When a signal is being distributed to a large number of physical lines in parallel, the line capacitance causes a high current surge on each change of signal polarity. The corresponding voltage peak in the *CR* circuit *C*7 and *R*5 is used at the left hand grid to over-ride the incoming signal. This prevents the output relay contacts from changing over until the line current has fallen to a safe value.

Output Circuit. Fig. 9.88 shows the circuit used for distributing signals to the switching centre.

Resistors *R*1 and *R*2 in the ± 80 V supply leads limit the surge current under maximum output conditions. The voltage drop across these resistors is insufficient to introduce significant distortion.

The filter *LCA* together with capacitors *C*4, *C*5, and *C*6 constitute a radio-frequency suppressor.

Capacitors *C*1, *C*2, *C*3 and resistor *R*11 form a spark quench circuit to minimize damage due to arcing across the relay contacts.

Protection of Signal Feeds. Since a number of lines may be simultaneously connected to the output of a distribution relay set it follows that the presence of a low insulation or similar fault on any one of these lines may prevent the correct reception of the service signal on all lines and would probably overload the output relay contacts.

The risk could be eliminated by including a standard current limiting device, i.e. a resistor bulb, in each service signal supply lead to every item of switching equipment served. This method is, however, impracticable owing to the multiplicity of resistor bulbs which would be required. Protection is therefore provided by including resistor bulbs in the send legs of station lines and trunk circuits to protect the switching equipment from faults external to the switching centre.

Facilities. The detailed facilities provided by the complete Signal Distribution Relay Set circuit shown in Fig. 9.89 are—

(*a*) Receiving WRU, OCC, MOM, I.R., T.C.H.R.,

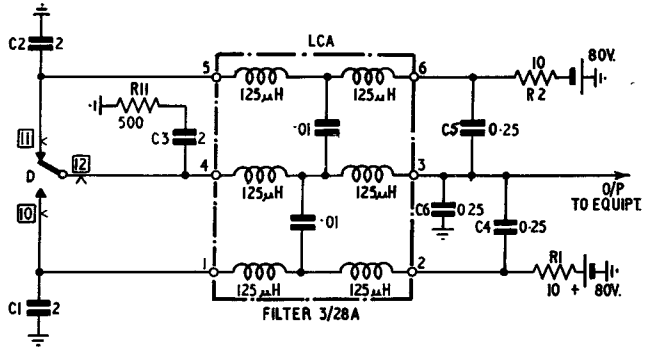


FIG. 9.88. OUTPUT CIRCUIT: SIGNAL DISTRIBUTION RELAY SET

DER S, DER T, NC, T.S.T., 20 c/s and H.R.T. Signals and the Test Messages from the signal generators, and repeating them to the switching equipment.

(*b*) Receiving the WRU P.P. and S.F.P. as double-current signals and transmitting them to the switching equipment as earth pulses.

(*c*) Distributing the signals only on receipt of a start earth.

(*d*) Coupling of relay sets distributing WRU, OCC, MOM, T.C.H.R., DER S, DER T and NC signals and WRU P.P. and S.F.P. in pairs, so that the load on either one of the pair may be transferred to the other, either manually to facilitate maintenance, or automatically on the failure of the valve anode or heater current in one relay set.

(*e*) Raising a "Deferred" alarm on the failure of one relay set valve circuit of a key coupled pair, and a "Prompt" alarm on the failure of both.

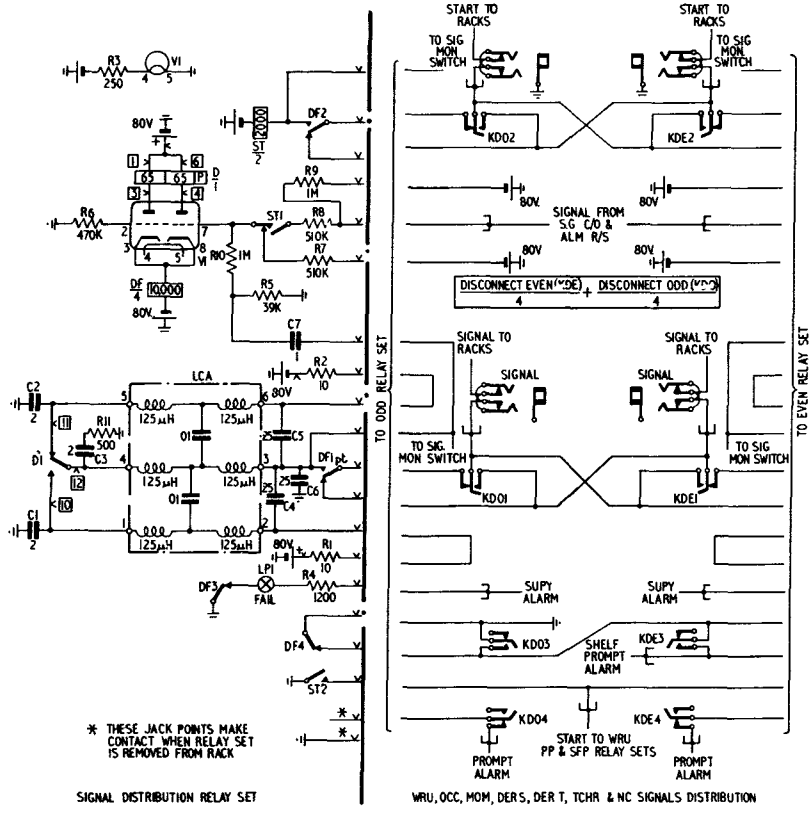


FIG. 9.89. SIGNAL DISTRIBUTION RELAY SET AND TYPICAL DISTRIBUTION CIRCUIT

(*f*) Raising a "Prompt" alarm on the failure of the valve circuit of relay sets distributing Test Messages, T.S.T., 20 c/s, I.R., and H.R.T. signals.

(*g*) Raising a "Prompt" alarm if one of a pair of coupled relay sets is removed from the rack without first transferring the load to the other relay set.

(*h*) Provision of "alarm" type fuses for the signals distributed on an individual relay set basis.

(*i*) Provision of a start relay for the distribution of I.R. signals to spare lines.

Test Message Phasing Pulse Distribution Relay Set. To ensure that calling lines do not receive an incomplete test message it is arranged that the wait signal (MOM) is returned on the seizure of a Test Message relay set via a special services final selector. On the commencement of the next announcement, a phasing pulse is transmitted from the T.M.P.P. relay set to connect the test message to the calling line.

Two interconnected T.M.P.P. relay sets are provided and operated on an Odd and Even basis. One of the pair is nominated as Main and serves the switching centre, the other functions as Reserve. Manual nomination of Main is effected by key operation.

Principle of Operation. The T.M.P.P. is produced by a valve/Carpenter relay circuit, similar to that already described for the Signal Distribution Relay Set, controlled by three leads designated *PX*, *PY*, and *PZ* from the Test Message Signal Generator. These three leads are shown in Fig. 9.75 and the circuit of the T.M.P.P. relay set is shown in Fig. 9.90.

The T.M.P.P. relay set is prepared for the transmission of the T.M.P.P. by the extension of a start

earth from the Test Message Distribution Relay Set. The T.M.P.P. is initiated when the potential on the *PZ* lead is raised from — 80 V to — 54 V at the commencement of the start element of the first character in the test message announcement. This rise in potential is recognized by the valve and causes relay *D* in the valve anode circuit to change-over and connect earth to the T.M.P.P. distribution leads via the *PD* and *PE* relays. The potential of the *PZ* lead remains at — 54 V until the end of similar to those already described for signal distribution relay sets.

***S* and *Z* Pulse Distribution Relay Set.** The 12 and 30 second *S* and *Z* pulses are received from the signal generator as earth pulses. As highly accurate timing is not required, 3,000 type relays are suitable for distribution purposes. Repeating relays are necessary to avoid overloading distribution relay contacts and it is arranged that a maximum of six relays is served by any one contact.

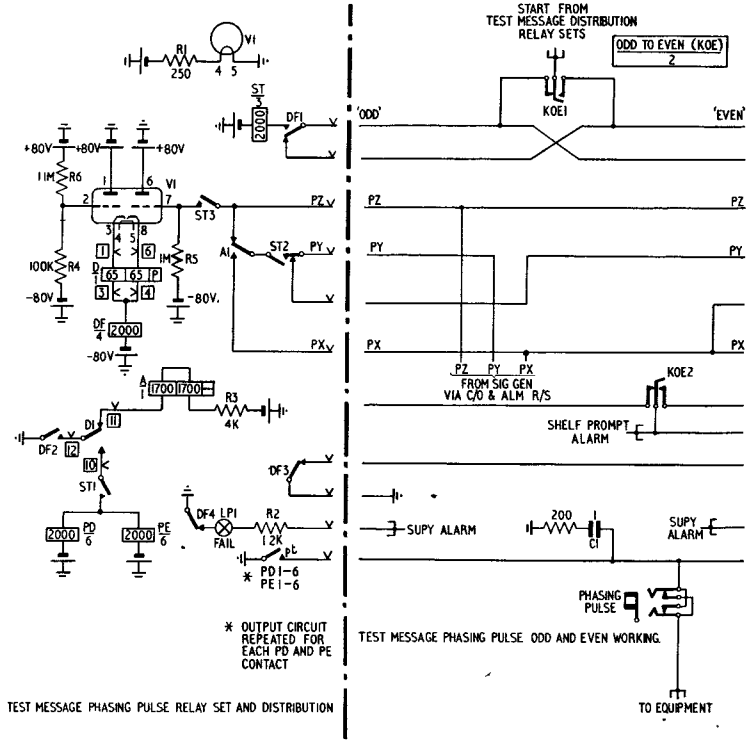


FIG. 9.90. TEST MESSAGE PHASING PULSE RELAY SET AND DISTRIBUTION

the fourth element of the first character of the test message announcement, when the potential again becomes — 80 V. The duration of the T.M.P.P. is thus 100 msec corresponding to the transmission time of five signal elements.

This method of producing the test message phasing pulse guarantees that the pulse is accurately synchronized with the text of the test message and thereby ensures that switching to the test message signal occurs at the correct instant. The required accuracy could not readily be obtained by the straightforward use of mechanically operated spring sets.

The test message phasing pulse distribution relay sets are provided with coupling and alarm facilities

Typical distribution arrangements for *S* and *Z* pulses, including the *S* and *Z* relay set, are shown in Fig. 9.91. The location of test and isolation points is clearly indicated and the operation of the circuit is self-explanatory.

Signal Distribution Test Circuit. The signal distribution test circuit shown in Fig. 9.92 forms part of the control panel mounted on the S.D.R. It is a high impedance monitor circuit suitable for observing output signals from either the signal generators or the distribution relay sets, which are patched to the circuit by double plug-ended cords as required.

Two neon lamps one of which glows to — 80 V and the other to + 80 V indicate the polarity of the

incoming signal. Alternatively a relay may be introduced which permits earth pulses to be tested. A test position is also associated with the test panel into which signal distribution and test message phasing pulse distribution relay sets may be jacked and tested by means of the keys with which the position is equipped.

Service Signal Monitor Arrangements. To facilitate regular observation of service signals at points throughout a switching centre, monitor facilities are provided on the Test Desk by means of a relay set and two uniselectors mounted on the S.D.R. The relay set and uniselectors are controlled from keys and switches mounted on the test desk so that the testing officer can monitor all signals without leaving the test desk to manipulate plugs and cords on the S.D.R. The relay set includes a valve monitor circuit for repeating signals to the test desk where they may be checked for distortion on an electronic start-stop T.D.M.S. and for code accuracy on the test desk teleprinter.

Two multi-position rotary switches on the test desk are used to mark the banks of the uniselectors, so that on the operation of a start key the uniselectors drive to the marked signal output and extend the signal lead (and start lead where necessary) associated with the marked uniselector position to the monitor circuit.

Facilities. The detailed facilities provided are—

(*a*) Access via two uniselectors to the signal generator and distribution relay set outputs corresponding to all teleprinter signals.

(*b*) Two rotary switches and a start key on the test desk to establish connexion to the required signal.

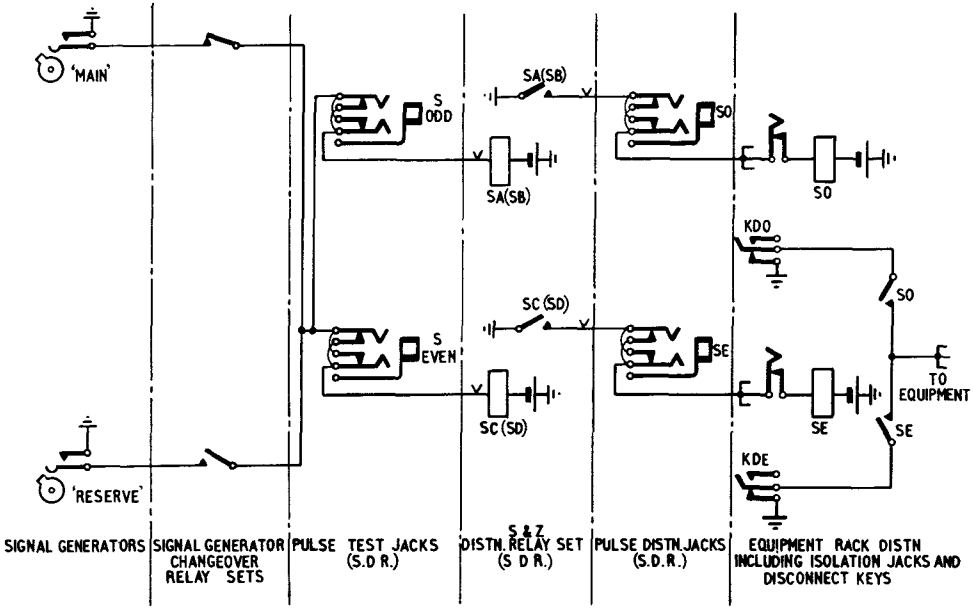


FIG. 9.91. *S* AND *Z* PULSE DISTRIBUTION: TYPICAL ARRANGEMENTS

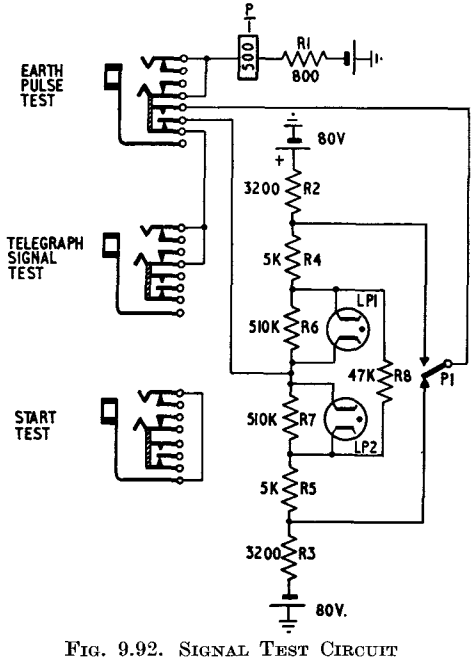


FIG. 9.92. SIGNAL TEST CIRCUIT

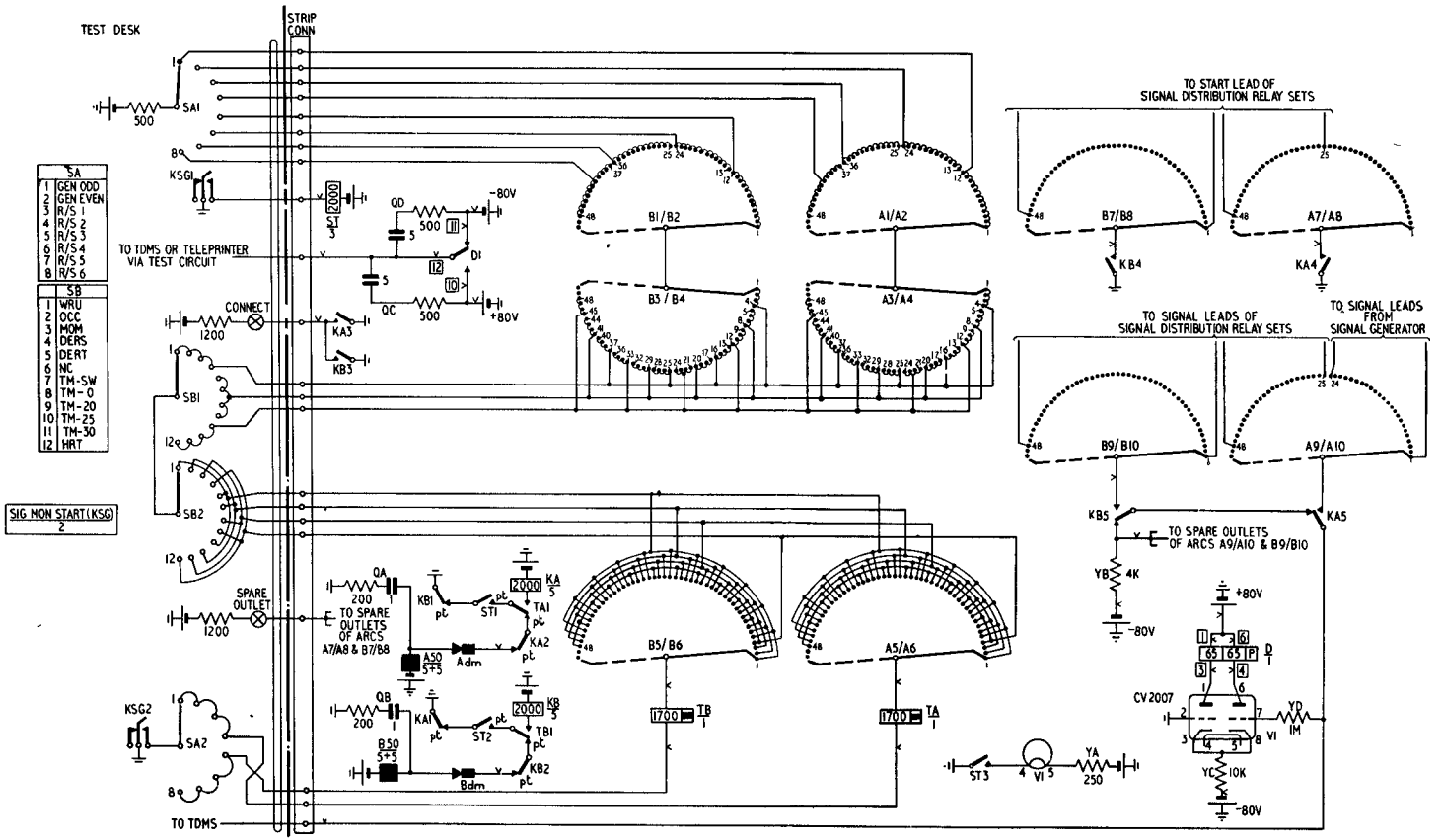


FIG. 9.93. SIGNAL MONITOR RELAY SET

(*c*) Lamp indications that the marked uniselector position has been seized and that a spare uniselector contact has been selected.

(*d*) Extending a start condition when required.

(*e*) Repetition of incoming signals via the valve monitor circuit to either a teleprinter or electronic start-stop T.D.M.S.

(*f*) Connexion of the incoming signals directly to an electronic start-stop T.D.M.S.

alarm, including the alarm delay relay set, are shown in Fig. 9.94.

An alarm condition is indicated by the operation of shelf alarm relay *RA*. A start condition is extended via the rack *ST* and *S* relays to the alarm delay relay set. The pulsing relays *PS*, *PSA*, and *PR*, operated by 0·75 sec pulses (produced by a relay group) for a 9 sec delay, or the 30 sec *Z* pulse for a 3 or 6 min delay, control the stepping of the

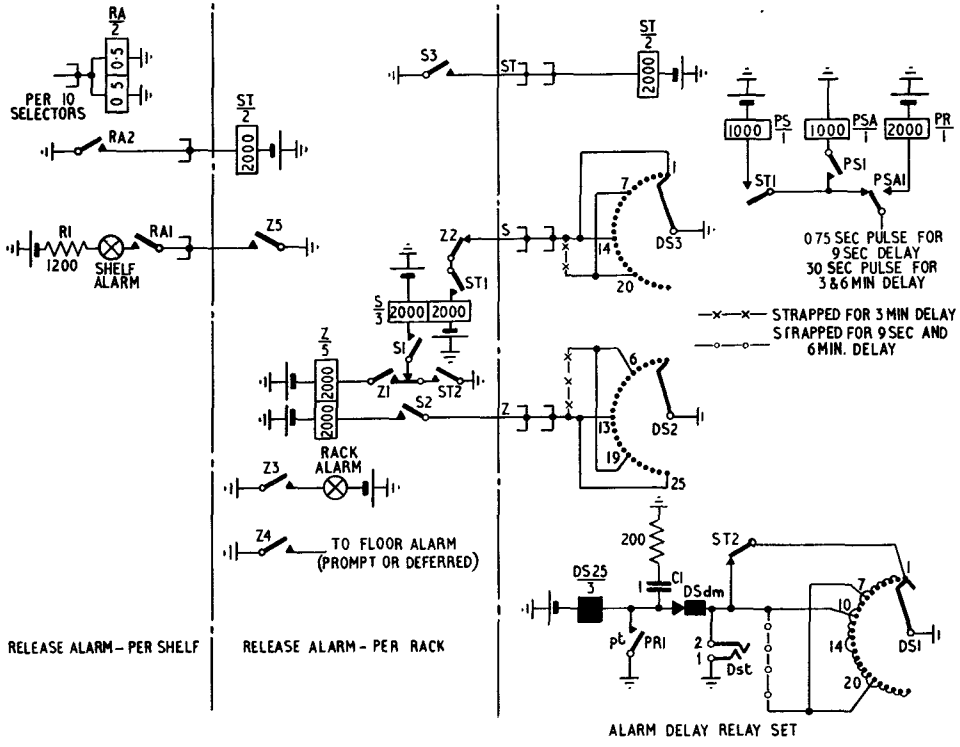


FIG. 9.94. DELAYED ALARM: TYPICAL ARRANGEMENTS

The circuit of the Signal Monitor Relay Set is shown in Fig. 9.93.

Alarm Delay Relay Set. Selector release alarms, final selector supervisory alarms and group selector supervisory alarms require minimum delays of 9 sec, 3 min and 6 min respectively between the recognition of a fault condition and the operation of the appropriate alarm. The necessary delay is achieved by the use of *S* and *Z* pulses. The *S* pulse prepares the alarm circuit and the *Z* pulse raises the alarm.

The interval between successive *S* and *Z* pulses, controlled by a uniselector, provides the required delay period.

The typical arrangements for providing a delayed uniselector. Earth extended at appropriate instants over the *S* and *Z* wires raises the appropriate rack and floor alarms after the required delay.

Detailed Facilities. The detailed facilities provided are—

(*a*) Connecting pulses alternately on the *S* and *Z* leads with a predetermined interval between successive pulses.

(*b*) Driving the timing uniselector to its next home position should the fault condition cease before the end of the delay period.

(*c*) Delaying the operation of the stepping circuit so that transient conditions, such as selector release, will not cause unnecessary operation.

(*d*) Stepping 3 and 6 min delay uniselectors

under the control of the 30 sec Z pulse and 9 sec delay uniselectors under the control of a 0·75 sec pulse produced by a relay group.

(*e*) A uniform method of operation so that relay sets providing the different delay periods are interchangeable.

Maintenance. The maintenance of a teleprinter automatic switching system is a matter of considerable complexity, involving as it does, not only automatic switching mechanisms and circuits but telegraph machines and transmission equipment. It has been necessary therefore to develop much special test equipment to ensure that not only is the apparatus maintained in good order but that faults are rapidly located and cleared. Detailed descriptions of test equipment and maintenance methods are beyond the scope of this book and it is possible to cover in the following paragraphs only the more salient features of this aspect of telegraph engineering.

In considering the arrangements made for maintenance, the system can be roughly divided into—

(*a*) Switching centre equipment.
(*b*) Telegraph lines and transmission equipment.
(*c*) Station apparatus and teleprinters.

Switching Centre Equipment. The maintenance techniques for the switching centre equipment are very similar to those used in automatic telephone exchanges. In the main they are directed towards ensuring that the mechanisms are maintained in good mechanical and electrical adjustment. The staff keep a constant watch on the operation of the switches and are assisted by routine testers which apply to individual selectors and relay sets a series of functional and electrical tests. The routine testers are used to check the condition of the equipment at regular intervals, the object being to detect faults before they give rise to service difficulties. From this point of view it is desirable that the interval between tests should be short but this tends to increase maintenance costs and, in practice, the frequency of routine testing is a compromise between the two conflicting factors.

Routine testers are provided for—

(*a*) Final selectors.
(*b*) Group selectors.
(*c*) Trunk relay sets, and relay sets outgoing from group selector levels.

The following description of the group selector routine tester may be regarded as typical of routine tester practice.

Group Selector Routine Tester. The group selector routine tester is illustrated in Fig. 9.95, and is mounted on a wheeled trolley and is connected to the group selector under test by means of plugs and cords. Power supplies for the tester are obtained from a jack on the group selector rack.

Table 9.5 gives a schedule of the tests which are applied, automatically, in sequence under the control of uniselectors in the tester. The test cycle is started by the START key and the lamp panel on the sloping face of the tester indicates the test which is being applied at any instant. If a fault is found, the uniselectors cease stepping and the lamp corresponding to the unsuccessful test remains lit.

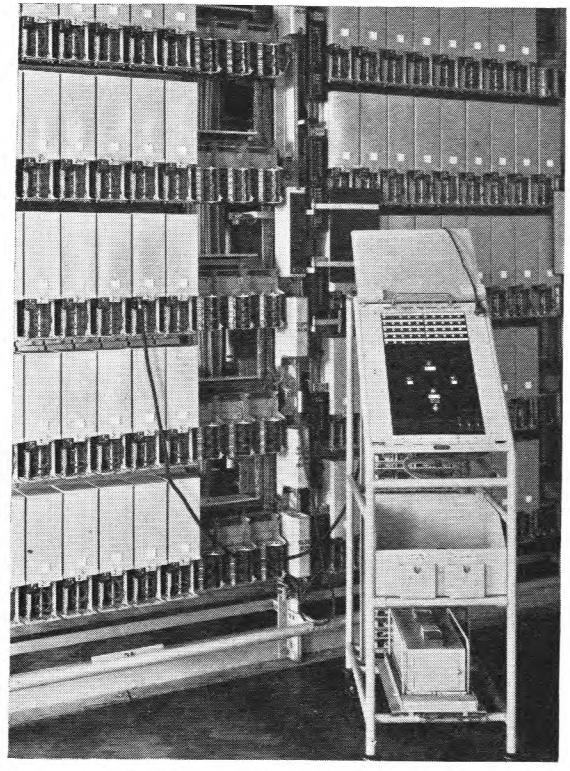


FIG. 9.95. GROUP SELECTOR ROUTINE TESTER
(*By courtesy of H.M. Postmaster-General*)

Keys are provided to modify the test cycle to deal with first, second or trunk selectors. The pulse machine mounted in the tray at the foot of the tester generates trains of pulses of appropriate speed and ratio to apply critical stepping tests to the selectors.

Line Testing. To provide facilities for dealing with line and apparatus faults, each switching centre is equipped with an Engineering Control Board (E.C.B.) and either a test desk, or a speak and test set. In order to gain economies by concentrating staff and common use of test equipment, the E.C.B. caters for all types of teleprinter circuits

TABLE 9.5

Schedule of Tests Applied by Group Selector Routine Tester

Test No.	Description of Test	Remarks
1	SELECTOR BUSY. The lamp is lit if the selector does not test free.	
2	1st. TEST LINE BUSY. If the first test line (level 9 outlet 18) is busy the tester waits.	Three outlets on the group selector multiple are intercepted so that the switching of the selector to these outlets can be checked.
3	2nd. TEST LINE BUSY. If the second test line (level 9 outlet 19) is busy, the tester waits.	
4	3rd. TEST LINE BUSY. If the third test line (level 9 outlet 20) is busy, the tester waits.	
5	'A' RELAY OPERATE 'P' WIRE EARTHED. This checks the operation of relays A, B, and BA and the return of holding conditions on the P wire.	
6	'A' RELAY RELEASE. The release of relay A followed by the connexion of the free condition to the P wire is checked.	
7	PROCEED TO SELECT SIGNAL MIN. The 'proceed to select' pulse is checked to be not less than 20 milliseconds.	First and trunk selectors only.
8	SELECTOR RELEASED. The restoration of the selector and reconnexion of the free condition to the P wire is checked.	
9	PROCEED TO SELECT SIGNAL MAX. The "proceed to select" pulse is checked to be less than 40 milliseconds.	First and trunk selectors only.
10	IMPULSING 80/20. The stepping of the selector to pulses of ratio 80 per cent break/20 per cent make at 11 pps is checked.	
11	'C' RELAY RELEASE MIN. This checks the minimum release lag of relay C after vertical stepping.	
12	TEST LINE 9/9 PB. This checks that the selector self drives to outlet 17 on level 9.	
13	HA RELAY SWITCHED. This checks the operation of relay HA in switching to outlet 19 on level 9.	
14	PB WIRE DISC. This checks for extraneous potentials on PB wiper.	
15	SB WIRE DISC. This checks for extraneous potentials on SB wiper.	
16	RB WIRE DISC. This checks for extraneous potentials on RB wiper.	
17	MECHANICAL RELEASE. This checks that the selector restores to normal from level 9 outlet 19 in less than 200 milliseconds.	
18	SELECTOR SEIZED. Similar to test 5.	
19	FORCED RELEASE. Checks forced release after seizure without dialling.	First selectors only.
20	SELECTOR NORMAL. Similar to test 8.	
21	SELECTOR SEIZED. Similar to test 5.	
22	'B' RELAY RELEASE MIN. Checks that the release lag of relay B is greater than 120 milliseconds.	
23	SELECTOR NORMAL. Similar to test 8.	
24	SELECTOR SEIZED. Similar to test 5.	
25	'B' RELAY RELEASE MAX. Checks that the release lag of relay B is less than 180 milliseconds.	
26	SELECTOR NORMAL. Similar to test 8.	
27	SELECTOR SEIZED. Similar to test 5.	
28	IMPULSING 50/50. The stepping of the selector to pulses of 50 per cent make, 50 per cent break is checked.	
29	'C' RELAY RELEASE MAX. Checks the maximum release lag of relay C after pulsing in test 28.	
30	TEST LINE 9/9 PB. This checks that the selector self drives to outlet 18 on level 9.	
31	HB RELAY SWITCH. This checks the operation of relay HB in switching to outlet 20 on level 9.	

TABLE 9.5 (*contd.*)

Test No.	Description of Test	Remarks
32	PA WIRE DISC. Tests for extraneous potential on PA wiper.	
33	SA WIRE DISC. Tests for extraneous potential on SA wiper.	
34	RA WIRE DISC. Tests for extraneous potential on RA wiper.	
35	SELECTOR NORMAL. Similar to test 8.	
36	IMPULSING 11th STEP. Checks stepping to 11th step level 9.	
37	HA RELAY SWITCHED. Checks relay HA operates when selector is stepped to 11th step.	
38	S2 SPRINGS OPERATED. Checks that S2 springs operate when the selector is stepped to 11th step.	
39	SERVICE SIGNAL CHECK. Checks that service signals are returned from the 11th step position.	
40	SELECTOR NORMAL. Similar to test 8.	
41	+ 80 V. S WIRE. Checks that + 80 V. battery is connected to the selector S wire.	

in addition to those connected to the automatic switching system.

Engineering Control Board. A general view of an E.C.B. is given in Fig. 9.96.

The main purpose of the E.C.B. is to provide ready access to the lines for testing but it also provides patching facilities so that lines can be re-routed to meet temporary traffic needs or breakdown emergencies.

To provide access for testing and patching each line is routed via a group of six jacks connected as shown in Fig. 9.97.

The jacks marked LINE and EXCHANGE give access to the lines and switching equipment for patching, whilst those marked TEST are intended primarily to enable the line to be extended to the test desk via a test trunk. The test cords used have six conductors and are terminated at each end on six way plugs (Plugs No. 609). The TEST jacks are wired so as to permit the interception of lines without breaking the continuity of the line conductors thereby safeguarding against unnecessary interference with traffic and also permitting a switched connexion to be patched to the test desk without risk of releasing it.

This is arranged by ensuring that the test desk circuits loop the tip and sleeve conductors of the test cords. Since on insertion of the plug into the circuit TEST jacks the tip and sleeve of the plug make contact with the corresponding jack springs before the line is broken at the inner tip springs,

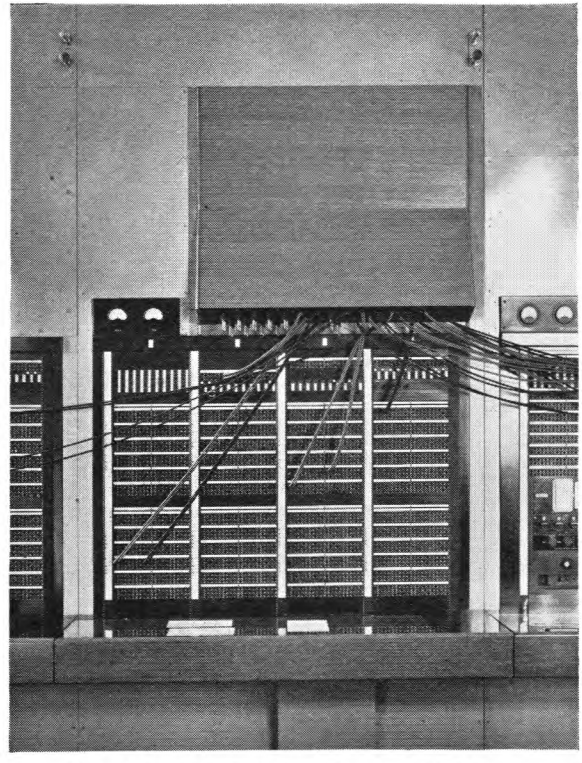


FIG. 9.96. ENGINEERING CONTROL BOARD
(*By courtesy of H.M. Postmaster-General*)

interruption of the line currents does not occur, provided the other end of the cord has been plugged into the test desk trunk. The connexion to the ring springs of T.A.S. trunk circuit TEST jacks, is provided so that the trunk can be busied from the E.C.B. by means of the T.C.H.R. signal which can be connected to the ring conductor of the test cord. This arrangement enables trunk lines to be busied from the E.C.B. without the need for discriminating keys in the test circuits.

For relayed lines, the group of six jacks is connected between the relay units and the switching equipment. It is necessary, therefore, to provide extra jacks on the line side of the relay unit to provide access to the line for testing.

The E.C.B. is used to connect lines to the observation equipment and for this purpose the observation equipment tapping relay sets are terminated on a row of jacks which are patched to

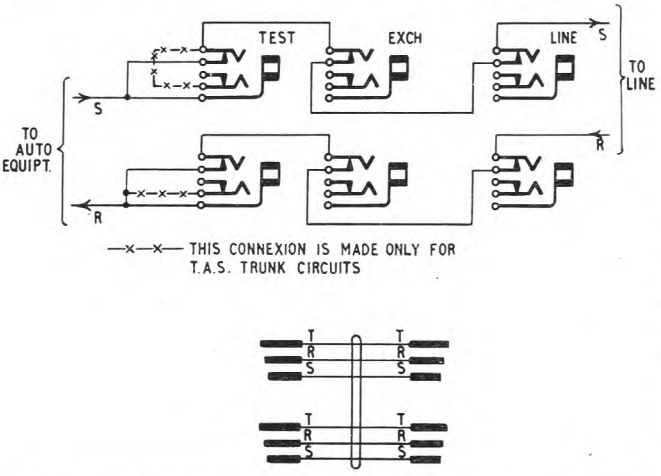


FIG. 9.97. E.C.B. CIRCUIT INTERCEPTION JACKS AND TEST CORD

the TEST jacks of the lines on which it is desired to make observations. Test access to the patched circuit is obtained by an additional pair of TEST jacks associated with each pair of observation jacks. Occasionally, for staffing reasons or because of equipment faults, teleprinter working to a station becomes temporarily impossible and it is necessary to change to telephone working over the teleprinter line. For this purpose, a telephone and key switching unit are provided at the station, whilst at the E.C.B. tie lines are provided to the phonogram room to enable the station line to be patched to calling equipment on the telephone-telegram suite. This facility is known as T.T. reserve working.

Among the other facilities provided on the E.C.B. are jacks for distributing the Test Message and Teleprinter Speed Test Signals, call alarms to enable faultsmen to call in on lines intercepted for test, and miscellaneous jacks which permit marking, spacing, loop and earth signals to be connected to lines. In addition a mains operated megger is provided to enable insulation resistance measurements to be made. A pair of centre-zero milliameters are available for line current measurements and for use with the cord test jacks for checking the condition of test cords.

The Test Desk. Test desks are provided at those centres having an appreciable amount of testing work.

Fig. 9.98 shows a typical test desk installation. To ensure effective co-operation with the distant maintenance staff and to permit rapid reporting and clearing of faults, it is essential that good facilities for communication are available. For this reason telephone lines are provided to the nearest telephone exchange as well as teleprinter circuits into the teleprinter automatic switching system. Telephone speaker circuits are also provided to adjacent repeater stations and elsewhere as necessary.

The general design of the desk allows for suites of up to five positions to be formed. The cordless principle has been adopted, the incoming lines and test trunks being terminated on keys with multipled calling and busy lamps as necessary. The position equipment includes a Teleprinter 11C, an Electronic T.D.M.S., a hand micro-telephone, a tray for filing fault record cards and a sheet of plate glass under which frequently used information is displayed. By adopting the cordless principle the layout of the position equipment has been simplified and the risk of obscuring the display screen of the T.D.M.S. has been eliminated.

The face of the test desk, in addition to accommodating the keys and lamps for the incoming lines

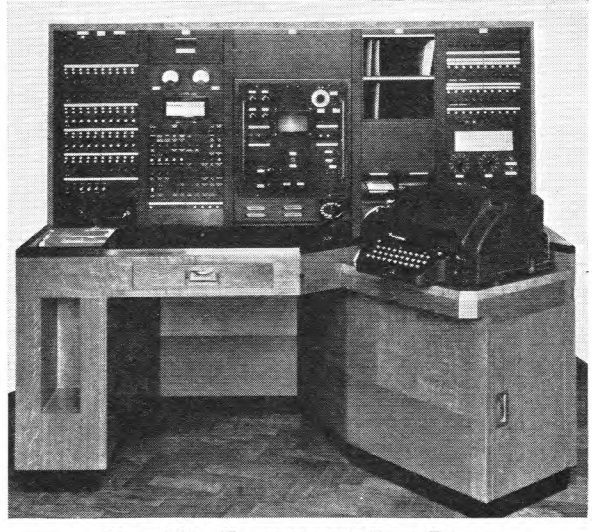


FIG. 9.98. ENGINEERING TEST DESK
(By courtesy of H.M. Postmaster-General)

and test trunks, also includes the electronic T.D.M.S., a d.c. test voltmeter, two centre-zero milliameters, miscellaneous test keys and compartments for holding fault record cards for circuits receiving the attention of the testing officer.

Access to lines for testing is by patching on the E.C.B., three test trunks being provided from each test desk position for this purpose. The tests which can be applied to a line extended to the test desk include—

(*a*) Measurement of line conductor resistance, insulation resistance and checking for "foreign" batteries by means of a test voltmeter circuit. The voltmeter used is of the centre-zero type in order to deal with telegraph signalling batteries and has two ranges 110–0–110 V and 11–0–11 V.

(*b*) Measurement of line currents by means of two centre-zero milliameters connected in series with the two line conductors.

(*c*) Measurement of teleprinter signal distortion and baud speed by means of an electronic T.D.M.S.

(*d*) Transmission of test message signals to teleprinter stations to enable faultsmen to check the receiving margin of the teleprinter. This augments the facilities available in the automatic switching system of dial access to test message relay sets and is primarily for use with teleprinters not connected to the automatic switching system.

(*e*) Transmission of the teleprinter speed test signal to teleprinter stations to enable faultsmen to check the teleprinter motor speed.

(*f*) Transmission of a 25 msec negative pulse to simulate the "proceed to select" or "call confirmation" signals to enable the functioning of distant switching equipment to be checked.

(*g*) Checking that the speed and ratio of dial pulses received from teleprinter positions are within the limits 9–11 p.p.s. for speed and 74–57 per cent break for ratio. The test voltmeter is used as an indicating device in conjunction with a resistor-capacitor timing circuit which measures selected portions of the pulse train. The voltmeter connexions are arranged so that a deflexion to the left indicates "Out of Limits" and a deflexion to the right "Within Limits."

(*h*) Monitoring of teleprinter signals in either direction of transmission. The monitoring circuit uses thermionic valves and it has a very high impedance thereby avoiding mutilation of working signals. Another feature of the circuit is that the free line signal (continuous spacing) results in the teleprinter electromagnet being held to mark, so preventing the receiving cam from continuously rotating. Spacing elements of teleprinter characters are, however, correctly interpreted by the monitoring teleprinter.

(*i*) Transmission of the holding relay test signal to check the performance of the clear signal detecting relays both in the switching centre and at teleprinter stations.

(*j*) Calling, clearing, and where appropriate, dialling, to check the function of distant equipment whether of the sequence or pulse signalling types.



FIG. 9.99. SPEAK AND TEST SETS
(*By courtesy of H.M. Postmaster-General*)

The test desk also provides facilities for concentrating and centralizing alarms, both into and out of the building accommodating the teleprinter automatic switching equipment.

The first test desk in the suite accommodates the rotary switches which enable the service signal outputs on the S.D.R. to be connected to the test desk for monitoring by the T.D.M.S. and test-desk teleprinter. Keys are also provided to enable the test-desk voltmeter to be used to check the voltages at the ends of the bus bars carrying the — 50 V, + 80 V, and — 80 V supplies.

Speak and Test Set. This test set, illustrated in Fig. 9.99 is primarily intended for testing on V.F. station lines, at the M.C.V.F. terminal at the station end of the circuit, but is also used at switching centres when the amount of testing work does not justify the provision of a test desk. It is designed for testing on all types of teleprinter circuits using either pulse or sequence type signalling.

In addition to line testing facilities the speak and

test set is also provided with access to the teleprinter switching network by means of a speaker circuit connected to the special services final selector multiple. The speaker circuit has wait facilities so that if the teleprinter is engaged on testing, or is not in use with its motor switched off, a caller receives the MOM signal, a lamp and bell

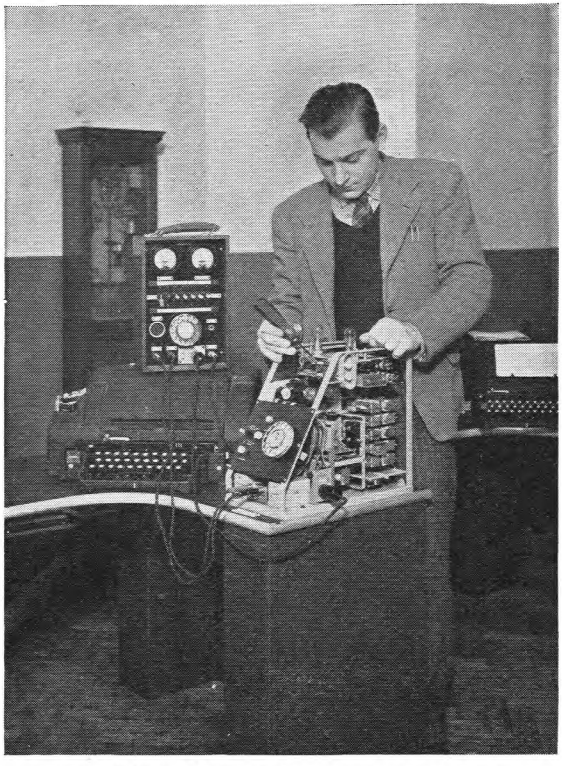


FIG. 9.100. MANUAL TESTER IN USE AT A TELEPRINTER STATION
(By courtesy of H.M. Postmaster-General)

alarm being given meanwhile on the speak and test set. When the call is answered the MOM signal is disconnected, but answer-backs have to be exchanged manually (the facility of automatically taking the answer-back available for regular teleprinter stations is not included in the speaker circuit of the speak and test set). The speaker circuit is, however, provided with a station fault alarm facility so that, when a fault is encountered, the DER S signal is returned to the caller. The circuit arrangements do not provide for the line to be locked out since in general M.C.V.F. terminals have only one speaker circuit and it is obviously undesirable to lock up the only line to a terminal because of a transient fault. Access to lines for testing is by patching either on the S.A.R. at M.C.V.F. terminals or on the E.C.B. at teleprinter switching centres.

The test facilities provided include—

(*a*) Calling, clearing, and when appropriate dialling on circuits employing either pulse or sequence signalling.

(*b*) Measurement of line currents by means of two centre-zero milliameters, connected in series with the line conductors.

(*c*) Checking the speed and ratio of dial pulses received from teleprinter stations, by means of an external dial speed and ratio test set.

(*d*) Monitoring teleprinter signals.

(*e*) Transmitting a 25 msec pulse of negative battery to simulate the "proceed to select" signal to facilitate checking the functioning of teleprinter station equipment.

(*f*) Extending the line under test to a separate T.D.M.S. to enable the distortion and baud speed of teleprinter signals to be checked.

Testing of Teleprinter Station Equipment. The testing facilities provided at a teleprinter station cover the requirements of both the teleprinter and the associated switching equipment. The facilities for checking the teleprinter speed and margin by means of signals transmitted from the switching centre have already been described. The arrangements for dealing with the switching apparatus include the provision of spare items such as the automatic dial, polarized relay, position relay set, teleprinter cords, etc., which can be rapidly plugged into circuit in place of faulty items to restore service.

For routine testing and fault localizing a small portable tester is available so that a series of tests can be applied manually to the position equipment. This tester permits much more detailed localization than is possible by testing from the test desk at the switching centre.

Fig. 9.100 shows the tester in use on a teleprinter position.

By intercepting the line wires, it is possible by simple key operation to simulate calling, clearing signals, etc., and the response of the position equipment to them can be observed. To gain access to the line conductors for testing, jacks are provided on the dialling unit which are accessible only when the cover is removed.

A further range of tests is made possible by using the tester in conjunction with the teleprinter as a source of timed signals. Thus, by inverting single teleprinter characters "Letters" or "V" it is possible to produce negative impulses of 20 msec or 40 msec duration, suitable for checking the ability of the position relay set to accept the proceed to select

signal. The tester dial provides facilities for checking the response of the relay set to clearing signals. By dialling digits 2 or 3 into a simple relay group contained in the tester, positive impulses of suitable duration are produced to check that the timing of the *RA* relay (which recognizes the clearing signal) is within limits.

Service Observation Equipment. Service observation equipment is provided at each of the large switching centres to enable the traffic performance of the system to be checked.

A diagram of the general layout of the observation equipment is shown on Fig. 9.101 and the observation desk is illustrated in Fig. 9.102.

The observation desk is normally installed in a small room adjacent to the main instrument room and is operated by specially trained staff. The information provided by service observations is analysed to provide statistics concerning the service offered by the network and the efficiency of the operating staff.

To gain access to the teleprinter circuits for observations to be made, the tapping relay sets are wired to jacks on the E.C.B. and these are patched to the TEST jacks of the lines nominated for observation. Normally a fresh batch of lines is connected to the tapping relay sets periodically in accordance with a prearranged programme notified

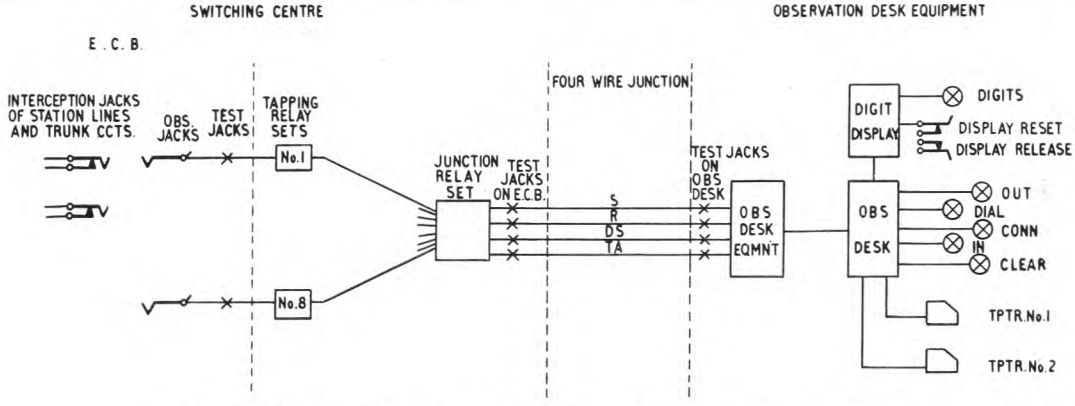


FIG. 9.101. GENERAL LAYOUT OF SERVICE OBSERVATION EQUIPMENT

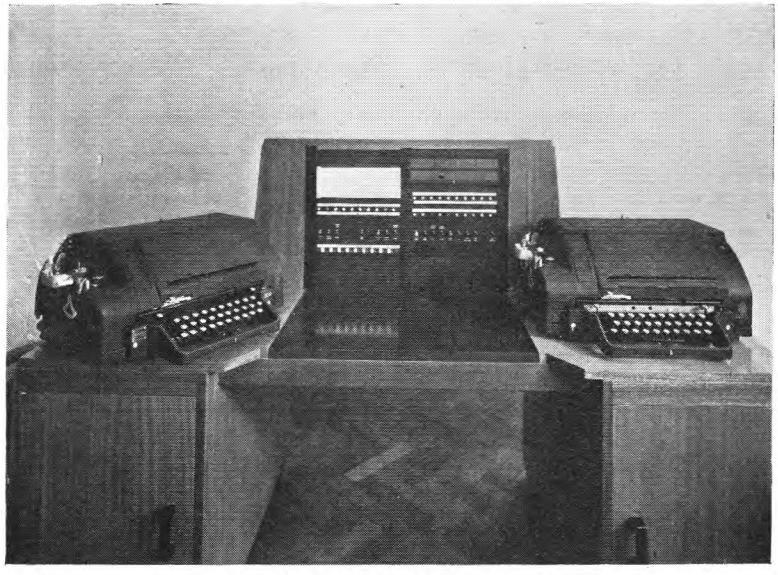


FIG. 9.102. OBSERVATION DESK
(By courtesy of H.M. Postmaster-General)

to the maintenance staff. Eight tapping relay sets are provided, permitting eight circuits (trunks and/or station lines) to be connected for observation at any one time. The tapping relay sets feed the monitored signals to the junction relay set and thence via a four wire junction to the observation desk. The monitoring circuits employ thermionic valves to enable a high tapping impedance to be used, thereby avoiding the attenuation and mutilation of working signals.

The functioning of the equipment is briefly as follows. To open the desk for service the DESK OPEN and OBS CONN keys are operated. The first tapping relay set to monitor an originating call immediately seizes the junction relay set which is busied to the remaining tapping relay sets. The junction relay set feeds the signals to the desk equipment to light lamps on the display panel of the observation desk to indicate to the observing telegraphist the following information.

(*a*) The number of the tapping relay set engaged. (Temporary labels are fitted to show the designation of the circuit associated with each tapping relay set.)

(*b*) Whether the call is incoming or outgoing.

(*c*) The transmission of the "proceed to select" signal.

(*d*) The digits dialled. A maximum of eight digits can be displayed by means of lamps mounted behind numbered stencils.

(*e*) The transmission of the "call connected" signal.

(*f*) The transmission of the clearing signal.

In addition to the lamp displays, two teleprinters are provided for monitoring teleprinter signals.

The observing telegraphist is provided with a stop watch and a chart for recording salient points regarding each call monitored. The information recorded includes particulars of ineffective calls and the reason for the calls failing, e.g. busy conditions, faulty lines, mis-dialling by the calling telegraphist, etc., and information regarding the time taken to set up the connexion and to transmit the message, etc. In addition, by comparing the tape from the monitoring teleprinter with the original message it is possible to check the accuracy of the keyboard operation.

The keys on the observation desk provide the following facilities.

(*a*) *Desk Open.* This key connects the heater supply to the valves in the monitoring circuits.

(*b*) *Observation Connect.* This key connects the observation desk to the four wire junction and its operation is normally delayed until 30 sec after the operation of the DESK OPEN key in order to allow the valve heaters to warm up.

(*c*) *Display Reset and Release.* This key provides for extinguishing and relighting the digit display during the course of an observation.

(*d*) *Observation Manual Release.* This key is operated after a call has been completed to clear down the display and to reopen the desk for a new call.

(*e*) *Automatic Release.* This key, which is combined with the OBS M/RLSE key, provides facilities so that when a call under observation is cleared the display is extinguished and the desk automatically opened for further traffic.

(*f*) *Camp On.* This key enables a circuit selected in the normal course of observation to be locked to the junction relay set so preventing other tapping relay sets from switching. This enables the selected circuit to be continuously observed.

(*g*) *Duplex.* This key enables the signals in the two directions of transmission to be recorded on separate teleprinters.

(*h*) *Teleprinter Continuous Run.* By operating this key the teleprinter motor can be run continuously. This minimizes motor brush wear when observing on busy circuits. Normally the observation desk teleprinter motor starts and stops at the beginning and end of each observed call.

(*i*) *Teleprinter No. 2.* For simplex connexions, only one teleprinter is used to record the answer back code and service indications such as MOM as well as the message. By means of the TPTR No. 2 key the second teleprinter is switched into circuit in place of the first teleprinter.

(*j*) *Circuit Select.* This key provides facilities for camping on to a nominated circuit without having to wait for that circuit to seize the junction relay set in the normal manner. To do this, the OBS CONN key is restored to normal and the CAMP ON key is operated. The CIRCUIT SELECT key is then repeatedly operated to step the junction relay set to the required tapping relay set, as indicated by the lamp display on the observation desk. The OBS CONN key is then re-operated.

In addition to the foregoing keys, facilities are also provided to give an alarm in the event of paper failure on the monitoring teleprinter and testing facilities are provided to assist maintenance of the desk equipment.

Trunking of Typical Switching Centres

The various components of switching equipment have now been discussed, their functions have been explained and the method of association for the routing of straightforward calls has been described. It is now necessary to consider the complete trunking of typical switching centres.

Types of Switching Centre. Centres are classified

either as Zone or Area switching centres. Zone centres provide tandem switching facilities for the completion of calls between switching centres not interconnected by direct trunk routes. Area centres are not used for tandem switching.

The Zones Centres are selected from among the larger switching centres and are judiciously located in the network so that any pair of teleprinters may be interconnected by a transmission path whose maximum distortion is within prescribed limits (see Chapter 6).

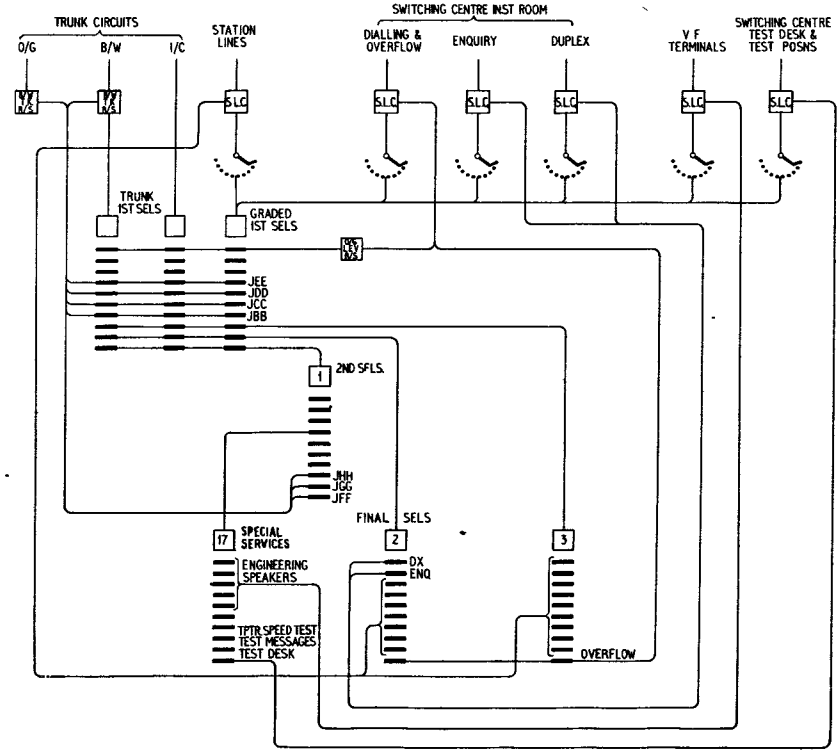


FIG. 9.103. AREA SWITCHING CENTRE: TYPICAL TRUNKING

Area Switching Centre Trunking. The trunking arrangements for a typical area switching centre are shown in Fig. 9.103. It will be seen that a three digit numbering scheme is employed for station lines obtained via the two final selector units.

Trunk Routes to Other Switching Centres. Access to other switching centres is obtained via first and second selector levels by means of single and two digit codes respectively. The point of insertion of Bothway Trunk Relay Sets into "Outgoing Only" and "Bothway" Trunks is clearly illustrated. The level multiples of trunk first selectors terminating "Incoming Only" and the incoming side of "Bothway" trunks are commoned to the level multiples of graded first selectors serving station lines. If access to trunk routes, final selectors and other services could be obtained from first selector levels, then second selectors would not be provided.

Main Switching Centre Instrument Room. Level "O" of first selectors provides direct dialling access via Outgoing Selector Level Relay Sets to the teleprinter positions in the main instrument room associated with the switching centre. The Overflow level (level 1) of both final selector units is teed to the same outlets to route overflow traffic to the instrument room teleprinters.

Inquiry Positions. A separate group of teleprinter positions shown connected to final selector level 29, is provided to deal with inquiry and similar traffic. Suspense and Overflow facilities on these circuits are unnecessary.

Duplex Positions. Under breakdown conditions, or in the event of unusually heavy traffic due to emergency or to other causes, it would clearly be desirable to be able to set up the equivalent of point-to-point circuits between instrument rooms as required, and to operate these connexions on a duplex basis. To facilitate the disposal of traffic under these and similar conditions, a separate

group of Duplex positions can be provided in the instrument room of certain important offices. Access to these positions, which are not provided with Suspense and Overflow facilities, is made via specially allocated final selector levels.

Special Services. It will be seen that a group of Special Services Final Selectors is terminated on level 17 of second selectors. These selectors provide access to services introduced principally as maintenance aids. In addition to the teleprinter speed

Auxiliary Overflow Centres. It will have been observed that at Area switching centres the overflow levels of all final selector units are connected to a common group of positions in the main instrument room; usually the normal dialling positions. The main instrument room thus becomes the night-service centre or "night-appointed" office for all station lines served by the switching centre. Thus when an office closes for the night (or at other times) and the station lines are placed out-of-

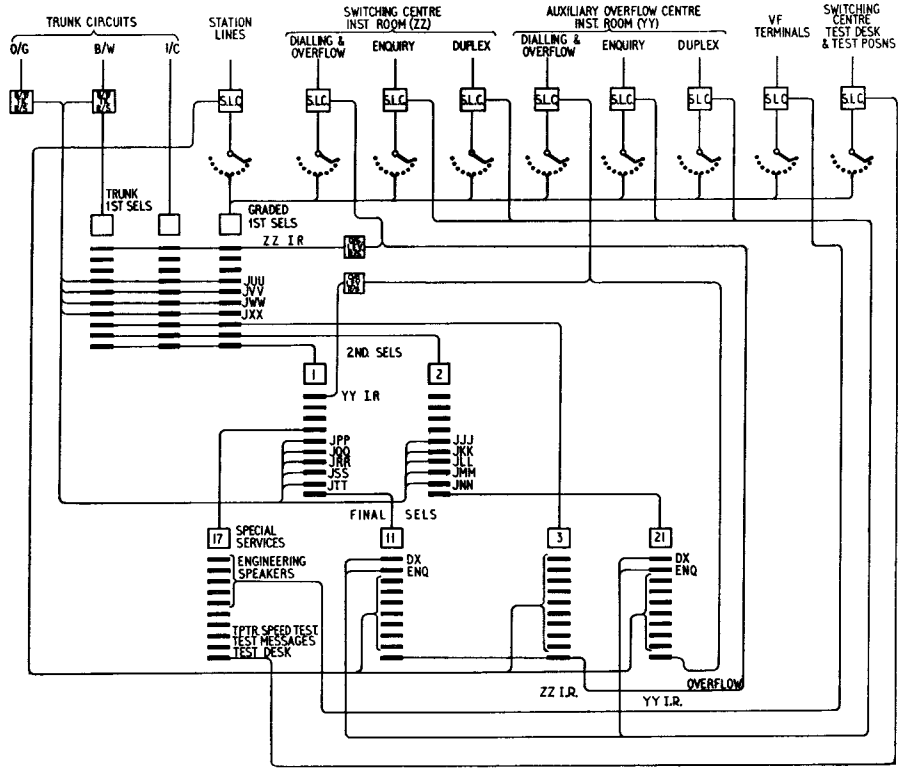


FIG. 9.104. ZONE SWITCHING CENTRE: TYPICAL TRUNKING

test signal and the range of distorted test messages, access is given to lines serving switching centre engineering test positions, the Test Desk, if provided, and also to V.F. terminals associated with the switching network.

Zone Switching Centre Trunking. The trunking of a typical Zone switching centre is shown in Fig. 9.104. The similarity to the Area centre trunking scheme shown in Fig. 9.103 will be readily observed. A mixed three and four digit numbering scheme for station lines is illustrated. Three final selector units are used, one directly from a first group selector level, the others from second group selector levels.

service, all incoming calls are routed to the "night-appointed" office. The service area of a Zone switching centre is generally far more extensive than an area switching centre and may include several "night-appointed" offices. To facilitate the handling of overflow traffic at all times, including night traffic, Auxiliary Overflow Centres have been established. An Auxiliary Overflow Centre is usually one of the larger instrument rooms not directly associated with an adjacent switching centre, but well situated to serve as "night-appointed" office for smaller offices in the vicinity.

By providing separate final selector units to serve the offices in the "night-appointed" office area, the

overflow traffic from these offices is segregated from other switching centre overflow traffic and routed to the appropriate Auxiliary Overflow Centre. Normal access to the Auxiliary Overflow Centre is usually obtained via a two digit code, the outlets being teed to the appropriate final selector overflow level. Instrument room *YY* in Fig. 9.104 clearly illustrates this principle. It will be seen that provision can be made for separate groups of Duplex and Inquiry positions if required.

Gradings, Grading Charts, and Trunk Distribution Frame. The method of interconnecting successive ranks of selectors and of providing access to circuit groups by means of gradings has been described in an earlier section. The gradings are formed on a trunk distribution frame (T.D.F.) similar to that shown in Fig. 9.105.

The bank contacts of uniselectors and first and second group selectors are cabled to the T.D.F. and terminated on horizontal strips of grading tags, the grading connexions being made by vertical straps of bare tinned copper wire. The graded outlets are cross-connected by flexible "jumpers" to the incoming side of the successive selector or relay set, either directly if terminated on another T.D.F. tag strip or via a tie cable to the Intermediate Distribution Frame (I.D.F.).

Grading Charts similar to Fig. 9.106 are mounted in glass-fronted frames, secured at a convenient height to the rack carrying the equipment concerned, to facilitate call tracing and fault location.

Rack Construction, Cabling, etc. A detailed description of rack construction, cabling methods and other similar aspects of trunking is beyond the scope of this book. The equipment used throughout the Teleprinter Automatic Switching System is standard B.P.O. 2,000 type. The more detailed treatment of 2,000 type equipment which is given in *Traffic and Trunking Principles in Automatic Telephony* by G. S. Berkeley, applies broadly to the teleprinter switching equipment.

Basis of Provision of Lines and Switching Plant. The automatic switching system has to fulfil two main functions. Firstly, to provide a more rapid and efficient means of transmitting telegraph traffic from one office to another than was hitherto possible; secondly, to achieve a substantial direct economy in the cost of handling traffic. To attain these objectives it is necessary to lay down bases of provision of lines and switching plant which, although providing an economic network, do at the same time ensure a minimum delay in establishing calls due to inadequacy of plant provision.

Reference has been made to the gradual decline of Public Service Telegraph traffic in the U.K. over the past 20 years and since this tendency is expected to continue, little or no provision for growth has been made in the U.K. Network. The seasonal character of inland telegraph traffic has already been stressed. The provision of automatic switching and terminal equipment on a "seasonal pressure" basis is both uneconomic and impracticable. Peak traffic requirements have thus received close

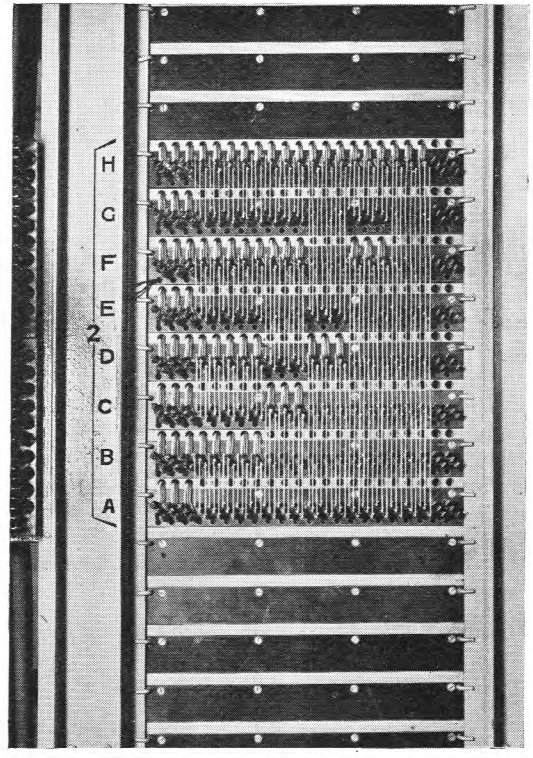


FIG. 9.105. TRUNK DISTRIBUTION FRAME
(By courtesy of H.M. Postmaster-General)

consideration in determining the bases of provision for both switching equipment and circuits. These will now be defined.

Lines to Teleprinter Offices. The Station Line Circuits connecting teleprinter offices to the switching centre equipment are provided on a bothway basis for routes of from 1–20 circuits. Requirements in excess of 20 are met by division into uni-directional and bothway components.

Table 9.6 shows examples of the traffic loadings which are used in determining the scale of circuit provision to teleprinter offices with suspense facilities.

The estimates of messages overflowed and delayed are based on assumptions which it is known are not strictly fulfilled in practice. These include

the holding time of messages and the manner in which individual holding times depart from the mean; the extent of batching, i.e. the transmission of more than one telegram per call; the proportion of traffic which originates at the teleprinter end of the circuit; and the effect of the overflow centre

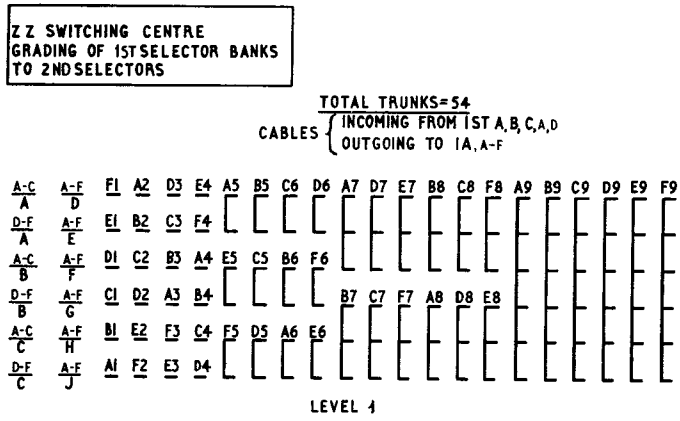


FIG. 9.106. TYPICAL TRUNKING CHART

offering overflow traffic to the station since this tends to further destroy the pure chance character of the traffic offered. (See later paragraph.) However, in spite of these factors, some of which are extremely complex to allow for in a practical

TABLE 9.6

Basis of Provision of Station Lines with Suspense Facilities

No. of Lines	No. of "Wait" Contacts	Messages	Erlangs	Percentage of Messages Incoming to Teleprinter Office		Average delay on Delayed Calls (Sec)
				Overflowed	Delayed	
1	1	18	0·3	8·4	21·6	34
2	1	42	0·7	4·7	13·3	26
3	1	69	1·15	4·0	9·0	15
4	1	99	1·65	2·2	7·8	12
5	2	140	2·33	2·1	6·1	9
7	2	216	3·6	1·5	4·5	5
10	2	324	5·4	1·1	2·9	3

system, the table affords a satisfactory basis for circuit provision.

This table can also be used to estimate the volume of overflowed traffic which must be handled at the overflow centre and to estimate the average increase in call duration due to the suspense facility. This is in general found to be extremely small (about 0·6 sec per call on average) and, therefore, does not materially affect the loading of the operators or the provision of trunk circuits and switching equipment.

Station Lines from Group Selector Levels (e.g. *Switching Centre Main Instrument Room*). Delayed hunting facilities are not provided on these circuits. Since the instrument room and associated switching centre equipment are generally in proximity, normally within the same building, the cost of line provision is not an important factor. These circuits are provided to afford a Grade of Service of 0·002 (Availability 20). A standard Traffic Capacity Table is used for this purpose. In most switching centres this group of lines also carries overflow traffic from the first (overflow) level of the Final Selector Units in the switching centre; at the same Grade of Service.

If the aggregate volume of overflow traffic is considerable, the provision of a separate group of overflow circuits, also at a Grade of Service of 0·002, may be contemplated.

Trunk Circuits. The economic advantages of an automatically switched network, achieved by the elimination of retransmission, would be reduced if a significant number of repeat calls were necessitated by insufficiency of plant.

Taking into account the comparatively low cost of providing telegraph circuits on M.C.V.F. systems, the main trunk routes interconnecting switching centres are provided to a design Grade of Service of 0·02. The standard Traffic Capacity Table for an availability of 20 is reproduced in Table 9.1.

Routes not exceeding 20 circuits are provided on a bothway basis. Routes in excess of 20 circuits are partially divided into incoming, outgoing and bothway components, gradings being employed when necessary.

Switching Equipment. The proportion of the total cost of handling inland telegraph traffic represented by the switching equipment is small. For this reason and those stated at the commencement of the previous paragraph, switching equipment was provided initially at a Grade of Service of 0·001. Standard Traffic Capacity Tables corresponding to an availability of 20 and 24 are reproduced in Tables 9.2 and 9.3.

Smoothing Effect of Limited Traffic Sources. For design purposes telegraph traffic has been assumed to exhibit "pure chance" characteristics; an assumption which would be valid if the number of

traffic sources was large. However, the number of traffic sources associated with Inland Teleprinter Automatic Switching Centres is small; the volume of traffic originated per line being comparatively large. Typical practical examples found in the U.K. network are as follows—

Switching Centre A: 35 sources originating a total of 6 Erlangs.

Switching Centre B: 70 sources originating a total of 20 Erlangs.

Switching Centre C: 180 sources originating a total of 40 Erlangs.

The effect of this limited number of comparatively heavily loaded sources is to introduce an element of smoothing into the originated traffic, a tendency which is increased at each switching stage. It is well known that the "smoother" the traffic the fewer the number of trunks required to carry a given volume of traffic at the same Grade of Service. The existence of this element of smoothing is revealed by the results of traffic records, but Pure Chance Traffic Tables are nevertheless employed in estimating switching equipment and circuit quantities.

Maintenance of Grade of Service. Although the overall volume of traffic handled by the network is falling annually, a watchful eye must be kept on the Grade of Service since local increases may occur because of plant rearrangements or other reasons. Before additional plant is brought into use, the grade of service at a particular switching stage is allowed to fall to a value termed the Critical Grade of Service. This is normally a worse grade of service than that with which the plant is initially provided. For example, plant provided to give a grade of service of 1 in 500 normally has a critical grade of service of 1 in 200.

Three methods of checking the Grade of Service are provided by—

1. Determination, by eleventh step or Overflow

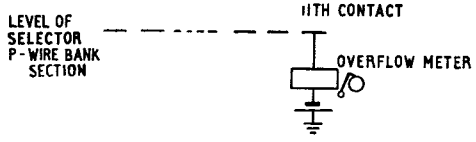


FIG. 9.107. CONNEXION OF OVERFLOW METER

Meters, of the traffic failing to find a free trunk circuit or selector in a group.

2. Determination, by Late Choice Call (L.C.C.) and Late Choice Unit (L.C.U.) Meters, of the traffic carried by the last selector in a uniselector grading.

3. Determination, by Automatic Traffic Recorder, of the traffic carried by a group of trunk circuits or selectors.

Overflow Meters. An overflow meter is an electrically operated Veeder type meter which is connected to the *P* wire of the eleventh step contact of group selector levels serving trunk routes or succeeding selector ranks. The method of connexion is shown in Fig. 9.107.

When a selector steps to a particular level and, after hunting round the bank, fails to find a free outlet, the wipers rotate to the eleventh set of bank contacts. The earth condition extended over the selector *P* wiper operates the overflow meter which registers one lost call, an appropriate service signal being returned to the calling line. The meter remains energized until the call is released.

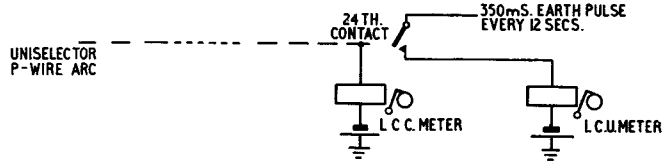


FIG. 9.108. CONNEXION OF L.C.C. AND L.C.U. METERS

To simplify the use of overflow meter readings it is necessary to determine the number of overflow meter operations (i.e. the number of lost calls) corresponding to the persistence of critical grade of service conditions for a given period, usually the Busy Hour. This number of lost calls is termed the Critical Overflow. If a group of 25 selectors has a capacity of 14·5 Erlangs at the critical grade of Service (0·005), the Critical Loss will be—

$$14{\cdot}45 \times 0{\cdot}005 = 0{\cdot}072 \text{ Erlangs.}$$

Since the average call duration has been taken as one minute—

$$\text{Critical Overflow} = 0{\cdot}0072 \times 60 = 4{\cdot}32.$$

Thus if five or more calls are overflowed during the Busy Hour, the Grade of Service afforded by the group of 25 selectors is worse than 0·005.

Tables of Critical Overflow readings, equivalent to various Critical Grades of Service are available.

Late Choice Call (L.C.C.) and Late Choice Unit (L.C.U.) Meters. Since the equivalents of eleventh step contacts are not available on uniselectors, Overflow Meters to determine the number of calls failing to find a free graded first selector cannot be provided. Instead, a pair of meters is associated with the last outlet of the grading to measure the volume of traffic carried by this selector. The arrangement is illustrated in Fig. 9.108.

The Late Choice Call Meter operates each time the outlet is seized and will thus record the number of calls carried by the selector. The meter remains

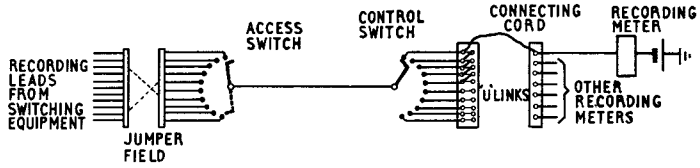


FIG. 9.109. AUTOMATIC TRAFFIC RECORDER: SIMPLIFIED SCHEMATIC

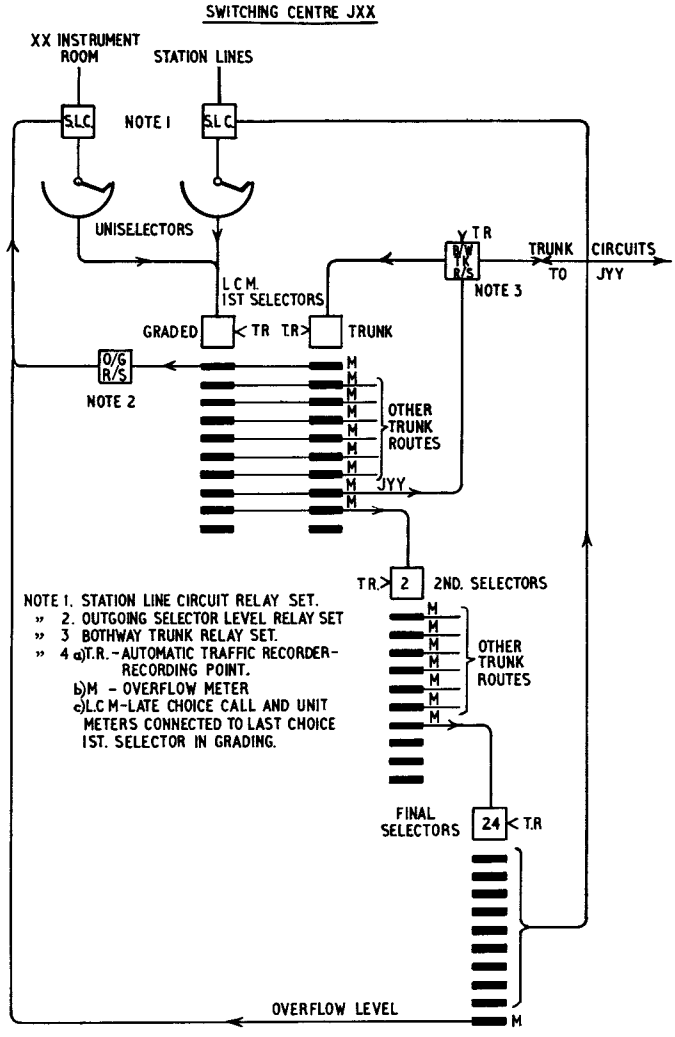


FIG. 9.110. PROVISION OF TRAFFIC METERS AND TRAFFIC RECORDING POINTS

operated for the duration of each call. The auxiliary contact of the L.C.C. meter completes a circuit from a source of 12 sec earth pulses to the L.C.U. meter, which thus operates once every 12 sec for the duration of each call. Clearly the L.C.U. meter reading divided by 300 will be numerically equal to the traffic carried in Erlangs—

$$\frac{\text{L.C.U.M. reading}}{300} = \text{traffic carried (Erlangs)}$$

Direct observation of the Grade of Service is facilitated by the determination of the number of calls carried by the last outlet and the number of 12 sec periods for which the last trunk is engaged when the traffic offered to the group of selectors is appropriate to the Critical Grade of Service. These factors are called the Critical Late Choice Call and Critical Late Choice Unit meter readings.

$$\text{Critical L.C.C. Meter Reading} = \frac{\text{Traffic carried by Last Choice (Erlangs)}}{\text{Average call duration (mins)}} \times 60$$

$$\text{Critical L.C.U. Meter Reading} = \text{Traffic carried by Last Choice (Erlangs)} \times 300$$

Thus for the T.A.S. system—

Critical L.C.U. Meter Reading

$= 5 \times$ Critical L.C.C. Meter Reading.

Tables of Critical Meter Readings, equivalent to a Grade of Service of 0·005, are available.

Automatic Traffic Recorder. This provides a means of determining the average number of selectors or circuits forming a group that are engaged over any period and thereby constitutes a direct means of measuring the traffic carried by the group.

Each group of selectors or circuits is tested every 12 sec, the number found engaged on each test being recorded on Veeder type meters. A further meter, called the Test Cycles Meter, records the number of tests made. By simple division, the average number of selectors or circuits engaged is obtained. This figure is numerically equal to the traffic carried in Erlangs.

The short testing interval of 12 sec has been chosen because the average call holding time of telegraph traffic is only 60 sec. The equivalent testing interval for most telephone switching equipment is 30 sec. This corresponds to an average telephone call duration of about 3 min. The proportionate error in both cases is small.

A comprehensive description of the Automatic Traffic Recorder is given in *Telephony* Vol. II by J. Atkinson. For the present purpose the following brief outline will suffice.

Traffic recording leads from the switching equipment are terminated on the banks of Access Uniselectors. The wipers of these switches are cross-connected to the wipers of Control Uniselectors, with the bank contacts of which are associated the recording meters. When the wipers of Access and Control Uniselectors interconnect a recording lead marked with an engaging earth and a recording meter, the meter operates once. A simplified sketch of the arrangement is shown in Fig. 9.109.

The following categories of switching equipment are connected to the Automatic Traffic Recorder—

1st Group Selectors.
2nd Group Selectors.
Final Selectors.
Bothway Trunk Relay Sets.

The capacity of the Automatic Traffic Recorder provided at each switching centre is governed by the quantity of switching equipment to be observed. Sufficient access and control equipment is installed to permit a Complete Traffic Record to be carried out simultaneously on all switching equipment.

Provision of Traffic Meters and Traffic Recording Points. The basis of provision of Overflow, L.C.C. and L.C.U. meters and Automatic Traffic Recording points, is illustrated in Fig. 9.110.

Frequency of Traffic Records. The incidence of traffic records is influenced by the seasonal traffic variations. Generally a national traffic record is taken immediately before Christmas when the national traffic peak occurs. If necessary, further records are taken before the August Bank Holiday period which is another traffic peak, especially for offices serving holiday centres. Records are also taken when tariff changes are made or new services introduced which are likely to have a significant effect on traffic levels. Normally, traffic records are taken between 10.30 a.m. and 12 noon to ensure that the busy hour traffic is recorded.

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2. *Traffic and Trunking Principles in Automatic Telephony*, by G. S. Berkeley.

CHAPTER 10

MULTI-CHANNEL VOICE-FREQUENCY TELEGRAPH SYSTEMS

THE ability to use a common form of line plant for telephone and telegraph purposes has important technical and economic advantages and greatly improves the flexibility of the services provided. Voice-frequency transmission of telegraph signals enables these advantages to be secured and has been developed so that it offers a standard form of telegraph circuit having a stable performance, which is largely independent of distance and readily interchangeable with other circuits of the same type.

Several early attempts were made to use alternating currents for telegraph transmission but were not commercially successful due to lack of suitable means for amplification and rectification of the signals. Between 1924 and 1931 traffic trials were made by the B.P.O. with two types of six-channel voice-frequency equipments; one, manufactured by Messrs. Siemens and Halske of Berlin, which employed a valve oscillator for each transmitting channel, and the other manufactured by the General Electric Co., which used a valve maintained tuning fork for the same purpose.

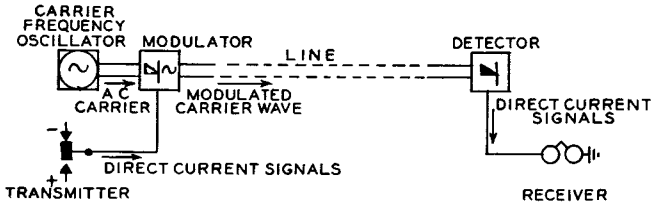


FIG. 10.1. ELEMENTARY SINGLE-CHANNEL VOICE-FREQUENCY TELEGRAPH SYSTEM

Carrier frequencies for use in multi-channel voice-frequency telegraph systems were standardized by the C.C.I.T. in 1931, in which year the engineers of the transmission systems group of Standard Telephones and Cables, Ltd., had brought a multi-channel system, based on these frequencies, to a high state of development. Field trials of this equipment resulted in its adoption as the standard of the B.P.O. and a programme of conversion of the telegraph network to voice-frequency working was commenced in 1931 and carried through to completion by 1936/1937. During the same period similar developments were taking place in the U.S.A. and, on a smaller scale, in Germany.

General Principles. The simplest form of voice-frequency telegraph communication is provided by a single-channel system for which the principal requirements are—

(*a*) A source of voice-frequency alternating carrier current.

(*b*) A keying device, whereby this voice-frequency carrier current is modulated by the transmitted telegraph signals.

(*c*) A line over which the modulated signal can be transmitted.

(*d*) A detector, in which the received signals are converted into direct current impulses to operate the receiving instrument.

Such a system is shown diagrammatically in Fig. 10.1.

The signals at the output of the modulator have an envelope of square form and therefore contain a series of sine wave components comprising the carrier frequency and upper and lower side-band frequencies, as explained in Chapter 1. In the case of a single-channel system having exclusive use of a transmitting line there is no necessity to restrict the band of frequencies transmitted and the side-band frequencies are only limited by the upper and lower cut-off frequencies of the line. It is possible, however, to transmit the telegraph signals quite successfully within a restricted band-width providing the latter permits the transmission of the side-band frequencies corresponding to the highest fundamental frequency of the telegraph signals. Thus, as explained in Chapter 5, the minimum band-width required for the transmission of amplitude modulated V.F. telegraph signals is equal to the speed of transmission in bauds, e.g. 50 c/s band-width is adequate for 50 baud telegraph signals.

In practice the effective frequency pass band of telephone cable circuits range commonly from a frequency of 300 c/s up to 2,000–3,400 c/s depending upon the type of plant employed. It is therefore possible, by frequency-division of the pass band of a normal telephone line, to accommodate a number of V.F. telegraph channels, the number depending upon the effective band-width of the telephone circuit and the maximum speed of signalling desired in the individual telegraph channels. This is the basic principle employed in M.C.V.F. telegraphy and it enables substantial economies to be effected in the cost of provision of telegraph circuits.

The accommodation of a number of channels on a single line requires that each shall work within a defined frequency band symmetrically disposed about a carrier frequency allotted to it, the carrier frequencies being chosen so that the working frequency bands do not overlap.

The outputs of the modulators require to be connected to the common line so that each is matched individually to the line impedance and so that interaction between the modulators is prevented, i.e. each must appear as a high impedance to the remainder. This is generally achieved by inserting a band-pass filter between each modulator and the line, the filters being designed to match the line at the carrier frequency and to present a high impedance outside their pass-band. Similar filters are connected at the receiving end between the line and each detector, so that the latter only responds to the signals intended for it.

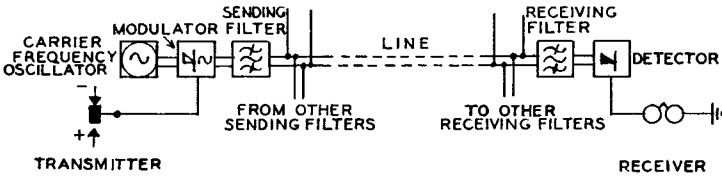


FIG. 10.2. A CHANNEL IN A MULTI-CHANNEL VOICE-FREQUENCY TELEGRAPH SYSTEM

A channel in a multi-channel voice-frequency telegraph system is shown schematically in Fig. 10.2.

Standardization of Frequencies and Band-width for Multi-channel Voice-frequency Telegraph Systems. The factors affecting the choice of frequency spacing for a M.C.V.F. telegraph system are fully discussed in Chapter 5, p. 150. With a view to facilitating international working the C.C.I.T. in 1929 standardized the speed of the teleprinter at 50 bauds which is equivalent to a maximum operating speed of 66 words per minute. On this basis and having in mind the factors referred to above, the C.C.I.T. in 1931 also standardized the spacing of the carrier frequencies to be used for M.C.V.F. telegraph working. For this purpose the C.C.I.T. recommended the use of the series of frequencies formed by uneven multiples of 60 c/s, the lowest frequency being 420 c/s. Thus the carrier frequencies are spaced at 120 c/s and those employed in an 18-circuit system, i.e. a system comprising 18 Send and 18 Receive channels, are shown in Table 10.1.

Allowing for the side-bands of the lowest and highest channels, the total frequency range required for an 18-circuit system is 360–2,520 c/s and thus this type of system may be operated over the types of telephone circuits available on all long distance routes. This arrangement provides for 18 channels working in a single direction over a two-wire circuit and it is usual to employ two such systems, working in opposite directions on the two pairs of a four-wire circuit, to obtain 18 telegraph circuits. Alternatively, it is possible to provide 9 circuits on a two-wire line, using different frequencies in the two directions of transmission.

Modern carrier cable circuits enable telephone circuits to be provided having a band-width extending from 300–3,400 c/s and it is thus possible to accommodate a greater number of V.F. telegraph circuits within this frequency band. The C.C.I.T. envisages that in such cases, as many as 24 channels can be operated simultaneously in each direction.

The telegraph carrier line frequencies employed for the additional channels 19–24 are also shown in Table 10.1.

TABLE 10.1

C.C.I.T. Standard Frequencies for use in Multi-channel V.F. Telegraph Systems

Channel No.	Carrier Frequency c/s.	Channel No.	Carrier Frequency c/s.
1	420	13	1860
2	540	14	1980
3	660	15	2100
4	780	16	2220
5	900	17	2340
6	1020	18	2460
7	1140	19	2580
8	1260	20	2700
9	1380	21	2820
10	1500	22	2940
11	1620	23	3060
12	1740	24	3180

Power Levels and Lines. The power transmitted to line on each channel is limited by practical considerations. On the one hand it is desirable to maintain the power at as high a level as possible, to minimize the effect of cross-talk interference from neighbouring circuits, (in other words to obtain a high signal/noise ratio). On the other hand, the power must not be so high as to interfere with neighbouring circuits and channels, or to produce overloading of line amplifiers and thus cause distortion of the signal wave-form as a result of the production of harmonics. To minimize interference with neighbouring circuits, it is

necessary to limit the total power transmitted in the system to a safe value; the power in the individual channels being so determined that the overall limit is never exceeded.

If the maximum instantaneous power permitted at a point in a multi-channel system is W watts, and the system comprises N channels working into a line of characteristic impedance Z, the maximum voltage E across the line impedance is obtained from the formula $W = \frac{E^2}{Z}$

so that $E = \sqrt{WZ}$.

This condition occurs when the carrier frequencies reach their peak amplitudes simultaneously. The maximum permissible voltage e per channel, is then $\frac{E}{N} = \frac{\sqrt{WZ}}{N}$, and the maximum permissible power (w) per channel is given by—

$$w = \frac{e^2}{Z}$$

$$= \left(\frac{E}{N}\right)^2 \times \frac{1}{Z} = \frac{WZ}{N^2} \times \frac{1}{Z} = \frac{W}{N^2} \text{ watts.}$$

The maximum power permissible in a M.C.V.F. telegraph system has been standardized by the C.C.I.T. at 5 mW, measured at a point in the line equivalent to telephone zero. For an 18-channel system therefore, the maximum power per channel is $\frac{(5 \times 10^{-3})}{18^2}$ W, i.e. 15 μW, measured at a point equivalent to telephone zero. The use of this power enables telegraph systems to be operated on standard telephone trunk circuits with negligible interference from, or with, neighbouring circuits.

A convenient arrangement, which is used in the B.P.O. network, is to work a multi-circuit telegraph system over a four-wire circuit which is identical with the four-wire portion of a telephone circuit between the terminal offices. This arrangement facilitates provision and maintenance work and has the important advantage that the four-wire portion of a standard telephone circuit is suitable, without readjustment, for use as a reserve line for the telegraph system, in the event of failure of the normal main telegraph line. Long distance telephone circuits are generally lined up to have a transmission equivalent of zero, measured between the two-wire ends of the 4W/2W terminations. The 4W/2W termination at each end introduces a loss of approximately 4 db, hence the input to the sending terminal amplifier is at a point — 4 db relative to zero telephone level, and the output of the receiving terminal amplifier is at a point + 4 db relative to zero telephone level. The power per channel at the input to the sending terminal amplifier must therefore not exceed 6 μW (i.e. 4 db below 15 μW), in the case of 18-channel systems and it is the practice in B.P.O. systems to limit the channel input power at this point to 4 μW, thus giving a margin of nearly 2 db below the permitted maximum. The power levels relative to zero telephone level, in a channel of an 18-channel system as used by the B.P.O. are shown in Fig. 10.3 and the figures in brackets indicate the channel power corresponding to the various levels. Fig. 10.4 shows for comparison, in schematic form, an 18-circuit telegraph system and a corresponding four-wire telephone circuit.

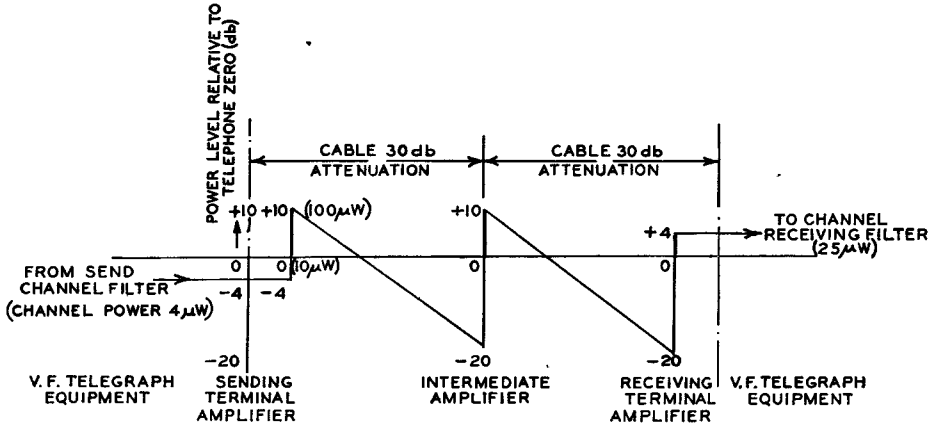


FIG. 10.3. CHANNEL POWER LEVELS IN AN 18-CHANNEL VOICE-FREQUENCY TELEGRAPH SYSTEM

The reason for the choice of 10 μW per channel, at a point corresponding to telephone zero, is that experience has shown that the slight decrease in

signal/noise ratio, caused by dropping the telegraph level below the 15 μW allowable by the C.C.I.T., is more than compensated by the resultant reduction in inter-channel interference due to cross modulation. Cross modulation arises chiefly from the non-linear characteristics of amplifier valves and loading coils and is accentuated by the use of high power levels.

In using a telephone circuit as a reserve line for a voice-frequency telegraph system, care is necessary to ensure that echo suppressors, where fitted, and voice-frequency signalling apparatus are disconnected when the reserve line is employed for telegraphy.

The constancy of output per channel from the receiving terminal amplifier is dependent upon the transmission equivalent (T.E.) of the four-wire line remaining unchanged. Changes in the T.E. are liable to occur on long amplified lines due to ageing of amplifier valves, variation in battery voltages at repeater stations and variation of characteristics of cables due to temperature changes. It is essential that V.F. telegraph systems shall tolerate the normal maintenance variations in line level which occur, without causing the signal distortion to become excessive, and for this purpose automatic compensation is provided in the V.F. telegraph receiving equipment. In the case of the standard B.P.O. 18-circuit equipment, the automatic gain control (A.G.C.) provided in the amplifier-detector circuit of the receiver will tolerate a range of line-level variations of 15 db, which is considerably more than should occur under practical conditions.

The B.P.O. Type 3 Amplitude-modulated 18- (or 24-) Circuit Voice-frequency Telegraph Equipment. This equipment, developed and manufactured by Standard Telephones and Cables, Ltd., England, is used extensively by the B.P.O. for the provision of 6-, 12-, 18- and, in a few cases, 24-circuit telegraph systems. It was originally designed to provide for a maximum of 18 sending and 18 receiving channels on one four-wire repeatered line. In recent years, however, due to wider band (i.e. 300–3,400 c/s) telephone circuits becoming more generally available, a need has arisen on some routes to operate Type 3 M.C.V.F. telegraph systems as 24-circuit systems. For 24-circuit working, channels 19–24 may be generated either as channels 1–6 (420–1,020 c/s) or as channels 7–12 (1,140–1,740 c/s) and the group of 6 channels is then frequency-translated, by group modulation with a carrier frequency of 3,600 or 4,320 c/s respectively, to the frequency band 2,580–3,180 c/s. The equipment required for a 24-circuit system therefore consists of that required for a standard 18-circuit system plus an additional 6 standard channels (i.e. channels 1–6, or 7–12) together with group modulating and demodulating equipment.

The channel equipment for one 18-circuit system is accommodated on three racks, each of which carries 6 channels, and it is thus convenient, when the maximum number of channels is not required, to provide either a 12-circuit or a 6-circuit system. The equipment is mounted on 10 ft 6 in. high racks, each 1 ft 8½ in. wide, and both sides of the rack are equipped with apparatus

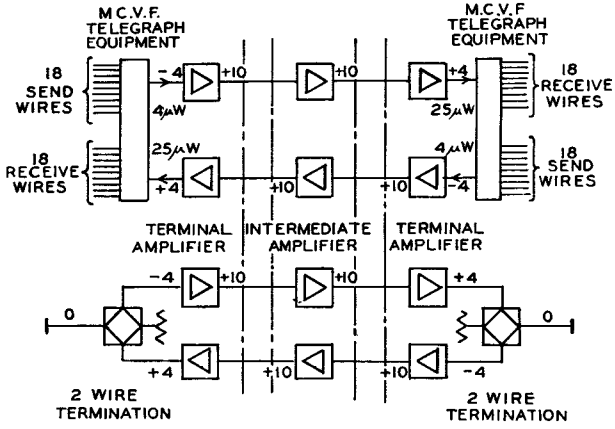


FIG. 10.4. COMPARISON OF POWER LEVELS USED IN A ZERO LOSS 4-WIRE TELEPHONE CIRCUIT AND AN 18-CIRCUIT M.C.V.F. TELEGRAPH SYSTEM

panels—an equipped rack is often called a "Bay" but the term "Rack" is now preferred.

Carrier frequency supplies and the necessary battery supplies to the channel equipment are distributed from a "Generator and Battery Supply Rack." The generators fitted on the generator rack will supply up to a total of ten 18-circuit systems, but the battery supply rack will cater for only five systems; thus a second battery supply rack is necessary when six to ten systems are required. Figs. 10.5 and 10.6 show the layout of equipment on a "Channel Rack" and a "Generator and Battery supply rack" respectively.

To provide for centralized testing and patching facilities (i.e. cross connexions by means of plugs and cords) on V.F. lines and channels and to the local lines and instruments connected thereto, a "Test and Special Apparatus Rack" is provided. This rack accommodates the jacks and other equipment sufficient for providing centralized testing and patching facilities on five 18-circuit systems and is also equipped with a Telegraph Distortion Measuring Set (T.D.M.S.)—for testing and lining-up the V.F. channels. When more than five 18-circuit systems are required in a V.F. terminal station a

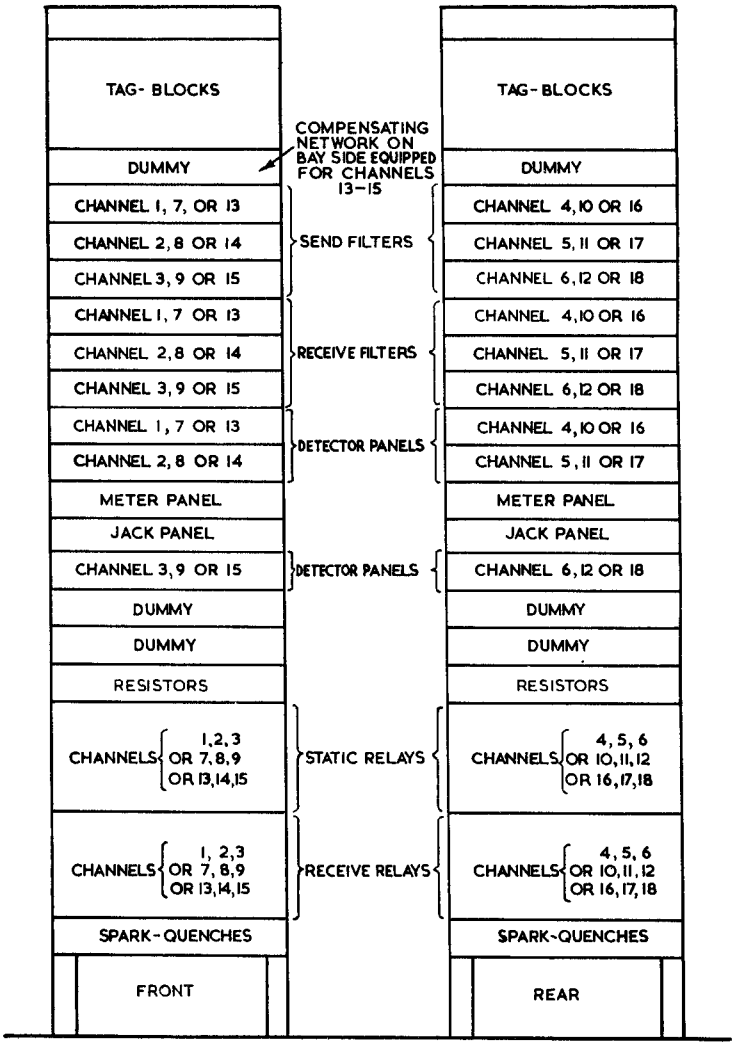


FIG. 10.5. B.P.O. TYPE 3 A.M. MULTI-CIRCUIT VOICE-FREQUENCY TELEGRAPH EQUIPMENT: EQUIPMENT LAYOUT ON A 6-CIRCUIT RACK

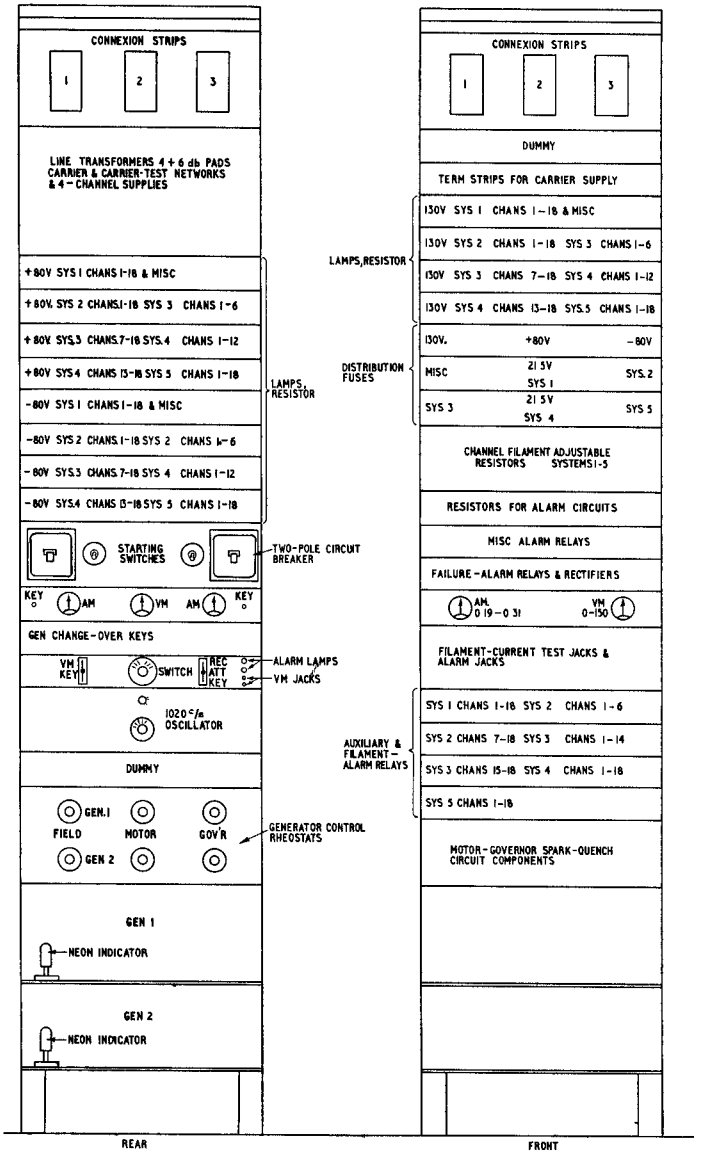


FIG. 10.6. B.P.O. TYPE 3 A.M. MULTI-CIRCUIT VOICE-FREQUENCY TELEGRAPH EQUIPMENT: EQUIPMENT LAYOUT ON A GENERATOR AND BATTERY SUPPLY RACK (FRONT AND REAR VIEWS)

"Special Apparatus Rack" (S.A.B. or S.A.R.) is required for systems 6 to 10 and each subsequent half group of five systems. This rack is similar to the Test and S.A. rack but is not equipped with a T.D.M.S. In practice it is usually found that one T.D.M.S. is adequate for all distortion testing operations on 30 systems. Fuller details of the equipment and use of the "Test and S.A. Rack" are given later in this chapter.

Carrier Supplies. The system obtains its carrier supplies from a motor alternator of special design having a d.c. motor working from the 160 V telegraph battery. In earlier designs a 24 V d.c. motor was used. The speed is controlled by means of a centrifugal governor and is maintained at 3,600 r.p.m. within limits of $\pm$ 0·25 per cent. The highest carrier frequency generated by the multi-frequency generator is 2,460 c/s, thus a motor speed error of 0·25 per cent will result in a carrier frequency error of 6 c/s on the 18th channel and this is the C.C.I.T. limit for M.C.V.F. systems operating over audio circuits. In the case of carrier circuits it is advisable that the frequencies of the telegraph carrier supplies should be controlled more closely and the C.C.I.T. in 1948 therefore recommended that a deviation of not more than 3 c/s from the nominal carrier frequency should be permitted. In recent years the B.P.O. has developed a refined form of governing, i.e. "valve controlled governing," which enables the speed to be controlled within much closer limits, viz. $\pm$ 0·1 per cent; details of this method are described later in this Chapter.

The alternator comprises 18 inductor alternators which produce the standard 18-channel carrier frequencies. The alternators have low internal impedance, good wave form and the output of each is adjusted within the limits $1 \pm 0{\cdot}05$ V. One multi-frequency generator supplies the carrier frequencies to a maximum of ten 18-circuit systems, carrier supply resistor pads being introduced in the individual feeds to each channel to prevent interaction between modulators on channels working at the same frequency on different systems.

Continuity of service is ensured by providing a second generator and change-over keys, the machines usually being run for alternate spells of duty of approximately two weeks. The carrier supply pad for each channel is tapped to provide a testing supply of 10 μW (— 20 db relative to telephone zero), this supply being made available on jacks on the appropriate channel rack. A rectifier voltmeter is provided on the generator rack and can be connected to any of the 18 outputs of either generator by means of a rotary switch, so that the output voltage can be verified readily. Adjustments to the output voltage of individual alternators are seldom necessary after the initial setting has been made, but slight readjustment of the common field excitation may be required on occasion. The multi-frequency generator is described in greater detail on page 343 and the carrier supply arrangements are illustrated in Fig. 10.7.

Modulation. The carrier supply feed to each channel is connected to the input of the sending

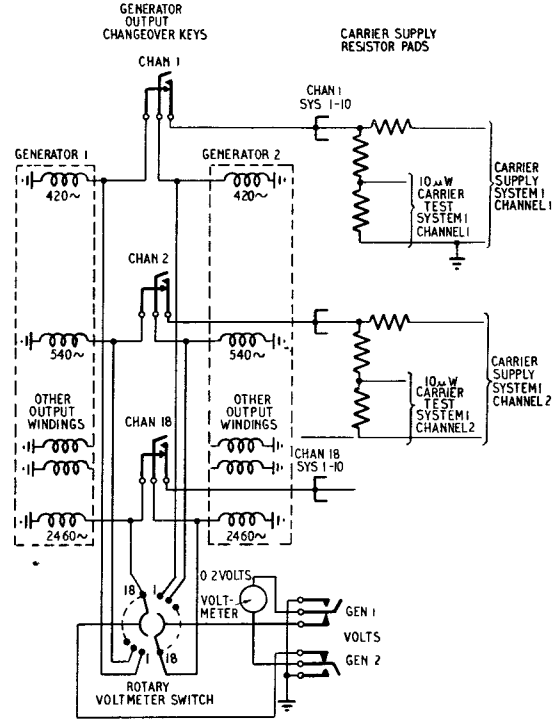


FIG. 10.7. B.P.O. TYPE 3 A.M. MULTI-CIRCUIT VOICE-FREQUENCY TELEGRAPH EQUIPMENT: DISTRIBUTION OF CHANNEL CARRIER SUPPLIES

filter via a modulator, which is controlled by double current signals from the telegraph transmitter. The circuit of the modulator is shown in Fig. 10.8 which also shows its relation to the remainder of the equipment. This type of modulator is usually called a "Static Relay" to differentiate it from the earlier form of send relay which was a polarized electromagnetic type. The static relay incorporates no moving parts and requires negligible maintenance attention, which is a great advantage. The operation of the modulator depends for its action upon the fact that the impedance of a copper oxide, or selenium rectifier, to a small alternating voltage may be controlled by the value and sense of a steady voltage on which the alternating voltage is superposed.

The voltage/current curve of a typical rectifier employed is shown in Fig. 10.9. When by reason of steady applied voltage, the rectifier is operating at points B or C shown in the curve, it offers a high impedance to the small alternating voltage which may be impressed upon it. When, however, the steady voltage applied is such that the rectifier conducts and its point of operation is moved to A, current flows in the rectifier bridge S. The rectifier elements then present their forward, i.e. conducting impedance, to the transformer T and this is very low. The equivalent impedance in the primary winding is $\frac{1}{100}$ of this value as the impedance ratio of the transformer is 100:1. Thus during spacing signals, the modulator operates as a low shunt impedance across the channel and so reduces the

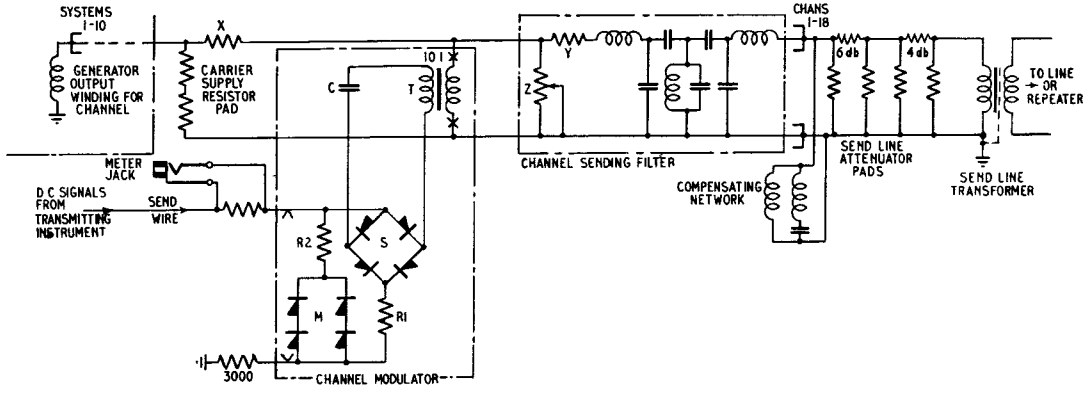


FIG. 10.8. B.P.O. TYPE 3 A.M. MULTI-CIRCUIT VOICE-FREQUENCY TELEGRAPH EQUIPMENT: SENDING CHANNEL EQUIPMENT

then its impedance to a small impressed alternating voltage is comparatively low.

Referring to Fig. 10.8 it will be seen that in the marking signalling condition, negative battery is connected to the send wire and a current flows in the rectifier network M and resistor R_2. The

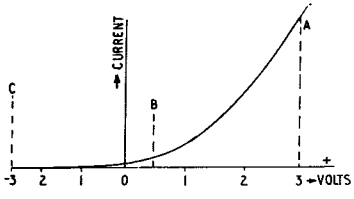


FIG. 10.9. TYPICAL VOLTAGE/CURRENT CHARACTERISTIC OF RECTIFIER ELEMENTS IN STATIC MODULATOR

voltage developed across these components is applied as a reverse voltage to the d.c. terminals of rectifier bridge S and exceeds the alternating voltage applied to the a.c. terminals of the bridge from transformer T. A reverse voltage is thus maintained across the rectifier elements, which consequently present a high impedance to the transformer so that very little carrier power is absorbed in the modulator. The attenuation due to the modulator in this condition, i.e. "marking loss," is approximately 1 db.

In the spacing condition, positive battery is connected to the send wire and the resulting voltage at the input of the sending filter and attenuates the signal, as measured at the output of the sending filter, by approximately 33 db—this is called the "spacing loss."

The modulator thus produces variations in the transmitted carrier of approximately 32 db, i.e. corresponding to variations in the power transmitted of the order of 1,500:1. That is to say that the carrier power transmitted when the modulator is spacing is approximately $\frac{1}{1500}$ of the power transmitted when marking.

Capacitor C prevents the circulation of direct current in the secondary winding which would otherwise occur due to unbalance between the elements of the rectifier bridge S. The build-up and decay of such a signal in the transformer would cause distortion of the signal envelope at the beginning and end of each signal.

Rectifier network M is made similar to the bridge S and resistors $R1$ and $R2$ are equal in value. This ensures that the d.c. characteristics of the modulator are such that for equal positive and negative values of signalling voltage, the corresponding values of spacing and marking current are equal. The advantage of this arrangement is that when signal reversals are transmitted for testing purposes, the presence of any bias is readily observable upon a centre-zero meter connected in the sending line. If no bias is present a zero reading will be given on the meter.

The type of telegraph modulator which has been described operates by virtue of its shunting effect on the circuit. If the send wire is disconnected there is no controlling current in the rectifier networks and a leakage path exists across the secondary winding of the transformer, due to the series impedance of capacitor C, rectifiers S and M and resistors $R1$ and $R2$. This results in a partial suppression of the carrier and a signal is transmitted which is attenuated by approximately 4 db only, with respect to a normal marking signal. Such a reduction in level is usually not enough to cause operation to spacing and the signal is therefore usually received as a marking signal.

Another type of telegraph modulator which is used in some V.F. systems is illustrated in Fig. 10.10 and operates as a series attenuator in the circuit. This modulator is used in a number of

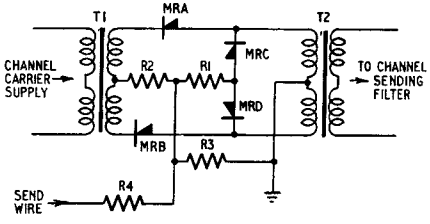


FIG. 10.10. SERIES TYPE MODULATOR

applications where it is required that the carrier shall be effectively suppressed when the send wire is disconnected. The marking loss with this arrangement is approx. 1·5 db and suppression of the carrier under spacing conditions is of the order of 50 db relative to a marking signal. A disconnected send line results in the carrier being suppressed by 27 db relative to a marking signal and this is received as a spacing signal. This type of modulator is generally required for use on radio telegraph systems.

When a marking condition (negative battery) is applied to the send wire, rectifiers MRA and MRB are conducting and current flows via $R4$, $R2$, and thence differentially via the two halves of the secondary winding of $T1$ to MRA and MRB respectively, and thence via the two halves of primary winding $T2$ to earth. The direct currents in the transformer windings, being in opposite senses in the two halves of each winding, produce no resultant polarizing flux and the carrier is transmitted with only the normal series losses due to the transformers. The potential drop in $R2$ is applied as a reverse voltage to rectifiers MRC and MRD which being non-conducting offer a high resistance. The shunt effect of MRC plus MRD is therefore very small.

When a spacing condition (positive battery) is applied to the send wire, rectifiers MRC and MRD conduct, whilst rectifiers MRA and MRB are biased by the potential drop in $R1$ so that they are non-conducting. A low resistance shunt path therefore exists across the secondary winding of $T1$, via MRC and MRD, and the series path becomes high resistance at MRA and MRB. The series loss in the modulator is then very high and is commonly of the order of 50 db, so that the carrier is effectively suppressed.

Resistor $R3$, in shunt with the modulator control network, limits the controlling current to the required value, whilst allowing normal values of send line current.

Sending Filters. The functions of the sending filters are—

(*a*) To restrict the side bands of the modulated carrier to the portion of the frequency spectrum allotted to the individual channel.

(*b*) To prevent the transmission of unwanted frequencies due, for instance, to harmonics which may be present in the carrier supply.

(*c*) To offer a high impedance to line, at the operating frequencies of other channels, so that one channel will not take appreciable energy from the others.

The considerations which determine the bandwidth of filters used in multi-channel systems are discussed in Chapter 5 as are also the elements of filter design. The information given is directly applicable to the S.T. & C. Ltd., equipment as used by the B.P.O., and it will be seen that the realizable performance of the filters depends upon the characteristics and accuracy of the practicable components used.

By careful design and manufacture, band-pass filters have been produced which conform closely to a standard and which have low losses within the pass-band, whilst presenting a high impedance to other channels. In this connexion, it is interesting to note that the power loss at the mid-band frequency of any channel, due to the shunting effect of the other 17 filters, is of the order of 2 db.

The form of sending filter used is shown in Fig. 10.8, from which it will be seen that the system is designed for the use of unbalanced filters, which are more economical in the use of components than the balanced type. The carrier supply is connected to the filter via a network comprising resistors X, Y, and Z. Resistor X prevents the application of an excessive load to the generator, when the modulator is spacing, and thus avoids interference with other channels using the same carrier frequency. The values of resistors X and Y are chosen so that the input of the filter is terminated

within the limits $600\sqrt{2}$ and $\frac{600}{\sqrt{2}}\,\Omega$, when the modulator is marking and spacing respectively. This ensures that the characteristic of the filter, as viewed from the line terminals, is substantially constant. Resistor Z is adjustable and provides means for setting the output power to the required value.

The power at the send filter output is adjusted so that the power into the line is 4 μW, which is equivalent to -4 db relative to 10 μW. This amount of energy is taken from other channels and thus cross-fire between channels is minimized.

The receiving circuit including the receiving filter is shown in Fig. 10.11 and the receiving filter will be seen to comprise basically two send filter sections. This sharpens the cut-off of the filter, so that the receiving filter exercises greater discrimination against unwanted frequencies than does the sending filter. By this means, the effects of inter-channel interference and cross-talk from adjacent telephone circuits are minimized.

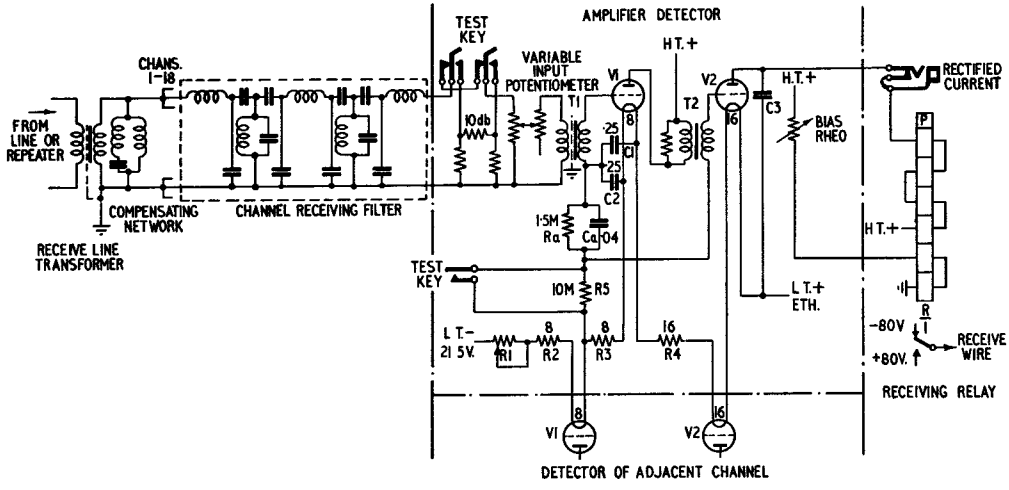


FIG. 10.11. B.P.O. TYPE 3 A.M. MULTI-CIRCUIT VOICE-FREQUENCY TELEGRAPH EQUIPMENT: RECEIVING CHANNEL EQUIPMENT

meets the normal B.P.O. requirements for working into the four-wire portion of a zero trunk telephone line. Where non-repeatered circuits are encountered, the 10 db sending attenuator is removed from the circuit, so that the power transmitted to line is 40 μW per channel. The attenuator has an incidental advantage, in that it presents a non-reactive 600 Ω termination to both line and filter. The effect of irregularities in the impedance-frequency characteristics of the line and the filter bank are minimized by the inclusion of the attenuator. The unbalanced sending circuit is connected to the balanced line circuit by a 1:1 transformer.

Receiving Filters. The receiving line, or terminal repeater output, is connected to the input terminals of 18 receiving filters via a 1:1 transformer, which separates the balanced line circuit from the unbalanced filter circuit.

The functions of the filter are—

(*a*) To accept with minimum attenuation the band of frequencies transmitted on the channel, and

(*b*) To offer a high impedance at frequencies outside the pass-band, so that no appreciable

The input terminals of the receiving filters are connected in parallel to the line transformer and the output terminals of each filter are connected to the input of an amplifier-detector. The power at the output of the receiving filter when the system is working on a well lined-up circuit is approximately 10 μW, the loss in the filter at the carrier frequency being of the order of 4 db. The mid-band loss of receiving filters actually varies from about 3·0 db for channel 1 (420 c/s) to 9 db for channel 18 (2,460 c/s) when connected in parallel with other channel filters in the system.

Compensating Networks. At the paralleling points of the output of the sending filters, and the inputs of the receiving filters, reactive compensating networks are introduced on 18-channel systems to provide a flanking impedance to improve the characteristics of the filters associated with the highest channel. With the type of filter employed, the asymmetry of the attenuation-frequency characteristic which is produced by the absence of a suitable flanking impedance, is not so pronounced at the 6th or 12th frequency as it is at the 18th.

The effect can be disregarded in the case of 6- and 12-channel systems and no compensating networks are provided in these cases.

The Amplifier-detector. Fig. 10.12 indicates the nature of typical telegraph signals in a V.F. telegraph channel throughout the various stages of transmission. Fig. 10.12 (*a*) shows the d.c. signals sent from the transmitting instrument. Fig. 10.12 (*b*) indicates the resulting modulation of the channel carrier frequency produced by these d.c. signals in the static relay (modulator). For simplicity, 100 per cent modulation is assumed, i.e. the carrier is completely suppressed during spacing signals (in practice the suppression is usually about 35 db). Fig. 10.12 (*c*) shows the form of the modulated carrier signal at the output of the send filter and the effect of the build-up time of the filter on the envelope of the modulation can be clearly seen. Fig. 10.12 (*d*) shows the similar transient effects produced by the receiving filter on the shape of the received signals.

The signals received from the output of the receiving filter have to be employed to operate the receiving instrument and these signals must, in some manner, be made to operate a receiving relay, so that the time intervals between the instants of restitution conform as closely as possible to the corresponding time intervals between the instants of modulation of the original signal at the transmitter, i.e. there must be minimum distortion.

It will be observed in Fig. 10.12 (*d*) that the signal envelope is symmetrical about points *R*1, *R*2, *R*3, *R*4, *R*5, and *R*6, which correspond to instants at which the amplitude of the signal envelope is 50 per cent of its steady state value, and that the time intervals "*t*" between these points correspond to the time intervals "*t*" between the original instants of modulation of the d.c. signals transmitted.

The aim in the design of the receiving V.F. equipment is to cause the receiving relay to restitute the signal at these points and this is one of the major problems of the design. For this purpose an amplifier-detector circuit is employed, operating in conjunction with a polarized telegraph receiving relay. The received signals from the output of the receiving telegraph filter are first amplified and then passed to a detector, which rectifies the modulated carrier signals to produce direct current signals which follow closely the shape of the envelope of the modulated carrier signal. The rectified current is a single-current signal and the receiving relay has therefore to be biased in opposition to the received signals and to an extent equivalent to a half of the amplitude of the received signals. Obviously, if the amplitude of the signals operating the relay varies then the signals given out by the relay will be distorted. Some discussion of the effect of variation in the level of the received signals is contained in Chapter 5. Assuming for the moment that the amplitude of the received signals remains constant, and this is the condition assumed

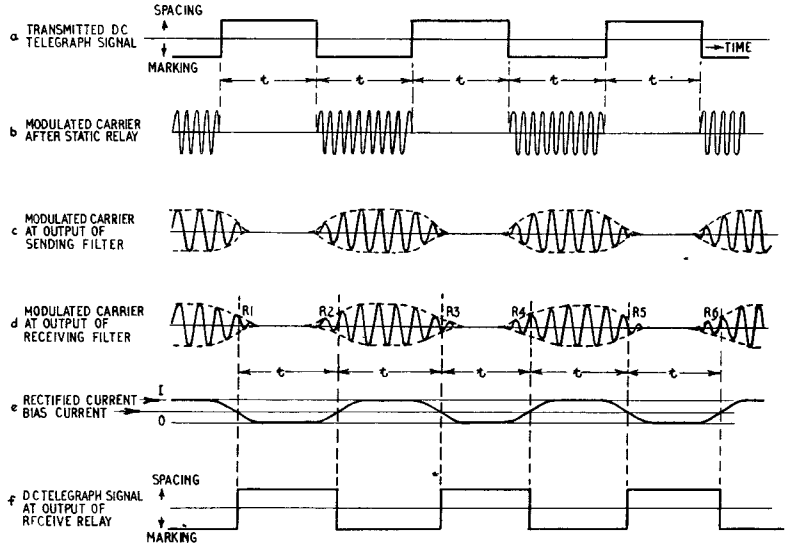


FIG. 10.12. WAVEFORMS OF TYPICAL TELEGRAPH SIGNALS AT VARIOUS STAGES OF TRANSMISSION IN A CHANNEL OF A M.C.V.F. TELEGRAPH SYSTEM

in Fig. 10.12, then with a perfect polarized receiving relay, the latter will operate at points corresponding to $R1$, $R2$, $R3$, $R4$, $R5$, and $R6$ of the received signal, using a fixed bias current on the relay equal to half the amplitude of the rectified received signals. The receiver in the case shown is therefore restituting the signals without distortion. This ideal is not attainable in practice but a high degree of performance is nevertheless obtained in practical design.

Fig. 10.11 shows the schematic circuit of the type of receiving equipment employed in B.P.O. Type 3 M.C.V.F. systems.

It will be seen from this figure, that the signals received from the line reach the input transformer of the amplifier-detector via the contacts of a test key and a constant-impedance input potentiometer, which is designed to present an impedance of 600 Ω to the filter. The potentiometer has a range of attenuation from 0–30 db and it is adjustable over this range in steps of 1 db. Transformer $T1$ steps up the signal voltage, which is then applied to the amplifier valve $V1$, and after amplification the signal is passed via transformer $T2$ to the detector $V2$. The rectified signals from $V2$ pass via one set of windings of the polarized receiving relay $\frac{R}{1}$, which is connected in the anode circuit of $V2$. The capacitor $C3$ shunting the relay coils provides a path for the carrier-frequency components in the rectified signals. The receiving relay has another set of windings which are connected to produce a spacing bias, which is adjustable. The relay bias current is adjusted initially to give the best working conditions and subsequently it is checked and adjusted, if necessary, at monthly intervals to compensate for ageing of the valves.

Since the receiving line level of the signals varies in time due to maintenance variations in the line transmission equipment and cables, it is desirable in practice to leave the bias current unaltered and to compensate for line level variations by a form of automatic gain control and limiting in the amplifier-detector circuit. These features in the B.P.O. equipment, which will now be described, cater for line level variations of ± 7·5 db from the nominal level. Referring to Fig. 10.11 it will be seen that the static grid bias for the amplifier valve $V1$ and detector valve $V2$ is derived from the voltage drop along the filament circuit, which carries a current of 0·25 A. The static bias of $V1$ is therefore the drop across $R3$, i.e. — 2 V, and the bias on $V2$ is — 12 V, at which voltage $V2$ operates at the lower bend of its anode current/grid voltage characteristic and thus functions as an anode-bend detector.

In order that the gain of the amplifier $V1$ may be kept adjusted at an appropriate value in readiness for the reception of signals, it is the practice in B.P.O. voice-frequency systems to arrange, in conformity with C.C.I.T. standards, that the carrier frequency is transmitted during idle periods, i.e. for marking signals. The receiving circuit can then be arranged so as to compensate automatically for changes in level of the input signal and so ensure that the value of rectified current is kept reasonably constant over a range of about 15 db. If no tone were received during idle periods then the receiver could not anticipate the power level which would be present when signalling commenced. The compensating circuit in the receiver has to be such that it can distinguish between a change in level due to variation in the line and a change in input level due to a spacing signal; this is done by having a compensating circuit with a long time-constant, viz. 5 sec.

In teleprinter signalling, the periods of no-tone in the V.F. channel are short, e.g. the longest period of spacing is an "all-space" signal, which comprises six elements of spacing signal and one-and-a-half elements of marking for the stop signal. Thus the longest period of spacing during teleprinter signalling is 120 msec and the automatic gain control in the receiver is such that the gain is not sensibly altered during such signals. It will of course be clear that this characteristic of the A.G.C. circuit also means that only slow variations in line level can be tolerated.

Operation of the A.G.C. During the idle condition (marking), the normal input power to the amplifier is about 10 μW and the gain of the amplifier-detector is such that a rectified current of about 5 mA is produced. Under this condition, the grid of the detector valve is rendered slightly positive with respect to its cathode, so that some grid current flows through the 10 megohm resistor $R5$. The resulting potential across $R5$ causes capacitors $C1$ and $C2$ to become slowly charged through the shunted capacitor network C_aR_a. The charge on $C1$ and $C2$ increases the static negative bias between grid and cathode of the amplifier valve $V1$ and so reduces its gain. During idle periods of the channel, capacitors $C1$ and $C2$ become fully charged and thus cause the gain of the amplifier to be reduced. Immediately a spacing signal commences, i.e. the carrier tone is cut off, capacitors $C1$ and $C2$ begin to discharge through R_a and $R5$, and the gain of $V1$ begins to increase and reaches a maximum when the spacing signal has been sustained long enough for $C1$ and $C2$ to fully discharge—this takes about 3 sec.

During normal teleprinter signalling, the periods of no-tone are only of the order of 20–120 msec,

which is insufficient to allow $C1$ and $C2$ to discharge appreciably and affect the gain of the amplifier $V1$.

If the level of carrier tone increases, due to variations in the line, the detector valve $V2$ will pass more grid current and thereby increase the charge on $C1$ and $C2$ and consequently apply more negative bias to the amplifier $V1$, thus still further reducing its gain. Conversely, if the level of the input carrier signal falls, the grid current in the detector valve will be reduced, thus reducing the static negative bias on the amplifier $V1$ and in consequence result in an increase in the gain of $V1$.

Although the application of A.G.C. in this manner tends to keep the rectified current in the detector reasonably constant, it does not do so completely, as will be made clear by reference to Fig. 10.13 which shows for different values of maximum input voltage how the rectified current varies for different ratios of (input voltage)/(maximum input voltage). For satisfactory performance of the amplifier-detector it is sufficient to ensure for all input signals within $\pm 7\frac{1}{2}$ db of the normal power level that the detector produces rectified currents of the same value when the input voltage is half the maximum input voltage, even though the rectified current begins to rise at different fractions of the maximum input voltage and reaches different maxima. This is the most important consideration since the receiving relay must operate with rectified currents corresponding to an input equal to half the steady value.

Anti-lockout Shunted Capacitor. The purpose of the shunted capacitor network C_aR_a is to prevent the capacitors $C1$ and $C2$ charging too quickly after a long period of no-tone. Such a condition is encountered in teleprinter switching systems conforming to C.C.I.T. signalling standards in which the disengaged condition of a circuit corresponds to no-tone in the channel and tone is restored when the circuit is taken for use. (See Chapter 8.)

During the long period of no-tone, capacitors $C1$ and $C2$ become discharged, so that only the static bias on the amplifier $V1$ is effective and therefore the amplifier-detector is in its most sensitive condition. If a tone signal, i.e. marking, is now received, then it receives the maximum amplification of $V1$; grid current flows and the resulting voltage developed across the 10 megohm resistors $R5$, charges C_a and $C1$ and $C2$. The capacitor C_a is of small capacitance compared with $C1$ and $C2$, and is therefore charged quickly, so increasing the bias of $V1$ and $V2$; but due to resistor R_a and the small capacitance of C_a the rate of charge of $C1$ and $C2$ is slowed down. As the charge on $C1$ and $C2$ increases, the grid bias on $V1$ and $V2$ is still further increased, so reducing the gain of the amplifier and limiting the value of the rectified current.

The drop in anode current of $V1$ resulting from the increase in bias voltage, causes an impulse voltage in the secondary of the intervalve transformer, which causes additional grid current to flow in $V2$, thus enhancing the biasing effect. Without the delaying effect caused by C_a and R_a in the rate of charge of $C1$ and $C2$ the *AGC* and limiting would be too vigorous under the signalling

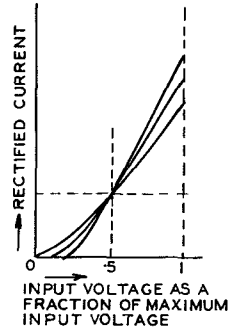


FIG. 10.13. RECTIFIED CURRENT IN DETECTOR FOR VARIOUS VALUES OF MAXIMUM INPUT VOLTAGE AND VARIOUS RATIOS OF INPUT VOLTAGE/MAXIMUM INPUT VOLTAGE

conditions described and would result in both valves being biased back to cut-off and causing "Lock-out." If this occurred, then on the application of tone (i.e. marking) after a long spacing period, the receiver would reproduce only a short mark followed by a space, during which the circuit would be completely insensitive to normal input signal levels. The sensitivity would then return gradually as $C1$ and $C2$ partially discharged via $R5$, until eventually a mark was produced in response to the incoming signal.

The lockout effect on V.F. channels is prevented quite successfully on B.P.O. equipment by the provision of the resistor-capacitor circuit R_a (1·5 megohm) and C_a (0·04 μF) and this arrangement has now been standardized on all equipment.

Lining-up a V.F. Channel. The process of adjusting a V.F. channel to obtain optimum performance is called "lining-up" a channel. The procedure is as follows—

A marking signal is first sent over the "send" channel and the "receive" channel, so that both static relays are in the minimum attenuation condition. The test keys on the detector panels are then operated and a milliameter connected to read the rectified current in each $V2$ anode circuit.

Operation of the test key on the detector panel to the mid-position, (see Fig. 10.11) inserts a 10 db

attenuator pad in the input of the amplifier-detector and also short-circuits *R5*, so that the gain compensating circuit is inoperative. The input potentiometer is then adjusted until a value of 3 mA rectified current is observed. The test key is then restored to its working position when the rectified current should rise to a value between 4 and 8 mA. When this has been done at both terminals, the detector circuits are correctly adjusted to the mid-point of their range of gain compensation.

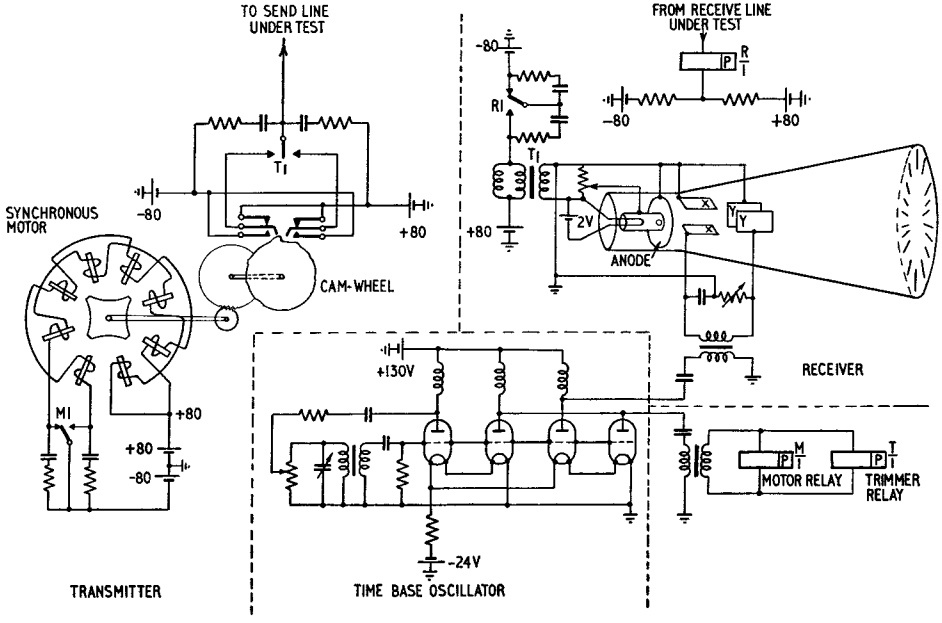


FIG. 10.14. PRINCIPLE OF TELEGRAPH DISTORTION MEASURING SET (T.D.M.S.) USED FOR TESTING V.F. TELEGRAPH CHANNELS

Telegraph signal reversals comprising 1:1 signals at 50 bauds are then transmitted over the Send and Receive channels and the received signals from the output of the receiving relay are observed on a Telegraph Distortion Measuring Set (T.D.M.S.), the operation of which is described later. The bias rheostat is adjusted at each terminal until the distortion of the reversals is a minimum. Distortion measurements on other telegraph signals, viz. 1:6, 6:1 and *Q9S* are then carried out in both directions of transmission using a Telegraph Distortion Measuring Set and if these are satisfactory the channel is ready for service.

Distortion Measurements on Voice-frequency Telegraph Channels. The performance of a telegraph circuit may be most readily measured and judged by the distortion which it introduces into signals which are transmitted over it. It is therefore common practice in modern telegraph systems to provide equipment to enable telegraph distortion measurements to be made and such measurements form the most satisfactory maintenance check of the performance of V.F. telegraph channels.

The principal requirements for carrying out end-to-end distortion measurements on telegraph circuits are—

(*a*) A source of undistorted telegraph signals, and

(*b*) A device for measuring the distortion present in the received signals.

Undistorted signals are transmitted at the sending end of the circuit and the signal distortion is measured at the receiving end. The distortion so measured represents the distortion due to the circuit. It will be understood that the conditions applied during the test should approximate as closely as possible to the actual working conditions of the circuit.

The apparatus generally used by the B.P.O. for measuring the distortion on V.F. telegraph channels was designed by Standard Telephones & Cables, Ltd., and is provided at all main V.F. telegraph terminal stations in the B.P.O. network. The equipment comprises a transmitter and receiver together with the necessary time base oscillator and is arranged to facilitate simultaneous testing in both directions of transmission, thus reducing the time taken in maintenance operations.

The complete T.D.M.S. is shown diagrammatically in Fig. 10.14.

The T.D.M.S. Transmitter. The transmitter comprises a telegraph relay $\frac{T}{1}$ which vibrates at the frequency of the time base oscillator. The tongue of the relay is connected to the line under test and the contacts of the relay are connected to the 80 + 80 V telegraph battery supply via two change-over contacts which determine the polarity to be applied to the relay contacts. The change-over contacts are actuated by a cam disc which is cut so as to produce the testing signal when rotated via suitable gearing by a synchronous motor. The synchronous motor has four armature poles and eight field poles which are connected alternately to the two side-contacts of another telegraph relay $\frac{M}{1}$. The return circuit of the windings is connected via a battery (generally the 80 + 80 V telegraph battery) to the tongue of the relay, so that if the relay is made to vibrate, a two-phase effect is produced in the field magnets, thus causing a rotating magnetic field. The windings of the motor relay $\frac{M}{1}$ are also connected to the time base oscillator, so that the motor rotates at a speed which is controlled by the oscillator.

Owing to the arrangement of the poles, the armature completes one revolution for every four cycles of the time base oscillator and the gearing is arranged, together with the cam contour, so that the shortest signal element represented upon the cam passes the change-over spring-sets in one cycle of the test oscillator. Thus the speed of transmission in bauds of the test signals is equal to the frequency of the time base oscillator in cycles per second. A mercury-filled fly-wheel, having perforated internal baffles, is fitted to the motor spindle to smooth out torque variations and obtain uniform angular velocity and, as the motor is not self starting, a handle is provided so that it can be run up to synchronous speed manually.

The two spring-sets, on the cam wheel, are adjusted so that each operates a quarter of a signal element before the trimmer relay contact $T1$ changes over to that spring-set. Since $T1$ changes over every half cycle of the oscillator (corresponding to half a signal element) the spring-sets are consequently arranged to operate with a displacement of half a signal element relative to one another. This is illustrated in Fig. 10.15 (*a*) where spring-set one is shown leading spring-set two by half a signal element. The trimmer relay is shown changing over to each spring-set a quarter of a signal element after the spring-set has changed its polarity.

This arrangement causes the signals represented by the cam contour to be reproduced in the output of the trimmer relay. The change-over events of the spring-sets, with the contact bounce which is inherent in such mechanisms, are screened from the line circuit and the change-overs in the transmitted signals are controlled by the trimmer relay which can be free from contact bounce. Fig. 10.15 (*a*) shows the generation, by this means, of signal reversals whose elements are of unit length. In Fig. 10.15 (*b*) the generation of reversals of two unit length are illustrated and it will be seen that any combination of signals can be generated, so long as their lengths are multiples of the unit signal element.

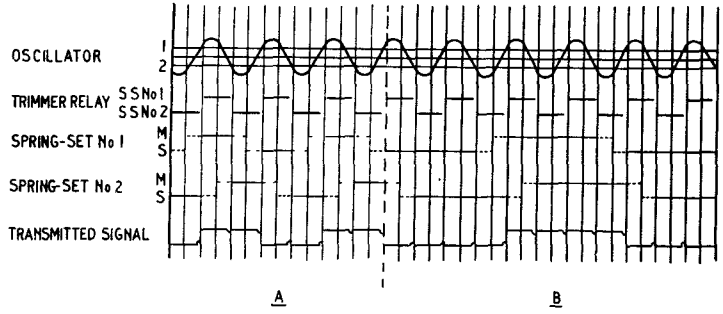


FIG. 10.15. T.D.M.S. TRANSMITTER: GENERATION AND TRANSMISSION OF SIGNAL REVERSALS

The T.D.M.S. transmitter is equipped with four cams which, by means of selecting keys, enable 1 : 1 unit reversals, 2 : 2 unit reversals, 6 : 1 signals (mark and space respectively) and *Q9S* in the teleprinter code to be transmitted as desired. A battery reversing key enables these signals to be inverted and the 6:1 signal, when inverted, provides a check on the behaviour of the amplifier-detector compensating circuit, since it gives a repetition of long spacing (i.e. tone-off) signals separated only by short marking intervals.

The T.D.M.S. Receiver. The receiver embodies a special application of the cathode ray oscillograph which forms the indicating element and enables the distortion to be displayed and measured on the face of the tube. The oscillograph tube comprises an evacuated conical glass envelope with a rounded end and a cylindrical neck which terminates in the connecting cap at the apex. The inside of the rounded end is coated with a fluorescent salt which has the property of emitting a green glow when subjected to electronic bombardment. The coated end of the tube forms the viewing screen and th

cylindrical neck contains the electrodes. The oscillograph is of the gas-focused type and operates at a relatively low anode voltage and employs electrostatic deflexion.

The electrodes comprise (*a*) a directly heated cathode, which is supplied with current from a separate insulated source, (*b*) a cylindrical focusing screen around the cathode, (*c*) a disc anode which is mounted at right angles to the axis of the tube and has a small hole in its centre, and (*d*) two parallel pairs of rectangular deflecting plates which are mounted at right angles to one another along the axis of the tube. The assembly is illustrated in Fig. 10.16. The cathode and anode of the tube are used to produce a stream of electrons along the axis of the tube, electrons being attracted with considerable velocity from the cathode to the anode. Those which reach the anode take no part in the display on the screen, but others emerge at great velocity through the hole in the centre of the anode and continue ultimately to impinge upon the fluorescent screen.

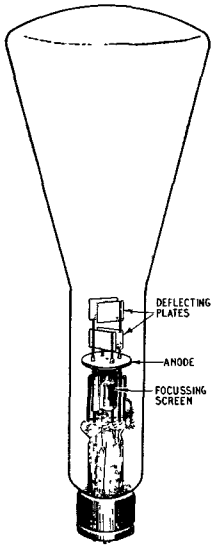


FIG. 10.16. PRINCIPLE OF CONSTRUCTION OF CATHODE RAY TUBE

In the absence of any constraining force, electrons emerging from the hole in the centre of the anode would repel one another and so diverge from the axis of the tube, whereas it is desired that they should converge to a point focus on the screen where they will combine in producing a bright spot or trace. To achieve this, the tube is filled with argon gas at a low pressure and this, coupled with suitable adjustment of the potential on the focusing cylinder provides the means of obtaining a point focus.

Argon gas is chosen because of its high molecular weight and the correspondingly low thermal agitation velocity at which the molecules move. Molecules of the gas lying in the path of the electron stream are bombarded by these electrons and, in consequence, lose electrons by secondary emission. As a result—the gas molecules acquire a positive charge. By this means a path is formed in the direction of travel of the electron stream, of positively charged ions which move very slowly in relation to the electrons in the stream. The existence of the positive charges counteracts the tendency of the electrons to diverge and, if the electron velocity is suitably controlled, the electron stream can be made to reach a point focus on the screen. The positive potential, relative to the cathode which is applied to the focusing cylinder, accelerates the electrons emerging from the anode and provides a means of controlling their velocity.

In the T.D.M.S. receiver there is no continuous source of anode voltage, the required voltage being produced only on the arrival of a signal so that a stream of electrons is projected on to the screen at the instant of arrival of each signal. This is arranged by means of a step-up impulse transformer $T1$ the secondary winding of which is connected between the anode and cathode of the tube. The primary winding is connected to the contacts of the receiving telegraph relay, via a capacitor circuit, to the 80 + 80 V telegraph battery supply and the windings of the relay are connected to the receiving line. Each operation of the relay armature, corresponding to each instant of restitution of the received signal, causes the application of a peaky voltage impulse between anode and cathode. In the absence of any deflecting force the electron beam travels along the axis of the tube and a bright spot is produced in the centre of the screen. A potential difference between one pair of deflecting plates, produces an electrostatic field which deflects the electron stream towards the positive plate. A similar potential difference between the second pair of deflecting plates produces a deflexion of equal magnitude but at right angles to the direction of the first one and, if both potential differences are applied at once, the deflexion produced is the vector sum of the two separate deflexions. The T.D.M.S. employs a deflecting field which is constant in amplitude and which rotates at the rate of one revolution per unit signal element.

One pair of deflecting plates (XX) is connected across a capacitor and the other pair (YY) across an adjustable resistor. The capacitor and resistor are connected in series with the output of the time base oscillator and the resistor is adjusted so that the sinusoidal voltages across the resistor and capacitor are equal. The voltage developed across the resistor (and therefore across plates Y Y) leads by 90° that across the capacitor (and plates X X) and this results in the production of a constantly rotating electrostatic deflecting field.

This is illustrated in Fig. 10.17 in which at time 0, the potential difference across the plates XX is zero whilst that across the plates YY is at its maximum value. The field produced is represented by PA. At time instant one, the potential differences across the two pairs of plates combine to produce a resultant field PB. Similarly points C, E, and F correspond to instants two, four, and five.

The deflecting field thus produced rotates continuously at the rate of one revolution per cycle of the oscillator (i.e. per unit signal element) and is present, whether or not signals are being received. At each instant of restitution of the received signals a radial flash on the screen indicates the position of the field at that instant. A radial flash or "spoke" is produced, instead of a spot, because the anode potential is not constant throughout the impulse which corresponds to the instant of restitution. The velocity of the electrons therefore varies during the impulse and the slower moving electrons are deflected further from the axis of the tube than the faster ones and a radial trace is produced.

If the signals arrive in a time sequence which is an exact multiple of the speed of rotation of the rotating field, then the flashes produced all fall in the same place on the screen and a single almost continuous flash is seen and this indicates zero distortion. Signal distortion causes some signals to arrive early and others late with respect to their true theoretical position in time, with the result that the successive flashes corresponding to them spread out over a sector of the circular screen. By means of a suitably divided radial scale the sector may be interpreted directly as a percentage of 360° (i.e. of one unit signal element) and thus the percentage distortion measurement read directly.

The characteristics of the fluorescent screen combined with the "persistence of vision" of the observer enables a number of signals to be seen together, so that the extent of the sector covered by the flashes may be estimated more easily.

Speed Range of T.D.M.S. The time base oscillator is provided with adjustable reactance in the tuned grid circuit, giving a range of frequencies from 30 to 120 c/s. The signals generated by the 1:1 cam can thus be varied between the limits 30 to 120 bauds as may be required. For normal maintenance of VF channels the oscillator is set to 50 c/s and signals transmitted from the 1:1 cam while the bias adjustment of the receiving circuit is being checked.

End-to-End Distortion Measurements. Wherever possible, distortion measurements are made on an end-to-end basis using a distortion measuring set at each end of the circuit. Signals are sent from one T.D.M.S. to the other and readings are taken in both directions of transmission at the same time. The nature of the received signal, i.e. 1:1, 2:2, 6:1, etc., can be seen by the characteristic deflexion of the pointer of the milliameter in the line circuit of the receiver and, with practice, and co-operation between the two operators, a series of readings can be taken quite rapidly.

Slight differences in frequency between the time base oscillators cause the display on the receiver screen to rotate slowly. This is not material, so long as it does not inconvenience the operator, and a small amount of drift can be ignored. The drift can be prevented by altering the setting of the oscillator at one end of the circuit and ceases when the two oscillators are operating at the same frequency.

The Multi-frequency Generator. As previously mentioned, the 18 carrier frequencies required are

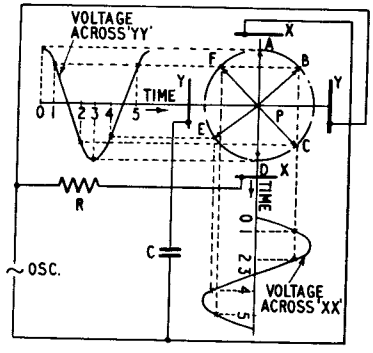


FIG. 10.17. PRODUCTION OF ROTATING ELECTROSTATIC FIELD IN CATHODE RAY TUBE

obtained from a multi-frequency generator which is capable of supplying the carrier frequency power for up to a maximum of ten 18 channel systems. The use of a generator has the following advantages over the alternative arrangement of providing valve oscillators—

(*a*) Saving in space required.

(*b*) Simplicity of checking the frequencies.

(*c*) Good frequency stability without special precautions.

(*d*) Accurate maintenance of inter-channel frequency spacing.

The multi-frequency generator comprises a direct current motor and 18 separate inductor alternators all mounted on a common shaft and housed within a single casing. The armature rotates at 3,600 r.p.m. and is controlled to within ± 0·25 per cent of this speed, over long periods of service, by means of a centrifugally operated electrical governor. The complete armature is shown in Fig. 10.18.

The Motor. The motor is a d.c. long shunt, compound machine, which is operated from the 80 + 80 V telegraph batteries. The motor has two field poles and two brushes and is started by a manually operated two-step starting switch and resistance. Protection against overloads is afforded by a circuit breaker, which has a thermal delay to

enable it to be set at a suitably low current without risk of operation during the short overloads which occur during starting.

The Governor. The governor normally supplied with the multi-frequency generator is assembled on a steel disc, which is mounted on an extension of the armature shaft at the commutator end of the motor. The essential features of the governor are a finely adjusted pair of contacts which operate centrifugally and a resistance network which connects the contacts to the segments of a special commutator. The external connexions are effected via two brushes, which bear on the commutator, and the connexions of the governor are as shown in Fig. 10.19. The circuit of the motor and governor is shown in Fig. 10.20 and the governor is connected across a portion of the motor shunt field resistance.

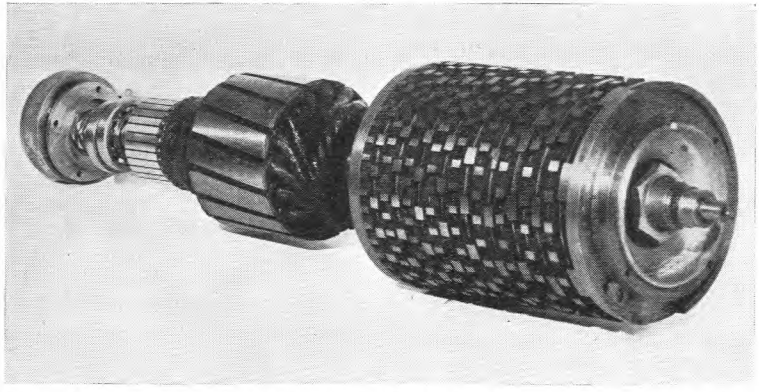


FIG. 10.18. ARMATURE OF AN 18-CHANNEL MULTI-FREQUENCY GENERATOR AND MOTOR
(By courtesy of H.M. Postmaster-General)

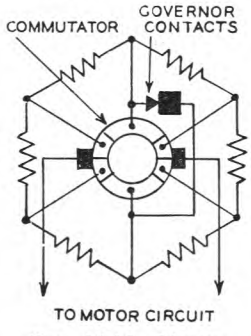


FIG. 10.19. MULTI-FREQUENCY GENERATOR: PRINCIPLE OF GOVERNOR CONNEXIONS

The governor contacts do not close until the armature speed reaches the required speed of 3,600 r.p.m. and the motor accelerates to this speed quite rapidly and would, if not checked, run to a considerably higher speed. When the governor contacts close, however, the governing resistance is short-circuited and hence the shunt field current is increased, consequently the armature back e.m.f. is increased and the resulting reduction in armature current causes the motor to decelerate. The contacts re-open when the speed falls a little and the motor again accelerates. The process is continued, so that the motor runs between an upper and a lower limit of speed, both of which are very close to the mean of 3,600 r.p.m., because in practice the contacts open and close once in every revolution.

The governor contacts operate about five million times a day and carry a current of approximately 80 mA. The shunt field winding in which this current flows is inductive and, without special precautions, sparking across the contacts would cause a seriously rapid transfer of contact metal and so upset the speed control. This transfer is much reduced by the use of the governor commutator

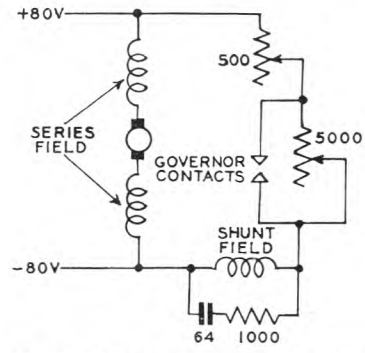


FIG. 10.20. MULTI-FREQUENCY GENERATOR: MOTOR AND GOVERNOR CIRCUIT

which reverses the direction of flow of currents through the governor contacts every half-revolution and sparking is minimized by the provision of a spark quench across the shunt field winding. By these means it is possible to run a multi-frequency generator continuously for one or two weeks, after which it must be stopped for routine cleaning and readjustment of the contacts. A spare generator is provided as a part of the terminal equipment to supply the carrier frequencies when one generator is taken out of service.

The Valve-controlled Governor. The method of governing so far described, in which the governor contacts operate directly in the shunt field circuit, has been called "direct-governing" to differentiate it from an improved method which was subsequently developed and now standardized in B.P.O. practice and which is called "Valve-controlled governing." In this method the operation of the governor contacts is employed to short-circuit a resistance in the grid-cathode circuit of a valve and so regulate its anode current. The valve anode current varies the total value of the shunt field current of the motor of the multi-frequency generator and so controls the speed of the machine. Since the valve grid circuit is non-reactive and the potential difference across the control resistance which is short-circuited is small, the governor contacts carry only a very small current and in consequence there is no sparking and hence no transfer of contact metal. The life of the contacts is thus very long and the generator may be run for periods of three to six months, without necessitating cleaning and readjustment of the contacts. Valve control governing enables more accurate speed control to be attained and an accuracy of 0·1 per cent is found possible in practice using this method.

Fig. 10.21 shows schematically the valve controlled governor circuit employed by the B.P.O.

The Generator. Each of the 18 inductor alternators, which together comprise the generator portion of the machine, consists of a laminated toothed rotor, mounted on the armature shaft, and rotating between two diametrically opposed sets of stator poles. The output windings are mounted on the poles of the stator and a d.c. exciting winding induces a continuous flux in the machine from pole to pole of the stator, through the armature.

The design is such that the total reluctance of the magnetic circuit remains constant as the rotor revolves, so that interaction between adjacently mounted inductors is avoided. The flux in each individual stator tooth varies, however, as the rotor teeth pass it; being at a maximum when a rotor tooth is directly opposite and at a minimum when an inter-tooth space is opposite. The variation in flux in the stator teeth, due to the rotation of the rotor, is cyclic in nature and has a frequency equal to the number of rotor teeth passing a stator tooth per second. The cyclic change in flux in the stator teeth induces an alternating e.m.f. in the stator windings which, by careful attention to the tooth design, approximates very closely to a pure sine wave. The 18 rotors are seen mounted closely together in Fig. 10.18 and the stators with their wound poles can be seen in Fig. 10.22 which also shows the main d.c. exciting windings which are common to the 18 stators. The alternators are so closely spaced that the 18 stators cannot be mounted with their poles in alignment along the machine and to accommodate the output windings without increasing the length of the machine, the stators are arranged in two groups, so that those of alternate inductors are in one group and the remainder in the other group, which is mounted with the poles at 90° to those of the first group. This arrangement is visible in Fig. 10.22.

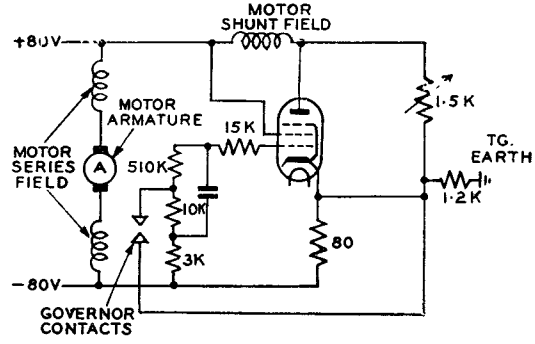


FIG. 10.21. MULTI-FREQUENCY GENERATOR: VALVE CONTROLLED GOVERNING OF MOTOR

The output of the alternators is controlled by the exciting field current which is supplied via a rheostat from the 21·5 V filament battery. The individual stators are provided with tapped windings, so that the output voltages of the 18 inductors can be equalized to a common value of 1·0 V $\pm$ 0·05 V. Suitable tappings are chosen by the manufacturer when the machines are first tested and usually only require attention after a machine has been dismantled in a workshop for a general overhaul. The output terminals of the multi-frequency generator may be seen in Fig. 10.23 which shows an exterior view of the generator carcase. The left hand terminal panel accommodates the motor terminals, and the larger panel to the right accommodates the adjustable tappings for the inductor windings at the top, and below these are the 36 output terminals for the 18 inductors and the terminals for the common exciting winding.

Speed Check of Multi-frequency Generators. It is necessary to maintain a close check of the accuracy of the speed control on multi-frequency generators, otherwise the channel carrier frequencies will not coincide with the mid-band frequencies of the channel filters and thus increased distortion of the telegraph signals would occur in the channels, with consequent loss of margin in the operation of circuits. For speed checking purposes a stroboscope

is used. Mounted on the end of the generator shaft is a stroboscopic disc which has 68 alternate black and white radial segments. The disc is illuminated by a neon lamp operating from an adjustable

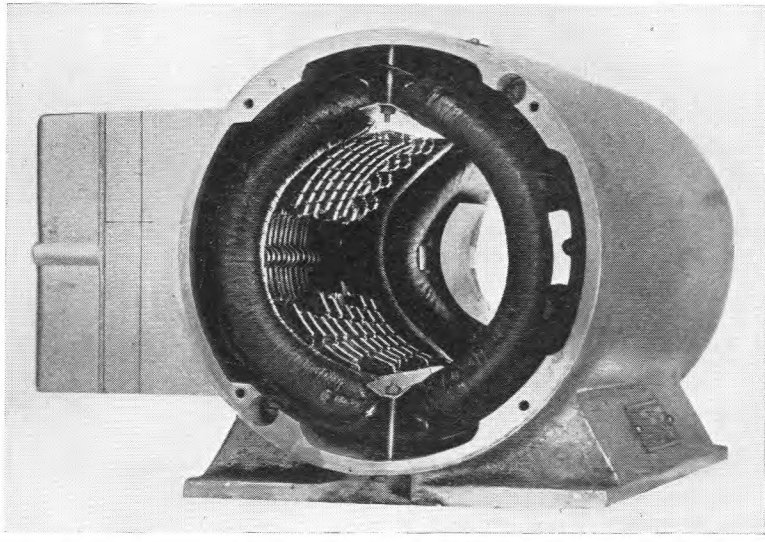


FIG. 10.22. STATOR OF MULTI-FREQUENCY GENERATOR SHOWING THE MAIN D.C. EXCITATION WINDINGS AND STATOR POLES FOR 18-CHANNEL FREQUENCIES
(By courtesy of H.M. Postmaster-General)

1,020 c/s oscillator and the speed of the generator may then be judged by the apparent rate of rotation of the disc. When the generator is running at

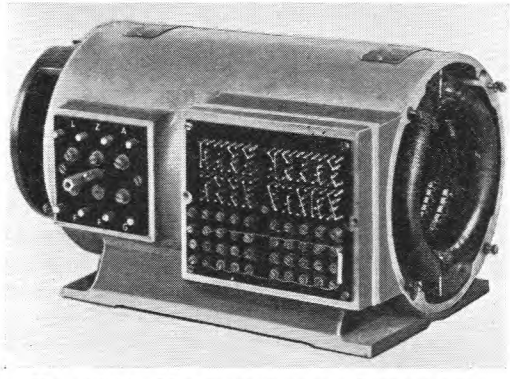


FIG. 10.23. MULTI-FREQUENCY GENERATOR: EXTERNAL VIEW OF THE STATOR
(By courtesy of H.M. Postmaster-General)

its correct speed, viz. 60 revs per second, 2,040 black or white segments pass per second. At this speed the illumination by the neon lamp, which strikes for each half-cycle of the applied frequency of 1,020 c/s, causes the stroboscopic disc to be illuminated 2,040 times per second and, therefore, the black and white segments will appear to be stationary. If the generator is running fast, the black and white segments on the disc will appear to be rotating in the same direction as that of the generator shaft, whereas, if the generator speed is slow then the apparent direction of rotation of the stroboscopic disc will be reversed. In either case, the apparent rate of rotation of the stroboscopic disc is proportional to the speed error.

The stroboscopic disc provides a quick and easy method of speed checking and facilitates speed readjustment. The speed accuracy of the multi-frequency generator is dependent, in this method of check, on the accuracy of the 1,020 c/s oscillator, and the periodical speed check consists firstly of a check of the frequency of the oscillator against a standard. It suffices to check the oscillator frequency once a week and at a set time; the oscillator at one main station in the M.C.V.F. network is adjusted against a laboratory sub-standard oscillator. Multi-frequency generators at this station are then set accurately on speed and the carrier frequency output of channel six is then employed as a source of standard 1,020 c/s tone, for checking other M.C.V.F. stations. As soon as this adjustment at the main station has been carried out, this tone is used to adjust the 1,020 c/s oscillators at all stations connected to the main station, generally by beating the output of the channel six receiver filter with a test output from the local oscillator, whose frequency is adjusted by a manually operated variable

capacitor in the oscillatory circuit, until the beat frequency is a minimum. Stations which are not connected to the main station, receive their checking tone from the most convenient station whose 1,020 c/s frequency has been checked.

If the four-wire line circuit connecting two M.C.V.F. terminals is on a carrier telephone route, the 1,020 c/s tone is liable to suffer frequency shift due to inaccuracies in demodulation from the telephone carrier equipment and if this occurs, the 1,020 c/s tone will not be received accurately and therefore will not be reliable for checking purposes. In this case other methods may have to be adopted to ensure the reception of an accurate 1,020 c/s frequency. Where there is an audio telephone circuit on the same route as the M.C.V.F. system the system can either be transferred temporarily to the circuit during the frequency check or the circuit used for the transmission of the 1,020 c/s test tone. Where this is not possible, the 1,020 c/s check may be accomplished accurately despite frequency shift in the carrier channel during transmission, by transmitting two frequencies separated by exactly 1,020 c/s and demodulating one against the other to obtain the required checking frequency of 1,020 c/s.

Testing and Patching Facilities

For ease and efficiency of maintenance testing of M.C.V.F. telegraph systems and channels, it is desirable, especially in stations having a large number of systems, to concentrate the testing apparatus at a central point in the M.C.V.F. apparatus room. V.F. channels are employed for a great variety of circuits and it is essential, if a good service is to be given, that routine tests and fault localizing operations should be performed with speed and accuracy. If a working channel is faulty and a spare is available, then it reduces the duration of the breakdown if the faulty channel can be replaced temporarily by the spare.

To meet the foregoing requirements the "Test and Special Apparatus (S.A.) Racks" are provided in M.C.V.F. terminal stations. The send and receive d.c. legs of all the channels are cabled to connexion blocks on the apparatus room I.D.F. via sets of jacks on the "Test and S.A." or "S.A." rack. At the I.D.F. the channel ends are cross-connected by jumper wires as required either—

(*a*) To cables leading to the instrument room where they are connected to instruments; or

(*b*) To manual switchboard line jacks or to automatic line switching equipment; or

(*c*) To other V.F. channel ends to make up through circuits; or

(*d*) To miscellaneous equipment, e.g. broadcasting or conference apparatus.

Whatever the nature of the service for which a circuit is employed there is need for quick access to the send and receive channels for testing and patching. This is the primary purpose of the Test and S.A. rack which is illustrated in Fig. 10.24 which also shows the equipment details. The S.A. rack is similar in all respects to the Test and S.A. rack except that it is not fitted with a T.D.M.S.

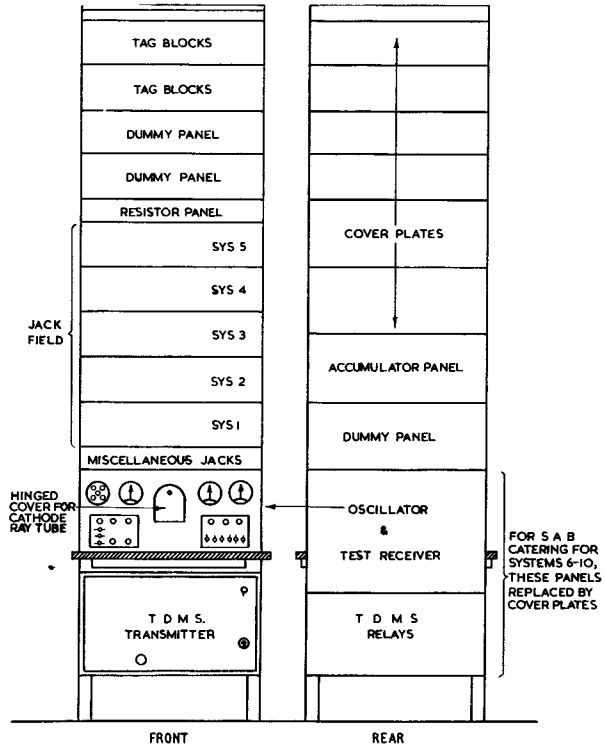


FIG. 10.24. TEST AND SPECIAL APPARATUS RACK (S.A.R.): EQUIPMENT LAYOUT, FRONT AND REAR VIEWS

Each of these racks accommodates testing access points in the line and channel circuits of five 18-circuit systems. The Test and S.A.R. is installed with the first system at a terminal and serves systems one to five. An S.A.R. is installed with the first system of each subsequent half group of five systems, unless the total number of systems exceeds 30 when a second Test and S.A.R. is usually installed to provide a second T.D.M.S.

The equipment provided on the S.A.R. includes—

(*a*) Test points for eight four-wire line circuits.

(*b*) Test points for the send and receive sides of 90 circuits (five 18-circuit systems).

(*c*) Miscellaneous circuits.

(*d*) Trunks to channel racks and other S.A.R.'s.

System Line Circuits. Each 18-circuit system

requires a four-wire line circuit and each 4-circuit system requires a two-wire line circuit. Facilities for testing eight four-wire circuits are provided so that a number of 4-circuit systems may if necessary be installed in place of some of the 18-circuit systems.

The line circuit testing points are provided by means of break-jacks which are mounted, together with miscellaneous circuit jacks, on a hinged panel at the bottom of the jack field on the front of the rack (Fig. 10.25). These jacks provide facilities for breaking the circuits and testing in both directions, changing-out circuits or inserting attenuators as required.

The line jacks are cabled to terminal strips at the top of the rack where they are brought into use, as required, by means of cabling to the I.D.F. and Generator and Battery Supply Rack. The jacks are allotted in the numerical order of the systems which they serve and, where an 18-circuit system is displaced by 4-circuit systems, sufficient jacks are reserved for four 4-circuit systems before allotting further jacks for additional 18-circuit systems. The method of labelling the line jacks is shown in Fig. 10.25 which illustrates a case where the jacks labelled SYS.2 are in use for four 4-circuit systems. GI, SMU, TW, and ACM are code letters for the names of the towns to which the systems are connected.

Channel Circuits. (Fig. 10.26.) Three jacks

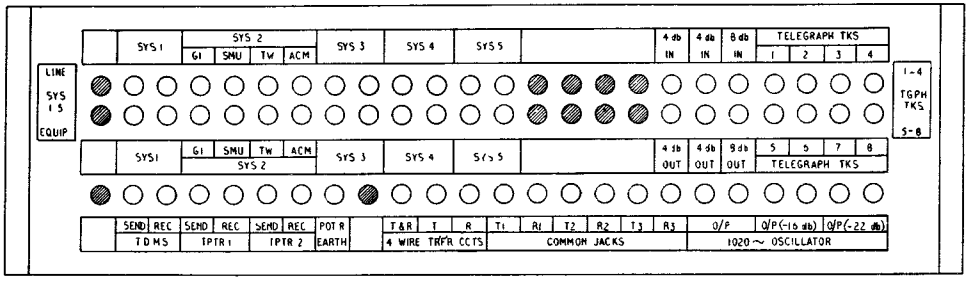


FIG. 10.25. 4-WIRE LINE AND MISCELLANEOUS TEST JACKS ON MISCELLANEOUS JACK PANEL OF S.A.R.

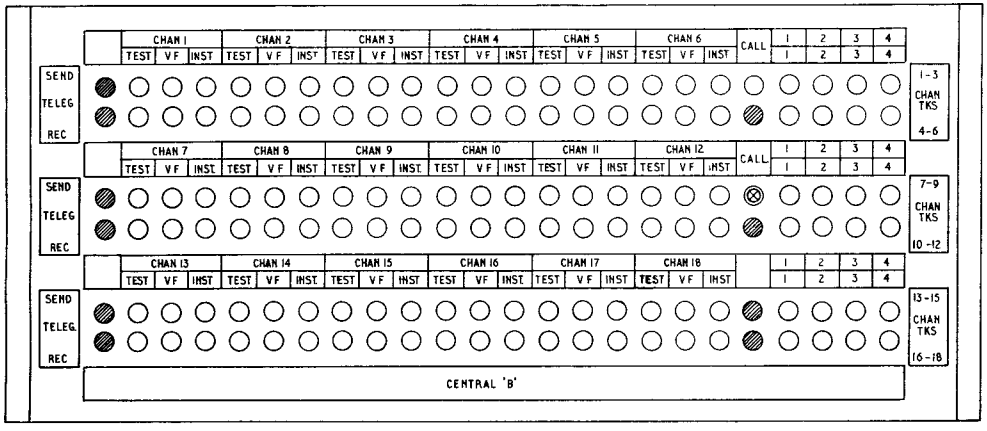


FIG. 10.26. ARRANGEMENT OF CHANNEL TEST AND PATCHING JACKS ON S.A.R. FOR AN 18-CIRCUIT SYSTEM

labelled TEST, V.F. and INST are provided in each send and receive channel. The connexions of

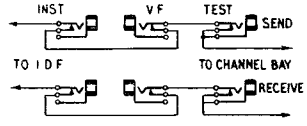


FIG. 10.27. WIRING OF CHANNEL JACKS ON S.A.R.

these jacks are shown in Fig. 10.27. The TEST jacks are used in conjunction with the teleprinter test position and provide means for terminating the channel side in either direction for test. The

V.F. and INST jacks are provided principally for the purpose of patching-out faulty channels and afford means of testing only in the direction indicated. All the channel/circuit jacks for each system

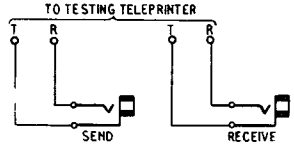


FIG. 10.28. TELEPRINTER TEST POSITION JACKS ON S.A.R.

are grouped together on a hinged jack-panel on the front of the bay, the lowest panel serving system 1 and the highest, system 5. Each panel also accommodates jacks on which two testing trunks to each side of the channel rack are terminated.

Miscellaneous Circuits. The layout of the miscellaneous-circuit jacks on the miscellaneous jack panel is shown in Fig. 10.25. Descriptions of the various circuits are given in the following paragraphs.

(*a*) *Teleprinter Test Position Jacks* (Fig. 10.28). These are wired to terminal strips at the top of the rack and are cabled thence to fixed test positions.

(*b*) *T.D.M.S. Jacks.* These jacks are wired directly to the line terminals of the T.D.M.S. transmitter and receiver.

(*c*) *1,020 c/s Oscillator Test Output* (Fig. 10.29). This has three appearances, giving different power

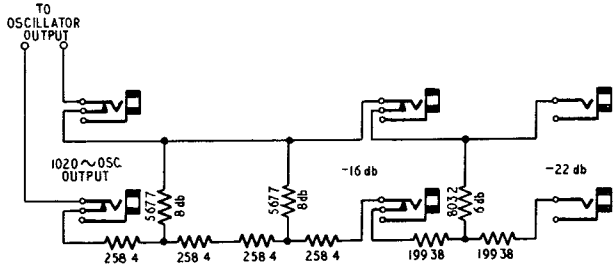


FIG. 10.29. 1,020 C/S OSCILLATOR TEST OUTPUT JACKS ON MISCELLANEOUS JACK PANEL OF S.A.R.

levels. To avoid errors due to bridging losses if two appearances were used at once, the jacks are arranged in series, suitable attenuators being provided. The first appearance is the maximum test output of 100 μW and is used for general purposes, including patching to S.F. IN of channel six when it is desired to transmit the oscillator frequency to another terminal. The second appearance is attenuated 16 db and affords an approximate power balance against the frequency received from the control station generator over channel six, when the static relay is uncontrolled. The third appearance is attenuated a further 6 db, i.e. 22 db below 100 μW and affords an approximate balance of power against the frequency received over channel six, when the control station oscillator is patched to the S.F. IN jacks.

(*d*) *The Common Jacks* (Fig. 10.30). These provide means of connecting three channel-rack

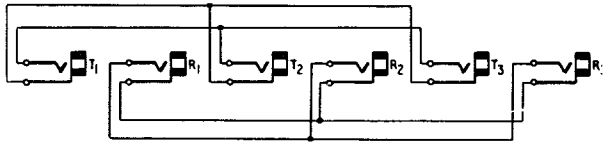


FIG. 10.30 COMMON JACKS ON MISCELLANEOUS JACK PANEL OF S.A.R.

trunks together, and are intended for use in conjunction with the 1,020 c/s oscillator test outputs, when it is desired to make a routine frequency check by beating the output against a test frequency supplied from the controlling terminal over channel six.

(*e*) *Transfer Trunks* (Fig. 10.31). These enable line circuits to be patched via channel-rack trunks,

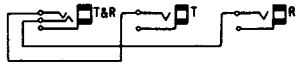


FIG. 10.31. JACKS FOR TRANSFER TRUNKS ON MISCELLANEOUS JACK PANEL OF S.A.R.

when it is desired to test the channel output power to line. The trunks are terminated on the tip and ring springs of a single jack at one end and the tip springs of two jacks at the other end.

(*f*) *Rack Trunks* (Fig. 10.32). Eight jacks are provided on each S.A.R., for use as trunks to other

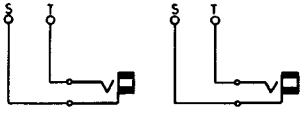


FIG. 10.32. JACKS FOR RACK TRUNKS ON MISCELLANEOUS JACK PANEL OF S.A.R.

S.A. Racks. These are intended primarily as a means of changing-out channels or linking-up channels between S.A. Racks which are not adjacent.

(*g*) *Attenuators* (Fig. 10.33). The 4 db and 8 db attenuators are terminated on jacks, so that they can be inserted in the line circuits if required. If it is desired to link together two lines, each having an overall gain of 8 db, at an intermediate terminal to provide a through-circuit between two other terminals, it will be necessary to

insert 8 db attenuation at the junction in both directions, so that the overall gain of the linked circuit will remain at the required value of 8 db.

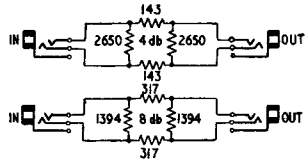


FIG. 10.33. 4 db AND 8 db ATTENUATORS AND JACKS ON MISCELLANEOUS JACK PANEL OF S.A.R.

(*h*) *Potentiometer Earth* (Fig. 10.34). A jack labelled POTR E is connected to the centre-point of a 20,000 Ω resistor, which is connected across the

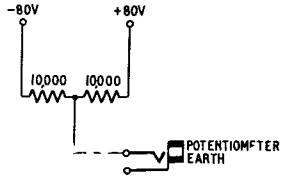


FIG. 10.34. POTENTIOMETER EARTH ON MISCELLANEOUS JACK PANEL OF S.A.R.

80 + 80 V battery supplies. This arrangement provides a facility for checking received signals for bias when the T.D.M.S. is already in use. To make this check, a patch is made on the S.A.R. between the V.F. receive side jack and the POTR E jack. On the channel rack a patch is made between the 35–0–35 mA meter jack and the receive side shunt meter jack, and any signal bias may be observed on this meter. Since a potential device is in use, the meter reading is unaffected by unbalance of the 80 + 80 V supply voltages.

Teleprinter Test Position. One or more teleprinter test positions is provided at each M.C.V.F. terminal. The position consists of a small table on which is mounted the testing teleprinter and its auxiliary apparatus and a tester which enables the various test conditions to be set up by operation of keys. The test position is wired to jacks on the S.A.R. In order to connect the teleprinter test position to a circuit connexions are made on the S.A.R. between the Teleprinter "send" and "receive" jacks and the test send and receive jacks of the circuit under test by means of two-way plug-ended cords. The tester circuit is arranged so that with all keys normal the line is uninterrupted.

The testing and miscellaneous facilities required on a teleprinter test position will depend upon the types of circuits to be tested but Fig. 10.35 shows the schematic circuit of a typical tester which is used extensively by the B.P.O. for testing teleprinter private wire circuits. This tester provides the following facilities—

(*a*) Teleprinter testing in either direction on any circuit connected through the S.A.R.

(*b*) Teleprinter monitoring on either the send or receive line of any circuit connected through the S.A.R.

(*c*) Local record cut-out on the testing teleprinter.

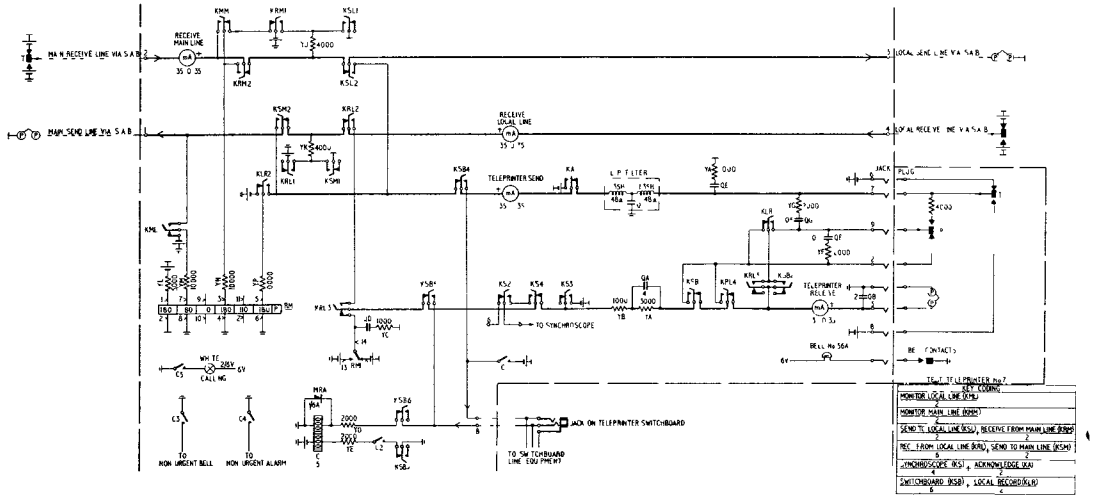


FIG. 10.35. SCHEMATIC CIRCUIT OF A TYPICAL TELEPRINTER TEST AND OBSERVATION POSITION

This is necessary when testing on a circuit connected to a conference unit.

(*d*) Originating and receiving calls from a teleprinter switchboard. This facility is useful for fault reporting and maintenance purposes.

(*e*) Testing the speed of distant teleprinters in

conjunction with a synchroscope (see Chapter 11).

(*f*) Checking the send and receive line current in any circuit connected through the S.A.R.

By appropriate key manipulation the testing teleprinter may be connected either to the local-line side or to the main-line side. Holding conditions are applied to the side not connected.

Under monitor conditions each wire of the circuit under test passes straight through the tester but is tapped by a high resistance leak circuit including a relay No. 299 AN. Thus by suitable key operation signals in either or both directions may be made to control the relay with negligible effect on the line conditions. As the relay tongue is connected to the testing teleprinter electromagnet, a printed record may be obtained of traffic passing in either or both directions of the line under test.

Holding battery and earth conditions applied to the line are protected to ensure that fault conditions on the side of a circuit not under test will not affect tests made on the other side.

In cases where a line is provided from the tester to a teleprinter switchboard, incoming signals from the switchboard operate audible and visible alarms, which remain operated until the switchboard key is operated. Under these conditions, connexions are such that the testing teleprinter is a normal extension from the switchboard. The detailed circuit operation should be clear from study of Fig. 10.35.

Power Supplies. The standard B.P.O. Type 3 M.C.V.F. equipment is designed to use battery power supplies. Three supplies are required—

(*a*) A L.T. (or filament) supply having a mean value of 21·5 V and regulated within ± 0·25 V. This supplies—

(1) Channel valve filaments—four in series.

(2) Multi-frequency Generator fields.

(3) Valve filaments in 1,020 c/s oscillator and T.D.M.S. oscillator.

(*b*) A H.T. (or anode) supply having a mean value of 130 V and regulated within ± 1 per cent. This supplies—

(1) Channel valve anodes and relay bias.

(2) Valve anodes in 1,020 c/s oscillator and T.D.M.S. oscillator.

(*c*) A ± 80 V (or telegraph) supply. Each 80 V supply is regulated within 76 V–92 V and the maximum difference between them must not exceed 4 V. This supplies—

(1) Telegraph signalling currents.

(2) The motors of multi-frequency generators (in older equipments the motors are supplied from the unregulated side of the filament supply).

(3) The T.D.M.S. motor.

(4) The motors of test teleprinters.

More detailed information is given in Chapter 14.

Although floating battery supplies are always provided in fixed stations, power equipments specially designed to operate without batteries have been successfully used in mobile M.C.V.F. terminals.

Four-circuit Voice-frequency Telegraph Equipment

To extend the advantages of M.C.V.F. telegraph working to minor routes which do not justify the provision of 12- or 18-circuit V.F. systems, a smaller type of system is employed, which provides up to four sending and four receiving channels.

The terminal equipment embodies many features of the 12- and 18-circuit system already described and, wherever possible, similar panels are used. The system was designed to work over two-wire circuits, but is generally worked over four-wire circuits with two-wire terminations.

The block schematic diagram in Fig. 10.36 indicates the system layout. Differences will be seen between the IN station and the OUT station and they are briefly as follows. The IN station is usually required to be installed at an existing V.F. terminal and obtains its carrier frequencies and power supplies from the multi-frequency generator and existing battery supplies in that station. The equipment is mounted in such cases on standard 10 ft 6 in. high racks and four such systems can be accommodated on two racks, thus occupying the same space as that required for the channel racks of a 12-circuit system. The OUT station is usually installed where other V.F. telegraph equipment does not already exist; the necessary carrier frequencies are therefore obtained from valve oscillators. The power supplies for the oscillators, detectors, and telegraph signalling are derived from rectifiers, the whole being assembled on a single rack, 8 ft 6 in. high by 1 ft 8½ in. wide, for operation from a.c. mains. When a 4-circuit system is required between two places, neither of which has an 18-circuit equipment already installed, then the out-station type, 8 ft 6 in. racks are employed at each end, for mains operation. The equipment at one end is arranged to cater for the carrier frequencies proper to an OUT station, whilst the other terminal operates at the appropriate frequencies for an IN station.

Where a 4-circuit system is required between existing terminals two IN station equipments are installed, one of these being arranged to cater for the carrier frequencies proper to an OUT station.

Frequencies used. The carrier frequencies used in the 4-circuit system are chosen from those

in use on the 18-circuit system; this permits standard filters to be used and the carrier supplies to be obtained from a multi-frequency generator where one exists. The type of circuit used to link the two terminals necessitates the use of different sending frequencies in each direction of transmission. Normally, the sending frequencies at the system controlling terminal are 420, 660, 900, and 1,140 c/s; frequencies of 1,380, 1,620, 1,860, and 2,460 c/s. In this manner the filter characteristics and impedance of the equipment are maintained.

Supplementary Networks. (See Fig. 10.36.) These are joined across those receive filters which are adjacent to a local send filter in the frequency spectrum. The supplementary network provides a path of low impedance for any of the adjacent transmitted frequency—which is at a relatively high level—which may have passed the receive

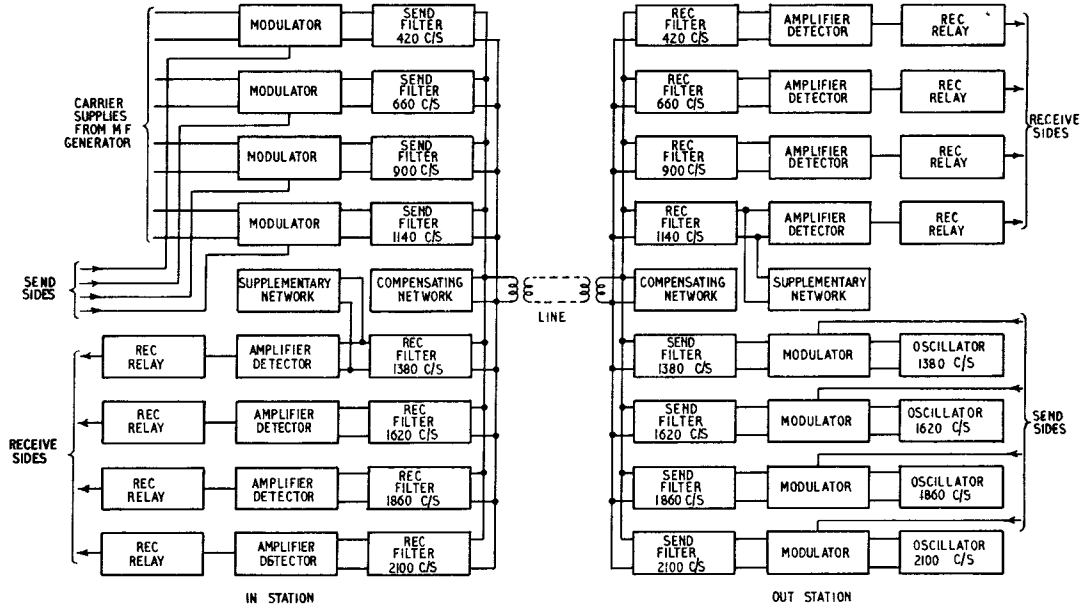


FIG. 10.36. BLOCK SCHEMATIC OF A 4-CIRCUIT M.C.V.F. TELEGRAPH SYSTEM

2,100 c/s being transmitted in the opposite direction. Four "Send" and "Receive" channels are thus obtained.

Spacing of Frequencies. As will be seen by reference to Fig. 10.36, the frequency spacing between channels is 240 c/s (double that employed on the 18-circuit system). This spacing permits the use of receive filters having fewer sections and a flatter characteristic than the filters employed on the 18-circuit system. The send and receive filters on the 4-circuit system are similar and are of the same type as the send filters used on the 18-circuit system; the receive filters, however, have the series resistance short-circuited and the shunt resistance disconnected.

The Compensating Networks. (See Fig. 10.36.) These are provided to simulate those filters—proper to the filter group—which are not employed in the 4-circuit system, i.e. they are equivalent in impedance to the filters for the frequencies 540, 780, 1,020, 1,260, 1,500, 1,740, 1,980, 2,220, 2,340, and filters; interference between the two-channels is thus diminished.

Transmission. Modulation of the carrier frequency is effected in a similar manner to that employed on the 18-circuit system. A static relay is used, controlled by the transmitter of the telegraph instrument associated with the particular channel. The output per channel, which is adjusted by means of the Z shunt resistance (semi-variable), connected across the input of each send filter, is usually set to 125 μW (measured at the send filter out jacks). This is equivalent to 100 μW to line, compared with 4 μW per channel in an 18-circuit system.

The normal overall attenuation of the line should not exceed 18 db over the frequency band 300–2,200 c/s. The frequency characteristic should be such that the signals received on any channel do not differ in level by more than 10 db from those on any other channel working in the same direction.

Balanced Attenuator. Provision is made for the

introduction of a balanced attenuator into the line circuit, for use on lines of low attenuation or, if necessary, to reduce the input to a terminal repeater.

Receiving. The receiving arrangements are similar to those of an 18-circuit equipment but using receive filters similar to the send type. The amplifier-detector unit is the same as that already described for the 18-circuit system and provides from an a.c. source of supply within the voltage range 100–250 V. Where a.c. mains are available they are used, whilst if the mains are d.c. a suitable motor alternator is installed. The d.c. voltages for the operation of the equipment are then obtained from rectifier units, whilst the carrier frequencies are obtained from valve oscillators.

Operating Speed. The 4-circuit system conforms to the recommendations of the C.C.I.T. as

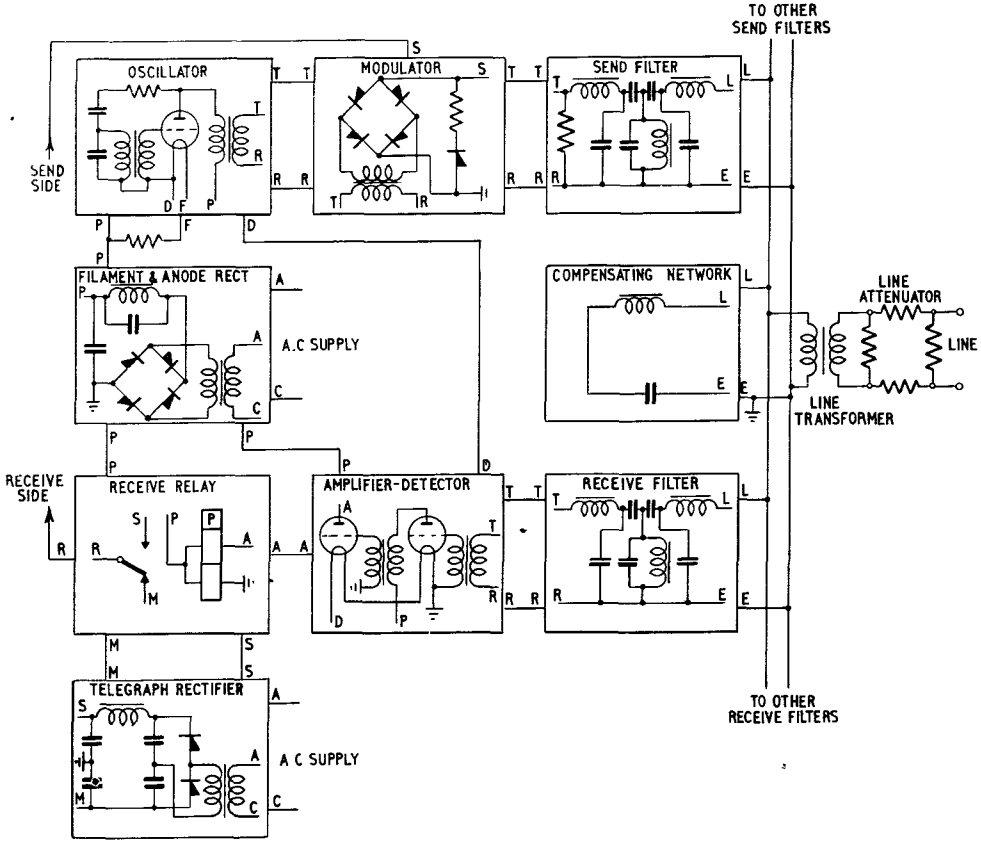


FIG. 10.37. SCHEMATIC CIRCUIT OF 4-CIRCUIT OUTSTATION M.C.V.F. TELEGRAPH EQUIPMENT

automatic compensation for a variation in input signal level of $\pm$ 7·5 db. The receive relay is the B.P.O. type relay No. 299AN, as used on the 18-circuit system.

Fig. 10.37 shows a schematic circuit of the 4-circuit outstation equipment.

Battery and Carrier Frequency Supplies. Where a 4-circuit system is installed at a main line V.F. telegraph terminal, the battery and carrier frequency supplies are derived from the same sources as those used for the 18-circuit equipment. Where a 4-circuit system is installed at other than a main line V.F. terminal, its power is derived already described for the 18-circuit system and the standard of reliability and speed at which the channels may be operated are similar to those of the 18-circuit equipment.

The B.P.O. Type 4 Amplitude-modulated 18- or 24-circuit Voice-frequency Telegraph Equipment

This is a post-war design of M.C.V.F. telegraph equipment adopted by the B.P.O. for use on land-line and short submarine telephone-type circuits. The equipment is designed and produced by Standard Telephones and Cables, Ltd., England,

and offers a number of important advantages over the earlier Type 3 equipment which is already extensively employed. The Type 4 equipment can inter-work with Type 3 equipment.

The physical design of the equipment is compact, and of attractive appearance, and it is built on the unit-type method of construction. All apparatus panels are designed on the jack-in principle with U-link connexions between panel and rack wiring. All equipment racks are fully wired even when supplied partially equipped. Thus, extensions to a partially equipped working system may be made very readily at any time. The circuit elements are, wherever practicable, grouped in hermetically sealed boxes so providing protection against climatic conditions.

Pressed-steel frameworks have replaced the steel racks of the Type 3 system and are designed as single-sided mountings. When bolted back-to-back to form a double-sided rack, the front-to-back and width dimensions correspond to those of Type 3 equipment when equipped on both sides. A new, more compact telegraph relay than the 299AN, is incorporated. It has fewer adjustable components and contributes to improved performance and simpler maintenance.

The system is designed for all-mains operation with individual rack-side power units, external 80 + 80 V signalling supplies, and, in larger stations, centralized 220 V H.T. supplies if desired. Two types of rack-side power unit panels are available, one which provides heater and anode current supplies to all valve circuits on the rack-side and the other, for use with a centralized 220 V H.T. supply, which provides the heater supplies only. These units are interchangeable.

Principal Features and Basic Improvements Incorporated in the Type 4 Equipment

The principal features of the Type 4 equipment are as follows—

No. of Channels
24 (maximum) per system.
Channel Carrier Frequencies
420 c/s to 3,180 c/s (i.e. 120 c/s channel spacing) and conforming to C.C.I.T. recommendations.
The tones are derived from valve oscillators in channel panels or, if preferred, from multi-frequency generators.
Sending Levels to Line
18- and 24-circuit systems — 24 dbm.
Received Levels from Line
18- and 24-circuit systems — 24 dbm.
A.G.C. Range
18 db with minimum distortion over 15 db.
Channel Distortion
Approximately 3 per cent on 50 baud mixed signals.
Permissible Maximum Telegraph Transmission Speeds for Mixed Signals
50 bauds with 8 channels in tandem.
or
75 bauds with 2 channels in tandem.
Send and Receive Physical Lines
Can be operated double-current or as single-current loop extensions in conjunction with a special single current loop extension relay rack.
Rack-side Dimensions
9 ft × 20½ in. × 7½ in.
Rack-side Requirements
24 circuit system—2 rack-sides.
12 circuit system—1 rack-side.
Centralized testing jack field per 5 systems giving test access to the send and receive d.c. legs of each channel—1 rack-side.
Multi-frequency generators (if desired)—1 Rack.
Power Supplies
Either—
(*a*) 200 — 250 V a.c. and
80 + 80 V d.c.
or
(*b*) 200 — 250 V a.c.
220 V d.c. (centralized) and 80 + 80 V d.c.
Testing Equipment
(*a*) Transmission Measuring Set Receive Unit for lining-up the transmission circuit over which the telegraph system operates.
(*b*) Telegraph Relay Test Panel.
(*c*) Electronic Telegraph Distortion Measuring Set (T.D.M.S.).
Tandem Connexions
If preferred, the V.F. receive relays need not be used at the intermediate points of interconnexion of channels in tandem.

The main equipment features of the Type 4 system can be seen from inspection of Fig. 10.38 which shows a typical 12-circuit rack-side and Fig. 10.39 which shows a 12-circuit and group modulator rack-side for channels 13–24.

The principal improvements in performance of the Type 4 equipment compared with Type 3 are as follows—

(1) Reduction in channel distortion, so providing greater margin in the operation of circuits, or permitting the interconnexion of a greater number of channels in tandem and thus improving the degree of flexibility of switched telegraph networks.

(2) Reduced liability to distortion of signals received after a prolonged period of "no-tone," which corresponds to the disengaged condition of circuits in switching systems conforming to C.C.I.T. recommendations.

(3) A uniformly high standard of performance from all channels. This is of particular importance for switching systems, as the effective distortion on any switched connexion must be based on that which can occur on the worst channels which may form the connexion.

(4) The new system enables the wider bands (i.e. 300–3,400 c/s) for telephone circuits complying

with C.C.I.F. recommendations to be fully exploited by operating 24 telegraph circuits.

(5) The facility is available for making permanent or semi-permanent tandem connexions of channels in different systems without the use of intermediate V.F. receive relays.

(6) Line-up and maintenance procedure for channels is simplified as the performance can be checked in local.

(7) The equipment can be operated directly from the a.c. mains supply. In B.P.O. practice all important stations equipped with Type 4 equipment are provided with no-break power supply arrangements to guard against mains failure. Details in this respect are given in Chapter 14.

The first three factors in the above list relate to distortion. In earlier systems distortion could be attributed to the transmitting circuit, to the receiver, or to some property common to both. In Type 3 systems the distortion most evident in the transmitting circuit was in the low frequency channels due to a phenomenon known as "carrier beat." The cause of carrier beat and the measures adopted to overcome it in the new system are described later. Broadly speaking it has been eliminated by pre-shaping the received double-current signals to give them an approximately trapezoidal waveform, thus removing the higher frequency components in the signals. This pre-shaping is done partly by a network at the input to the modulator and partly by the modulator itself. The change in design of the modulator has also increased its sensitivity and makes it possible for the detector output of one channel to be directly connected to the modulator of a channel in another system.

The distortion which is attributable equally to the transmitting and receiving equipments, due to the variations in the shapes of the channel filter curves in the neighbourhood of their cut-off, has been considerably reduced in the Type 4 system by producing greater uniformity and closer approach to the ideal shape in all channel filters.

Some of the distortion in the receivers of Type 3 equipment is due to the use of a form of resistance-capacitance filter following the detector stage to eliminate the V.F. carrier and harmonics. These have cut-off curves which reduce the effective band-width of channels and thus increase the characteristic distortion. In the new detector the V.F. carrier leak and harmonics are removed by means of a coil and capacitor type filter following the rectifier stage, which, because it does not reduce the overall band-width, does not on this account cause distortion. Being inherently more effective in eliminating the unwanted products, the new filter makes possible the use of a simplified and less costly receiving band-pass filter. This is now identical with the transmit filter.

Non-linear phase distortion in the system, which was a further cause of telegraph distortion, particularly at higher speeds, is reduced by a L.P. filter and delay network.

The telegraph detector, after initial adjustment,

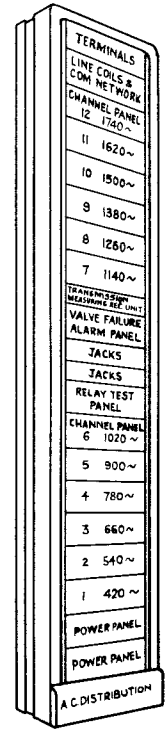


FIG. 10.38. B.P.O. TYPE 4 M.C.V.F. TELEGRAPH EQUIPMENT: RACK LAYOUT FOR CHANNELS 1–12

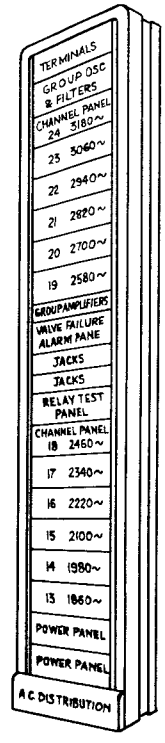


FIG. 10.39. B.P.O. TYPE 4 M.C.V.F. TELEGRAPH EQUIPMENT: RACK LAYOUT FOR CHANNELS 13–24

gives virtually zero bias over a range of 15 db corresponding to receive filter input levels of from — 20 dbm to — 35 dbm. For optimum working conditions it is necessary to place the nominal input level conveniently within this bias-free range for the given transmission equivalent of the line. To do this an adjustable attenuator is provided between the line input and filter. Outside the 15 db range the distortion is greater and increases rapidly with increase of range.

In Type 3 systems the distortion increases steadily as the transmission equivalent departs from its initially adjusted value. In the Type 4 system the performance remains virtually unchanged until the extreme limits of the permissible level variations are reached.

The channel carrier frequencies and signalling conventions are the same as in Type 3 equipment and conform to C.C.I.T. recommendations.

For 24-circuit working, channels 19–24 may be generated either as channels 1–6 (420–1,020 c/s) or as channels 7–12 (1,140–1,740 c/s) and the group of six channels is then frequency translated, by modulation with a carrier frequency of 3,600 or

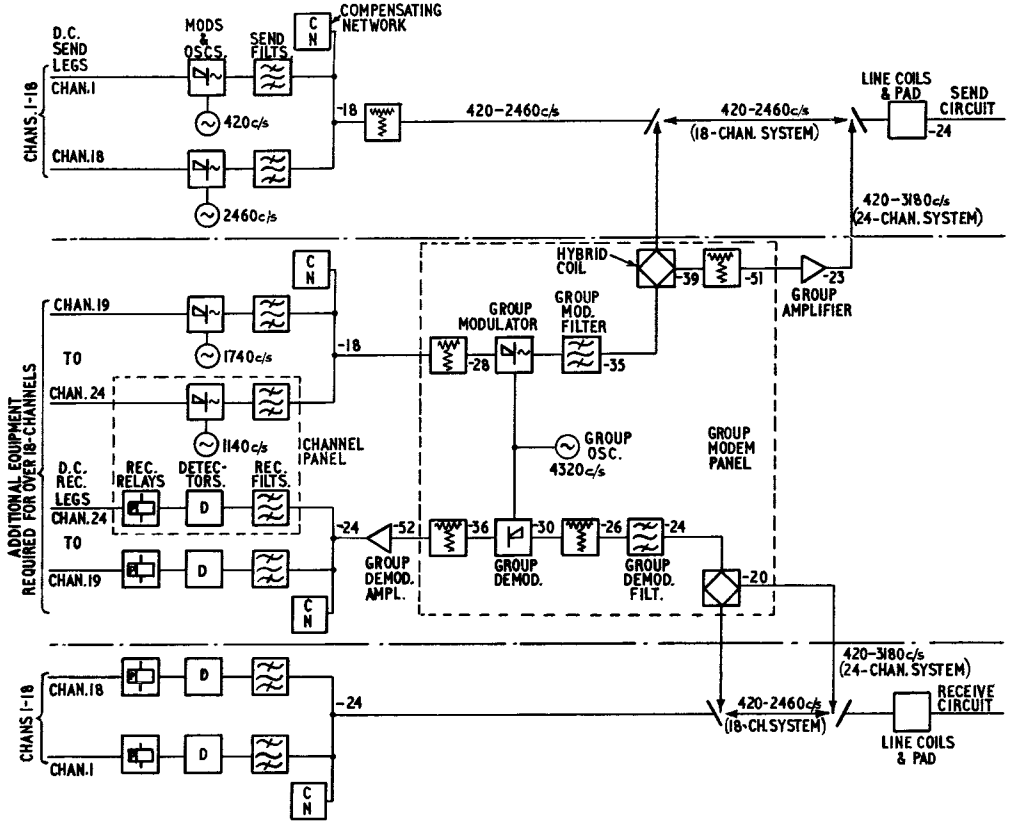


FIG. 10.40. BLOCK SCHEMATIC OF 24-CIRCUIT M.C.V.F. TELEGRAPH SYSTEM

4,320 c/s respectively, to the band of line frequencies 2,580–3,180 c/s. The optional choice of primary groups 1–6 or 7–12 is advantageous when existing multi-frequency generators are being employed for the carrier frequencies, as it is then possible to some extent to equalize the load. Fig. 10.40 indicates in block schematic form the basic circuit arrangements used for operating a 24-circuit system.

The Modulator. The modulator is a constant impedance, phase-reversing type which has been designed to minimize the effects of carrier-beat. Being a constant impedance modulator it has the advantage that when working from a multi-frequency generator it does not cause transient interference with the channels of the same frequency in other systems.

The number and extent of side frequencies present in a telegraph modulated carrier is inversely proportional to the build-up time of the signal elements, the steeper the slope the greater the number and the magnitude of the side frequencies. When the V.F. pulses applied to the send filter are almost square signals, as in the Type 3 systems, the number and magnitude of these frequencies are sufficient to cause interference, which is particularly noticeable in the lower frequency channels.

The explanation is as follows. When a carrier frequency f is modulated by a telegraph signal of fundamental frequency ϕ the modulation products comprise side-band frequencies of—

$$f \pm \phi, f \pm 3\phi, f \pm 5\phi, \ldots f \pm (2n-1)\phi.$$

From this it will be seen that when $(2n-1)\phi$ is

nearly equal to $2f$, side frequencies of the form $f - (2n - 1)\phi$ will be $f - 2f$ (approximately) i.e. $-f$. Thus it will be seen that high order side frequencies are possible which are adjacent to the carrier frequency.

Because of their location in the frequency spectrum such side-bands cannot be eliminated in the band-pass filter stage following the modulator. They therefore interfere with the carrier and main side frequencies which this filter is designed to pass. The effect of this interference is to cause a fluctuating or "beating" form of distortion.

When the carrier frequency of a channel is low, the order of the side-band responsible for carrier beat need not be very high before interference becomes appreciable. On Type 3 systems it was most noticeable on channel No. 1, i.e. 420 c/s and to a less extent on channel 2, i.e. 540 c/s at speeds of 50 bauds or more.

In the Type 4 system the input filter represented by $R1$, $R2$, and $C1$ in Fig. 10.41, which shows the principle of the modulator circuit, imparts a trapezoidal shape to the d.c. telegraph signal impulses and thus reduces the magnitude of high order side frequencies. In turn, the carrier beat effect is correspondingly reduced to the point where it is now negligible in all channels. Low frequency channels, as a result, have a comparable performance with higher frequency channels which is a great advantage in their utilization, especially in switching systems.

Principle of Operation of the Modulator. The principle on which the modulator operates will be apparent from Fig. 10.41 and the following description. There are essentially two circuits A and B linking the channel carrier supply with the output filter. The outputs of these two transmission paths are combined at the hybrid transformer $T2$ in such a way that when the level transmitted through each is in phase, the filter output is the sum of the two voltages. When the two voltages are in phase opposition (anti-phase), the filter output is the difference of the two voltages. The rectifier bridge circuits in path B are arranged so that in the spacing condition (i.e. S positive in relation to E) the transmission through path B is in phase opposition to path A and with $R6$ appropriately adjusted, the voltages in each path are equal. In these circumstances the output to the filter is zero.

Conversely, in the marking condition when the potential between S and E is reversed, the transmissions through paths A and B are in phase and the output is twice that of either path.

Considering these effects in detail, then when S is positive to earth, i.e. during spacing signals, direct current flows through $R1$ and $R2$ to "a" on transformer $T1$, where it divides differentially. One path is from a–b–c–d–e–f–g–h–i–r and thence to earth at E. The second path is from a–j–k–l–m–n–o–p–q–r and thence to earth at E.

The secondary windings of transformer $T1$ are accurately balanced and so also are the rectifier elements, and resistors $R3$ and $R5$. Hence considering the voltage drop when a positive current is flowing through the modulator from the transmit

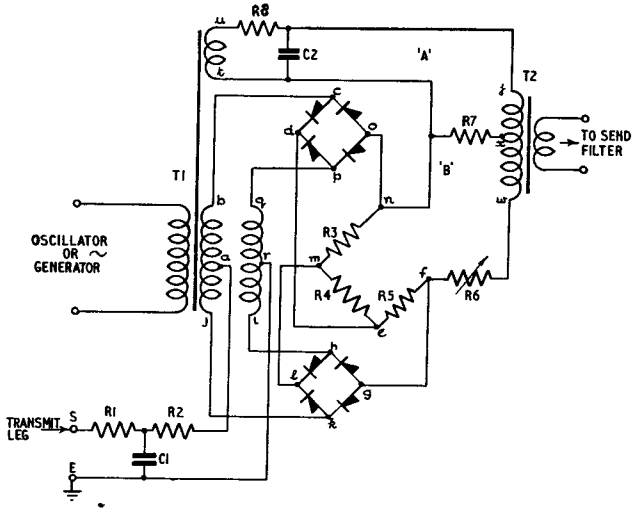


FIG. 10.41. PRINCIPLE OF CHANNEL MODULATOR (TYPE 4 M.C.V.F. TELEGRAPH SYSTEM)

leg S, it will be evident that the d.c. voltage drop through path a, b, c, d, to e, equals that through path a, j, k, l, to m. Thus the d.c. potential at "e" is equal to that at "m" and therefore no d.c. flows in $R4$. Similarly considering the paths n, o, p, q, r and f, g, h, i, r the d.c. potential at points "n" and "f" are equal and therefore no d.c. flows through the output circuit formed by $R6$ and $R7$ and the transformer winding "wx."

Considering now the a.c. conditions, then as the rectifier arms cd, op, and gh, kl are now conductive to a.c. as the result of the flow of d.c., then a.c. voltage from transformer winding "bj" appears across em, whilst the a.c. voltage from transformer winding "iq" appears across "fn." The a.c. potential of points e and f are equal and so also are points m and n. Thus a.c. does not flow between points e and f nor between points m and n. The a.c. output from winding bj is thus terminated across points e and m in $R4$ and causes no interference with the output from winding iq which appears across fn and is terminated in $R7$ and $R6$ and the output transformer winding wx.

When the potential of the transmit leg S is negative to earth, i.e. during marking signals, the rectifier arms oc, pd and gh, kl are made conductive. From similar considerations as before, it can be shown that the a.c. output from transformer winding iq now appears across points m and e and is terminated in $R4$, whilst that from transformer winding bj appears across nf and is terminated in $R7$ and $R6$ and the output transformer winding wx. It will thus be clear that the effect of marking and spacing signals on the modulator is to cause the winding wx of the output transformer $T2$ to be selectively switched to receive carrier tone either from winding bj or iq respectively of transformer $T1$. It will be observed that a carrier tone is fed continuously from winding ut of $T1$ to winding jx of $T2$. The tone from bj is in phase with that from ut but the tone from qi is in anti-phase. Hence for marking signals the effect on the secondary winding of $T2$ of the tones in windings jx and xw are additive and as they are adjusted by $R6$ to be equal, the voltage of the tone at the secondary winding of output transformer $T2$ is twice that produced by the tone fed through path A to winding jx. For spacing signals, the currents in windings jx and xw have equal and opposite magnetic effects and therefore no output voltage is produced at the secondary winding of $T2$.

The purpose of $R8$ and $C2$ is to ensure that the tone in jx is in phase with that in xw during marking signals.

The phase response in path B is directly proportional to the magnitude of the controlling voltage exercised by the line signal. Thus, if the controlling polarity changes linearly from a small marking voltage, through zero, to a small spacing voltage, then the output of path B will also change linearly from the additive phase condition, through zero, to the subtractive phase condition.

The output from the filter therefore changes linearly from the full steady state output when marking to the half value corresponding to zero d.c. control volts and thence to no-tone corresponding to the spacing condition. Marking and spacing d.c. signals therefore produce V.F. pulses which have a trapezoidal envelope and as already explained this avoids carrier beat interference.

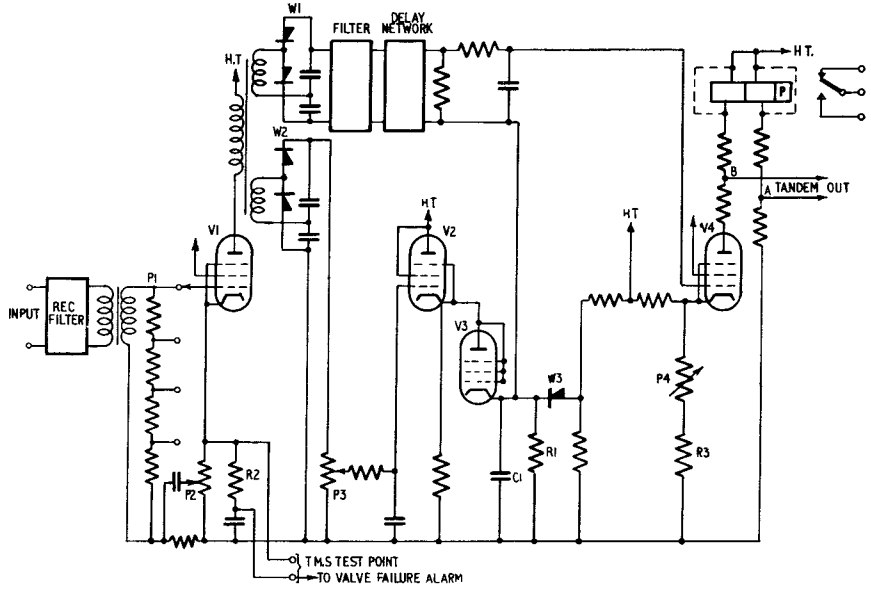


FIG. 10.42. PRINCIPLE OF AMPLIFIER-DETECTOR (TYPE 4 M.C.V.F. TELEGRAPH SYSTEM)

The Amplifier-detector Circuit. The improvements incorporated in the detector circuit of Type 4 equipment as compared with the detector of Type 3 equipment will be clear from the following description of the basic circuit. Fig. 10.42 is a schematic diagram of the detector circuit. The receiving filter comprises two stages; the first is at the input to the detector panel and is identical with the transmit filter, and the second, which is the same for all channels, follows after the signal rectification stage.

As already explained this new filter arrangement makes a valuable contribution to the detector both in terms of reduced distortion and greater simplicity.

Examining the circuit further, it will be seen that

the first valve $V1$ provides a standing voltage which is continuously monitored by the Valve Failure Alarm panel on each rack-side. This is set to give an alarm as soon as the monitored voltage on any detector panel falls below a certain value. In this way, timely warning is given of cathode emission falling off or H.T. or L.T. voltage failure.

At the same point in the circuit, the a.c. voltage developed across the resistance $R2$ when a steady tone is being received can be measured by the Transmission Measuring Set (T.M.S.) mounted on one of the rack-sides. The gain of valve $V1$ being adequate for measurement of the spacing level of incoming tone with the T.M.S., this test point is also convenient for measuring the efficiency of the transmit modulator after first looping the send filter to the receive filter.

The potentiometer $P2$ in the cathode circuit provides a gain adjustment over a small range to compensate for individual valve characteristics and other slight variations.

The output of the first amplifier stage is fed through a transformer to two voltage doubler rectifier circuits. The first of these, $W1$, passes a rectified signal through the second stage of filtration to a network which delays the pulses before they are applied to the grid of the output valve. This signal path, besides introducing delay, also makes some correction of phase distortion.

To ensure that the grid bias of the output valve is appropriate to the signal amplitude a bias voltage is developed in a second path which has no such delay feature. This bias voltage is derived from the second voltage doubler $W2$, the bias being developed across the reservoir capacitor $C1$ which constitutes an integral part of the grid-cathode circuit of the output valve. The two valves $V2$ and $V3$ in the bias path act as a cathode-follower and a diode respectively and ensure that the charging time of the capacitor $C1$ is very short. This means that the voltage across $C1$ develops very quickly after a long space and will invariably have achieved its correct value before the delayed signal is delivered through the signal path. When required, therefore, to work in conditions where, as is often the case in teleprinter switching networks, there are long periods of "no tone" there is negligible distortion on the first signal received.

The discharge time constant of $C1$, $R1$ being long, the correct bias, once built-up, is maintained over a period of time sufficient for the reception of many characters. Since, at high speeds, there is a tendency for the shorter elements of code signals to contribute little if anything towards maintaining the correct bias the long discharge time ensures low distortion at high speeds.

As a safeguard against false operation to line noise, the rectifier $W3$ and its associated potential divider circuit serve to ensure that the steady voltage across $C1$ never falls below a certain minimum even during periods of no-tone. Since this minimum is below the voltage of genuine signals, but above that of anticipated noise, false signals of small amplitude, due to noise, do not produce any change of anode current on the output valve $V4$ and the relay remains on its spacing contact in the no-tone condition.

It will be appreciated that, since the bias circuit virtually determines the correct relay response to signals, some form of bias adjustment is essential to regulate the magnitude of bias in relation to signal amplitudes. The total bias (grid-cathode $V4$) is the difference between the voltage across capacitor $C1$ and the voltage developed on the cathode resistors $P4$ and $R3$. Of the two bias controls available, $P3$ is most effective in controlling the bias of signals of large amplitude. After this end of the range has been adjusted, $P4$ becomes effective in varying the bias volts at the low end of the range. By progressively adjusting for minimum bias first with $P3$ and then with $P4$, the intermediate signals will automatically achieve their correct levels. The two adjustment levels are 15 db apart and over this range of input level there is negligible bias. Beyond this range, the bias starts to increase although satisfactory results are still obtained for a few db above and below the bias free range.

By short-circuiting the relay windings, the output stage can be coupled directly to the modulator of another system for tandem working. In this way, the output provides 1 mA double-current signals, point A on the circuit being maintained at a constant voltage to earth, while point B is made to vary an equal amount above and below the potential of A, depending on whether the output valve is marking or spacing.

Use of Frequency-modulated Multi-circuit Voice-frequency Telegraph Systems on Landline and Submarine-Cable Circuits

Until 1956 the C.C.I.T. had only recommended standardization of the characteristics of amplitude-modulated M.C.V.F. telegraph systems for use on international telegraph circuits, as the use of frequency-modulated systems had until then been confined mainly to a relatively small number of circuits, in a few national networks, on which the advantages obtained by the use of F.M. justified the additional complexity and greater cost of the equipment. The basic principles of F.M. and its comparison with A.M. have already been described,

and the reader is referred to Chapters 1 and 5 for this information.

The advantages conferred by F.M. compared with A.M. include improved signal-to-noise ratio (6 db improvement is theoretically obtainable), wider received signal level range, rapid response to changes of level (up or down) and improved performance at higher speeds of operation for a given frequency spacing between channels. These factors make frequency-modulated M.C.V.F. telegraph systems especially suitable for use on circuits in which high noise levels may occur, e.g. radio links, long open-wire lines and other circuits which are liable to frequent changes of level of short duration. In addition, where telegraph systems have to be operated over long submarine telephone cables and it is of paramount importance to exploit the available band-width as fully as possible, the use of a F.M. telegraph system is preferable to A.M. A good example of this use is the transatlantic telephone cable in which a frequency-modulated M.C.V.F. telegraph system is operated between London and Montreal (see bibliography Nos. 1 and 2). Using channels spaced at 120 c/s and with a frequency deviation of $\pm$ 30 c/s the overall distortion using mixed signals at 60 bauds is only 4 per cent and is less than 8 per cent at all signalling speeds up to 80 bauds. Each channel is therefore capable of carrying the aggregate signals of a 2-channel time-division multiplex system at a speed equivalent to 800 characters per minute.

In recent years there has been a considerable increase in the provision and use of telegraph channels for switched networks, e.g. Telex. For this purpose it is particularly desirable that the channels should be highly stable and have low distortion as some calls have to be set up over a large number of channels in tandem. The probability of errors in transmission has to be kept to an extremely low order and the required standards are not easily attainable in practice when using A.M. telegraph channels. Concurrently with the development of telegraph services, increasing use has had to be made of telephone carrier and coaxial systems for providing vehicle circuits for the telegraph systems, and whilst this has cheapened the costs of provision, practical experience indicates that these circuits are more prone to transient changes of level and noise than those which occur on audio circuits. These effects react adversely upon the performance of telegraph channels routed over them by causing increase of distortion and errors in transmission. Tests and practical experience in several countries have shown, however, that F.M. telegraph channels are less affected by these transient disturbances than A.M. channels and this has led to a greater interest in the use of frequency-modulated M.C.V.F. telegraph systems. In anticipation of a need for their use in international telegraph service the C.C.I.T. at the VIII th Plenary Assembly Meeting, Geneva, 1956, made a timely recommendation that the following international standards should be adopted for narrow-band frequency-modulated M.C.V.F. telegraph systems—

(1) That frequency-modulated voice-frequency telegraph systems should be able to provide 24 channels.

(2) That the nominal modulation rate should be standardized at 50 bauds.

(3) That it is desirable to adopt for the mean frequencies the series of frequencies furnished by the odd multiples of 60 c/s; the lowest frequency being 420 c/s in conformity with the frequencies already standardized for amplitude-modulated systems (see Table 10.1).

(4) That these frequencies should not deviate from their nominal values by more than 2 c/s.

(5) That the difference between the two characteristic frequencies (corresponding to the start and the stop conditions) should be 60 c/s, although a difference of 70 c/s may be used by mutual agreement between the Administrations concerned.

(6) That the tolerance permitted in this difference should be at most $\pm$ 3 c/s.

(7) That the total power transmitted to the telephone line by all the channels of a system should normally be limited to 135 microwatts at a point of zero relative level. This sets, for the average power of a telegraph channel (at a point of zero relative level), the limits given in Table 10.2.

TABLE 10.2

Normal Limits for the Power per Channel in a Frequency-modulated Voice-frequency Telegraph System

Voice-frequency telegraph system	Allowable power per telegraph channel at a point of zero relative level		
	In microwatts	In an absolute power level	
		Nepers	Decibels
12 telegraph channels, or less.	11·25	— 2·25	— 19·5
18 telegraph channels.	7·5	— 2·45	— 21·25
24 telegraph channels.	5·6	— 2·6	— 22·5

Nevertheless, by agreement between interested Administrations or Private Operating Companies these power limits may be raised for frequency modulated telegraph systems established on an audio telephone circuit or on a very long voice-frequency telegraph circuit routed on a channel of an open-wire carrier system, or on a channel of a radio relay system, or on a channel of a cable carrier system. The limits thus raised should never exceed those which have been fixed for the power (at a point of zero relative level) corresponding to the transmission of a continuous tone for amplitude-modulated voice-frequency telegraphy and which are given in Table 10.3.

TABLE 10.3

Limits which may be Applied, by Agreement between Administrations, for the Power per Telegraph Channel in Frequency-modulated Voice-frequency Telegraph Systems

Voice-frequency telegraph system	Allowable power per telegraph channel at a point of zero relative level		
	In microwatts	In absolute power level	
		Nepers	Decibels
12 telegraph channels, or less.	35	— 1·67	— 14·5
18 telegraph channels.	15	— 2·1	— 18·25
24 telegraph channels.	9	— 2·4	— 20·9

(8) That the frequency corresponding to the transmitted condition of start polarity is the higher of the two characteristic frequencies and that corresponding to the stop polarity is the lower.

(9) That in the absence of control current in the modulator of a channel, the frequency transmitted should be that corresponding to the start polarity.

(10) That in the event of the telephone circuit being cut, the receiving equipment should assume the condition corresponding to the start polarity.

(11) That the number of significant conditions of modulation is fixed at two but that the number may be increased if necessary by mutual agreement between the Administrations concerned.

Apart from the use of these standards for international F.M. telegraph systems they will, no doubt, considerably influence the design of systems for use in national networks. In this connexion the use of F.M. telegraph channels on the trunk routes of switched telegraph networks would be a most beneficial initial application for such systems and it seems likely that increasing use of them for this purpose will be made in the future.

Current developments in the field of transistors, in the direction of cheaper and more reliable units, are extremely promising and should enable both A.M. and F.M. systems to be developed which will have the advantage of occupying much less rack space than most existing forms of M.C.V.F. telegraph equipment using thermionic valves. At the same time, the use of transistors will have the additional advantage of enabling a considerable and welcome reduction to be made in the power consumption and heat dissipation of the equipment. Several manufacturers in the United Kingdom are actively developing transistorized M.C.V.F. telegraph systems at the present time (1957) and satisfactory designs can be confidently expected.

Operation of M.C.V.F. Telegraph Systems on Radio Links

For routes over which a number of radio-telegraph circuits are required it is desirable to employ some form of multi-channel working as this enables economies to be made in the radio-frequency band-width utilized and reduces the necessary provision and maintenance of radio transmitters, receivers and aerials, as compared with the use of a number of independent radio telegraph links.

The basic methods of channelling radio telegraph links are by means of either frequency-division, time-division multiplex or multiple frequency-shift systems, and the choice of method in any particular case is often limited by practical considerations imposed by the characteristics of the radio equipment available for the link. For example, Class "C" radio-telegraph transmitters are suitable for time-division or multiple frequency-shift systems, whereas frequency-division systems require the use of radio transmitters and receivers having adequately linear amplitude characteristics to limit the inter-modulation, and hence the telegraph signal distortion, to a low order.

One of the most important considerations in the design of multi-channel radio-telegraph systems, and indeed in any form of radio operation, is the necessity for economy in the use of the radio frequency spectrum. This factor is becoming increasingly important due to growing international demands for frequency allocations for various services. In telegraphy, it is essential to restrict the band-width utilized by individual channels to the minimum giving satisfactory operation at the signalling speed desired. The band-width allocated to each channel is a function of the maximum

signalling speed which the channel is required to transmit and it may also be affected by the methods adopted to counteract the effects of noise and fading.

Ideally, the characteristics of a channel should ensure that the distortion of the received signals never exceed the margin of the telegraph receiving equipment. This, however, is rarely possible in practice under all conditions of propagation, due to the effects of general and selective fading, interference and noise, but the design and operating arrangements adopted must nevertheless give the maximum periods of serviceability with the lowest practicable probability of error. On the more difficult routes this necessitates operating the channels in conjunction with automatic error-detecting and correcting equipment (see Chapter I).

An important contribution both to economy in band-width and stability of working telegraph channels is obtained by the use of synchronous telegraph signalling and the employment of such methods is always advisable on long distance H.F. radio telegraph links. For this reason the channels of multi-channel frequency-division radio-telegraph systems are commonly designed for a signalling speed capable of carrying the aggregate signals of either 2-channel or 4-channel time-division multiplex systems, thus enabling the advantages of both methods of channelling to be combined. Similarly, time-division multiplex systems are frequently operated in conjunction with the individual channels of multiple frequency-shift systems.

Power Level and Noise in Frequency-division Telegraph Channels. The power transmitted by each channel of a multi-channel frequency-division telegraph system must be as high as practicable to load the radio transmitter fully, but not so high as to overload it and cause intermodulation. In considering this question, the aggregate signals in a frequency-division telegraph system may be regarded as the sum of a number of equal amplitude vectors having a more or less random phase relationship. Thus, if there are C carriers of amplitude V which may be transmitted simultaneously then the maximum instantaneous amplitude that the aggregate signals can attain is CV. To pass this signal, without introducing intermodulation distortion, the peak power handling capacity P, of the transmitter must be proportional to $(CV)^2$. The power available for each channel is therefore $\frac{P}{C^2}$

Assuming the noise present in the common path is uniformly distributed in frequency, then the noise in each telegraph channel is proportional to its band-width. Hence the noise in each telegraph channel before demodulation is equal to—

$$n = \text{Total noise power in the common path} \times \frac{\text{Band-width of telegraph channel}}{\text{Total band-width}}$$

Before demodulation the average signal/noise ratio for a channel calculated on the foregoing basis would be proportional to $\frac{P}{C^2} \times \frac{1}{n}$, from which it will be seen that for a given transmitter peak power the signal/noise ratio in each channel deteriorates as the number of channels is increased. It may, however, be shown that as the number of channels is increased the chance of the aggregate signals approaching closely the peak amplitude quoted above for a given percentage of time becomes statistically less, and in practice this enables a somewhat higher power to be used for each channel. The following Table indicates typical values employed in practice. From this it will be observed that for up to four-channels the channel powers employed correspond to "voltage addition" and beyond this number they correspond to "power addition."

No. of Tones Simultaneously Transmitted	Maximum Level per Tone in db relative to Transmitter Peak Power Rating
1	0
2	− 6
4	− 12
6	− 13·8
8	− 15
12	− 16·8

When a common radio link is employed simultaneously for telephony and telegraphy, the level of the telephone channels is maintained at its usual value but in the channel used for telegraphy the level of the emission is reduced by up to 3 db if one telephone channel is also present, and by up to 6 db for two telephone channels.

Single-tone (ON-OFF) M.C.V.F. Telegraph Working. The simplest form of frequency-division telegraph system is that commonly used on land-lines and described earlier in this chapter. Since telegraph channels of this type employ on-off tone-keying, the operation of the system is equivalent to single-current working with its attendant disadvantages. The A.G.C. circuit in the amplifier-detector of each receiving channel caters for level variations in the received signals of the order of

± 5 to ± 10 db relative to the normal received input level. The time-constant of this A.G.C. is several seconds, commonly about five, so that the bias controlling the sensitivity of the detector remains sensibly constant during the tone-off elements of the code signals but adjusts itself to slow changes in level of the incoming signals.

Noise of gaussian distribution produces distortion which can be expressed in terms of the signal/RMS noise ratio of the channel but leads to no other complications. However, impulsive noise, which is usually in bursts of short duration and greatly in excess of the signal level, will increase the gain-control bias and cause the sensitivity of the detector to fall. Because of the long A.G.C. time-constant employed, the gain is depressed for an appreciable time during which the incoming signals may be lost.

Fading on H.F. radio circuits is often too great and too rapid to be compensated by the gain-control circuit of the M.C.V.F. telegraph equipment and, although the radio receiver may have a relatively fast acting A.G.C., it can only respond to general fades and does not provide any remedy for selective fading.

Because of the disadvantages outlined above this system is rarely employed on long-distance H.F. radio circuits.

Two-tone Working. It is evident that for radio use a telegraph system is required which is, as far as possible, immune from changes of signal level and to noise. This can be achieved most readily if some signal is being received all the time, i.e. during both marking and spacing signals, so that the equivalent of double-current operation is obtained. One method of realizing this is to use a two-tone system, employing one tone for marking signals and another for spacing signals. This arrangement approximates to frequency modulation.

In two-tone working, a common level control for both the mark and the space frequency is possible as one of the tones is always present to control the gain. It is therefore possible to use a much shorter time-constant than in a single-tone (on-off) detector, where relatively long periods of no-tone have to be bridged and the gain control in the two-tone detector panels is therefore able to follow the comparatively rapid changes of level experienced on a radio link.

The two frequencies of a two-tone channel are close together in frequency, so that they tend to be similarly affected by fading and circuit noise. The effect of fading and noise on the mark and space frequencies therefore tends to be self-cancelling at the output relay and, provided a reasonable signal/noise ratio is maintained and the circuit is not subject to much fading, a satisfactory service can be secured.

It should be noted that two-tone working has the practical advantage that certain amplitude modulated M.C.V.F. telegraph equipment in common use on landlines can be readily adapted to the purpose.

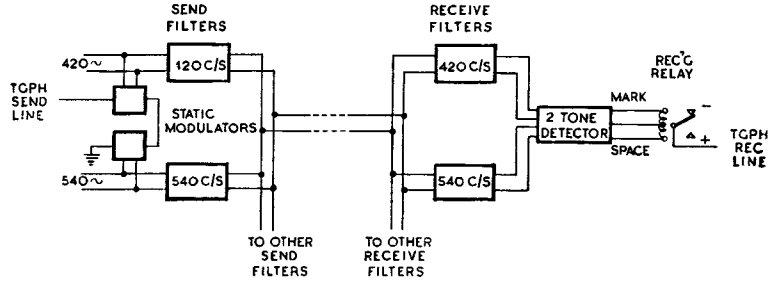


FIG. 10.43. SCHEMATIC CIRCUIT OF A TWO-TONE V.F. TELEGRAPH CHANNEL

However, two-tone working using standard M.C.V.F. telegraph equipment has the disadvantage that in comparison with on-off keying it doubles the band-width utilized by each channel and, due to the effects of phase discontinuity when one oscillator is switched on and the other off in passing from marking to spacing and vice versa, the signal distortion is higher if a common limiter is used than that of a channel employing true frequency-shift at the sending end. Fig. 10.43 shows a schematic circuit of a typical two-tone channel in which 420 c/s is used for marking and 540 c/s for spacing.

Two-tone Detector Panel. Fig. 10.44 shows the connexions of a two-tone detector panel, which comprises two single-tone amplifier-detector circuits. The anode voltage to each of the output stages is applied differentially through the windings of the receiving relay common to both detector circuits, the H.T. supply being connected to the centre-point of the relay. The top half of the circuit diagram shows the marking side and the lower half shows the spacing side. Both output valves $V5$ and $V6$ are biased by the voltage developed across the common cathode resistor R_B. When marking tone is received, it passes from the output of the marking-frequency filter to the input transformer. It then passes to $V1$ where it is amplified, the amplified output being applied to the anode of the diode $V3$. The diode acts as a full-wave rectifier and the resultant voltage developed across b–a appears on the grid of the

output pentode as a positive d.c. bias. Anode current is therefore passed by $V5$ and since it flows through the marking coil of the receive relay, the armature is operated to the marking contact. The function of C_L and R_L is to provide automatic gain-control on the output stages. If the signal voltage applied to the grid of the output stage $V5$ exceeds the fixed bias, grid current will flow and develop a voltage across R_L and reservoir capacitor C_L. This voltage holds the operating point of $V5$ in such a position that grid current only just flows and the anode current from $V5$ is thus maintained reasonably constant, irrespective of input level. The bias voltage developed across R_L is also applied to $V6$, which at this stage is receiving no signal, and thus prevents stray noise received through the spacing filter from materially affecting the marking signal. The time-constant of C_L and R_L (nominally 10 msec) is sufficiently small to compensate for the most rapid variations of input level normally encountered. The lower portion of the circuit operates when spacing tone is applied, except that the relay armature is operated to the spacing contact.

Bias adjustment is obtained from an input potentiometer which has the effect of differentially balancing the input tones to the marking and spacing detectors. With this detector, a range of input level approaching 50 db is possible without readjustment.

Diversity Operation. H.F. radio links are subject to severe selective fading, and two-tone operation is more susceptible to its effects than frequency-shift systems. However, by the use of diversity methods, which will now be described, much of the effect of selective fading can be overcome.

Frequency Diversity Working (four-tone and six-tone). It sometimes occurs that under the effects of selective fading one circuit is temporarily affected whilst another, spaced only a few hundred cycles away, is still working satisfactorily. By combining two two-tone circuits to work in parallel a four-tone circuit is derived in which it is arranged that the frequency which is being received at the higher level takes charge of the output relay, with the result that noise from the channel experiencing a deep fade is suppressed, and the signal controlling the output relay is always taken from the channel with the higher received level. The use of four-tone working gives a considerable improvement, compared with two-tone operation, on circuits subject to severe selective fading. Still further improvement can be secured by six-tone working, i.e. three tones for mark and three tones for space, thus utilizing three two-tone channels.

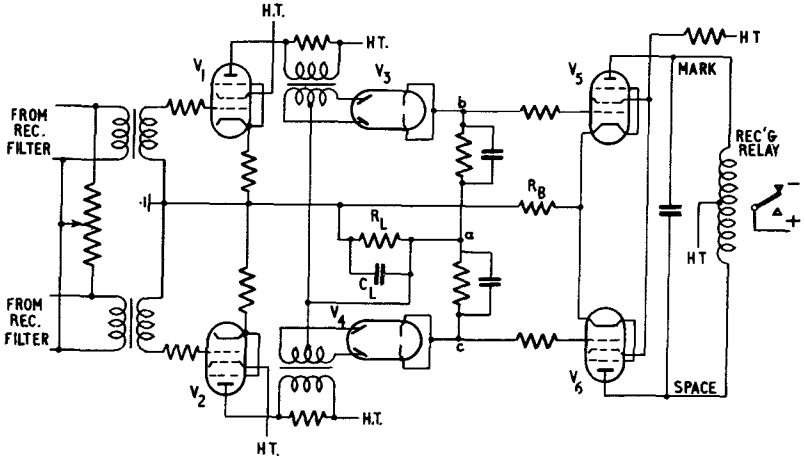


FIG. 10.44. SCHEMATIC CIRCUIT OF A TWO-TONE AMPLIFIER-DETECTOR PANEL

In four-tone and six-tone working the frequencies forming each two-tone channel are those of two adjacent basic channel frequencies, e.g. only 120 c/s apart, and the spacing between corresponding frequencies, e.g. mark tones, should be not less than 400 c/s as recommended by the International Radio Committee (C.C.I.R. Recommendation 106, London, 1953).

The following typical case of 120 c/s basic channels employed for 50 baud operation illustrates the application of the foregoing principles—

Signal Condition	Four-Tone Working	Six-Tone Working
Marking	420 c/s. and 1,140 c/s.	420, 1,140 and 1,860 c/s.
Spacing	540 c/s. and 1,260 c/s.	540, 1,260 and 1,980 c/s.

An obvious disadvantage of frequency-diversity operation is that it involves the use of a fairly wide band-width and reduces the permissible power per tone and hence the signal/noise ratio. This disadvantage can be avoided by the use of "space-diversity" instead of "frequency-diversity" methods.

Space-diversity Two-tone Working. Space-diversity operation reduces the effects of selective fading by the use of two, or even three, radio receivers with separate receiving aerials, spaced so that a given frequency is not likely to fade simultaneously on all receivers. A complete M.C.V.F. telegraph receiving equipment is connected to each radio receiver output and the two-tone detectors of each channel are paralleled in the same way as for frequency-diversity. This method is preferable to frequency-diversity operation when site space at the receiving station permits its use, as it requires no more than half the band-width of a four-tone channel. Also, less power is required for each telegraph channel for comparable performance. The use of space-diversity, whenever practicable, in preference to frequency-diversity is recommended by the C.C.I.R. (Recommendation 106, London, 1953).

The method of coupling the detector panels of the corresponding channels of each system is as follows. The output pentodes and receiving relay of two of the channels (in triple-space diversity) are not used and the outputs of the mark and space diodes of these channels are connected across points *a* and *b* (mark diode) and points *a* and *c* (space diode) of the remaining detector panel. Three marking signals are therefore applied to *V*5 and three spacing signals to *V*6 (see Fig. 10.44). During marking periods, the mark frequency which is being received at the highest level will take charge of the output valve and, similarly, the strongest signal takes charge during spacing periods. This arrangement prevents noise associated with the weaker signals from affecting the output.

Use of Amplitude Limiters. Where two-tone working is used and impulsive noise is present considerable advantages can be derived from the use of amplitude limiters. The mark and space frequencies are applied to a common limiting amplifier, the output of which is separated into two channels, by appropriate filters, before passing to the two-tone detector. One disadvantage of this method is that, because of the narrow channel band-width used on M.C.V.F. telegraph systems the build-up and decay times of the signals are an appreciable fraction of the unit signal element, overlap of the mark and space signals occurs in the limiter. This results in mutual interference between the two channel frequencies due to the non-linear characteristic of the limiter and produces an appreciable increase in the telegraph signal distortion, e.g. for 120 c/s channels working at 50 bauds, a minimum channel distortion of the order 15–20 per cent is obtained. Such channels may therefore require regeneration before they can be connected in tandem with landline VF channels. The foregoing limitation does not apply to two-tone systems in which the band-width is sufficiently wide to ensure short build-up and decay times.

Frequency-modulated M.C.V.F. Radio Telegraph Systems. The main benefits which can be obtained from a M.C.V.F. frequency modulated telegraph system compared with a system employing on-off keying are—

(1) It provides the equivalent of double-current operation.

(2) It is insensitive to large changes in the received signal level as variations in amplitude can be removed, provided they are not too severe, by an amplitude-limiting stage in the telegraph channel receiver.

(3) The effect of noise is reduced. Compared with a single-tone AM channel an FM channel, using tone of the same amplitude, has an inherent 6 db improvement in signal/noise ratio for noise distributed over the band due to its use of an essentially double-current principle.

The principal disadvantages of FM operation compared with AM are that it necessitates the use of more complex modulating, demodulating and carrier-frequency generating circuits in the telegraph channel equipment. Furthermore, accurate control of frequencies is of paramount importance otherwise bias distortion will be produced in the received signals. The distortion which will arise from frequency error is approximately proportional to the ratio of the error to the frequency deviation and is thus most important in the case of narrow band systems, e.g. in a multi-channel system employing a channel spacing of 120 c/s with 100 c/s effective band-width and 30 c/s deviation, an increase in distortion of approximately 2 per cent at 50 bauds will occur from a frequency error of 1 c/s.

It is therefore of prime importance to maintain very accurate control of the frequencies of the channel tones and also of the radio-frequency translation processes in the transmitter and the receiver. Control of the channel tone frequencies presents no great difficulty but it will be clear that in the radio channel it is necessary to employ either automatic frequency control (A.F.C.), with high instantaneous accuracy, reconditioned carrier demodulation or some equivalent method. Small residual frequency differences between the transmitting and the receiving ends of the system can be

catered for without any appreciable increase in telegraph distortion by the use of a pilot tone channel. The pilot tone is transmitted with the group of traffic channel frequencies and thus will undergo the same frequency change, due to errors in the frequency translation processes in the radio channel, as the group of traffic channels with which it is associated. At the receiving M.C.V.F. terminal a voltage is derived from the pilot tone, proportional to the frequency error, which is continuously applied to each telegraph channel to control an automatic bias-correcting circuit. This arrangement will compensate for frequency errors up to about 10 c/s in the case of narrow band 120 c/s channels; beyond this limit about 2 per cent distortion per 1 c/s error occurs at 50 bauds.

In independent side-band (ISB) and single-side-band (SSB) radio circuits the partially suppressed pilot carrier is normally — 26 db with respect to the level of the peak envelope power of the transmitter. In practice this level is sometimes too low for effective use owing to the effects of fading and noise and a local carrier (the frequency of which is controlled by the pilot carrier) is then employed for demodulation. During fading a small frequency error can accumulate which may affect the operation of narrow band FM systems and it may be desirable in such cases to increase the level of the reduced carrier.

The determination of the channel band-width necessary for a given signalling speed is not an easy matter and involves consideration of a number of conflicting factors of which frequency error of the nominal sub-carrier is one. It has already been shown in Chapter 1 that the modulation of a carrier frequency f_c by a sine wave modulating frequency f_m results in the production of side-band frequencies as follows, in addition to the carrier frequency f_c—

$$f_c - f_m, \qquad f_c + f_m$$
$$f_c - 2f_m, \qquad f_c + 2f_m$$

and so on to infinity.

The side-band components which result are clearly more complex than for amplitude modulation and the relative amplitudes of the carrier and side-frequency components are dependent upon the modulation index given by—

$$\frac{\text{Peak frequency deviation}}{\text{Modulation frequency}} = \frac{\Delta f}{f_m}$$

It will be appreciated that when a carrier frequency is modulated by telegraph signals the conditions are more complicated than are indicated by the foregoing, since each frequency present in the modulating signal contributes to the total frequency deviation and also to the production of side frequencies. The term "deviation ratio" is used in this case to denote the ratio of the maximum carrier-frequency deviation to the maximum frequency present in the modulating wave.

The energy content of the side-band frequencies lying outside the frequencies $f_c + f_m + \Delta f$ and $f_c - f_m - \Delta f$ is very small and the effective band-width of the modulated signal is therefore equal to $2(f_m + \Delta f)$. With increase in the modulation index the number of side-band frequencies of significant magnitude is greater. If, at the same time, the frequency deviation remains unchanged, the effective band-width is reduced, being equal to twice the sum of the frequency deviation and the modulating frequency. The foregoing relationship is valid for values of modulation index up to about four; for greater values a wider effective band-width is necessary.

When it is desirable to restrict the band-width of the channels as much as practicable, it is possible, without undue increase in distortion, to use a band not much greater than that necessary to transmit the first side-bands, providing the deviation is not so great as to produce second side-bands of significant magnitude. This condition is secured with a deviation ratio of approximately 1·25 and the following practical example of the use of this principle is of interest, e.g. using a channel spacing of 120 c/s and a deviation of 30 c/s. FM channels can be operated with 3 per cent characteristic distortion at 50 bauds. This performance is at least as good as single-tone AM channels employing the same channel band-width.

It is important to avoid the use of a deviation ratio of less than unity as, unless a reasonable amount of frequency swing is employed, the signal cannot be demodulated satisfactorily and the effect of frequency error becomes serious.

Signal-shaping Network and Channel Filter. In order to reduce the number and magnitude of the input signal harmonics and so reduce the side-band products of modulation, it is desirable to employ a signal-shaping network prior to modulation to limit the band-width of the modulating signals to something approaching that necessary for the fundamental frequency of the maximum telegraph signalling speed. This arrangement also simplifies the design of the channel send filters and reduces inter-channel interference. The channel receiving filters of an FM telegraph system need to have a greater discrimination against adjacent channels than those of standard AM systems to minimize inter-channel interference to comparable values.

To reduce unwanted modulation products it is desirable to select the FM channel frequencies so

that they are odd multiples of half the channel separation of the mid-band frequencies. Nevertheless, the advantages derived from the selection of channel frequencies bearing an odd harmonic relationship to each other can only be realized to a limited extent in FM systems, compared with AM.

Post-discriminator Channel Filters. A post-discriminator channel filter having a band-width of approximately 1·5 times the maximum fundamental signalling frequency is necessary for two reasons, viz.—

(1) To eliminate channel frequencies from the demodulated signal, and

(2) To eliminate demodulation components caused by noise and interference in the transmission link.

The latter is of special importance since it contributes to the FM improvement in signal/noise ratio obtained when the signal/noise ratio before the limiter exceeds a certain threshold value. The FM improvement relative to an AM system of equal power and low frequency band-width is equal to $\sqrt{3} \cdot \frac{\Delta f}{f}$, where Δf is the frequency deviation and f is the cut-off frequency after the discriminator.

Space-diversity and Frequency-diversity. Substantially similar advantages can be derived from the use of space-diversity or frequency-diversity operation of FM telegraph channels to those already discussed in the case of AM telegraph channels.

Performance of FM Telegraph Channels in the Presence of Interference. The performance of FM telegraph channels in the presence of interference can be adequately predicted from a knowledge of the signal/noise ratio and the frequency characteristics of the various component sections of the system.

With adequate limiting and restriction of frequency range after demodulation, the effect of single-frequency interference within the channel range is less when a greater deviation, with corresponding band-width, is employed. However, with random noise, the narrowest possible deviation and band-width permit satisfactory operation under poorer conditions of noise than can be tolerated with channels having a greater deviation and of course a greater band-width. It will be clear that, whatever deviation is used, the band-width of the channel should be no greater than that needed to accommodate the significant components of the signal, otherwise noise will be admitted unnecessarily. The narrowest band FM channel performs considerably better than either the corresponding on-off or two-tone circuit.

Effect of Selective Fading. The result of experimental work by the B.P.O. so far indicates that no strict conditions for the selection of a system can be laid down for use in particular fading conditions. For moderate selective fading, i.e. up to 1·5 msec delay difference with 20 db fade-depth, the narrowest deviation system gives best results, e.g. 120 c/s channels with 30 c/s deviation working at 50 bauds start-stop, gave low peak distortion and a low probability of exceeding 20–30 per cent distortion. For delays greater than 1·5 msec the distortion rose quickly to 100 per cent.

For worse fading conditions, i.e. up to 4 msec with 20 db fade-depth, wider deviation channels gave better results, e.g. 450 c/s channels with 150 c/s deviation, working at 50 bauds start-stop, gave peak distortions never greater than 45 per cent, although the probability of exceeding 30 per cent distortion was high. Hence satisfactory service could be given over the whole fading cycle provided telegraph regenerative repeaters were employed.

The use of synchronous methods of working the telegraph channels would, as already explained, provide a greater margin of operation under selective fading conditions. In this connexion, however, it is important to note that when time-division multiplex systems are employed (which of course always operate synchronously) the aggregate signalling speed needs to be limited, otherwise excessive distortion will arise due to multi-path delay distortion. For example, depending upon the length and nature of a radio link, multi-path transmission may cause path time differences up to about 4 msec.

With 50 baud signalling (i.e. 20 msec elements) this effect may cause up to 20 per cent distortion of the signal elements, whereas at 200 bauds (i.e. 5 msec elements) it may cause up to 80 per cent distortion and thus render the signals incapable of correct reception. For this reason the use of systems in which the aggregate signalling speed does not exceed 100 bauds, e.g. two-channel seven-unit error-correcting systems of 400 characters per minute per channel, are usually favoured. In such cases the effect of 4 msec multi-path distortion would cause not more than 40 per cent distortion, and this is tolerable. The successful operation of four-channel time-division systems is possible only on links over which time delay distortion is not serious and, as in any event the margin of operation of the equipment is less than for two-channel systems, their probability of error is greater.

Multiple Frequency-shift Working. Another system of multi-channelling is in use in which a different frequency is transmitted for each of the possible permutations of the signalling conditions, which may occur simultaneously for the combined

channels. A frequency-shift will therefore occur corresponding to each change of signalling condition on any channel.

The number of carrier frequencies required for an N-channel multiple frequency-shift system for channels employing binary code signalling is therefore 2^N. In practice, this method of working is normally restricted to two-channel operation as the number of frequencies to be transmitted and hence the band-width occupancy, becomes prohibitive beyond this point.

The system retains many of the advantages of a time-division multiplex system in that the peak power of the transmitter is fully utilized and a high degree of linearity therein is not required. Moreover some of the limitations imposed by multipath distortion on a time-division multiplex system are overcome if the telegraph channels are synchronized one with another when, for an equal number of channels of equal traffic capacity, the signalling speed of the multiple frequency-shift system is reduced below that of a time-division multiplex system by a factor equal to the number of channels.

Twinplex. The best known example of multiple frequency-shift working is known variously as "Twinplex" or "Frequency-shift Diplex." It provides two channels and therefore requires 2^2, i.e. 4 carrier-frequencies, for its operation. Alternatively, a twinplex system can be used to transmit one channel of a three-condition code, e.g. cable code, and may thus be useful for direct interconnexion of a radio circuit and submarine cable circuit employing cable code. When employed in this manner only three frequencies are used, each corresponding to one of the three signalling conditions employed in cable code, thus reducing the total frequency shift required. In practice, twinplex is mainly employed in conjunction with binary signalling codes and for this the transmitted signal is a constant amplitude carrier, the frequency of which is varied in four equally spaced steps, the spacing normally used being 400 c/s. The two codes commonly in use are given in the following Table.

Frequency	CODE 1		CODE 2	
	Signalling condition in Channel A	Signalling condition in Channel B	Signalling condition in Channel A	Signalling condition in Channel B
f_1	Space	Mark	Space	Space
$f_2 = f_1 + 400$ c/s.	Space	Space	Space	Mark
$f_3 = f_2 + 400$ c/s.	Mark	Space	Mark	Space
$f_4 = f_3 + 400$ c/s.	Mark	Mark	Mark	Mark

The twinplex system can be operated with the two channels at different speeds and unsynchronized, a facility which renders the system very flexible. With this method of operation the performance of one particular channel, A, is little affected by the signalling condition prevailing in the other, B, but due to the finite operating time of certain gating circuits in the terminal equipment, the reverse is not the case and, under certain conditions, appreciable distortion can occur on the B channel. The performance of the system can be improved by operating the A and B channels synchronously so that the signal transitions in each channel occur simultaneously. In this manner the performance of the two channels can be made equally good and both are then suitable for transmitting time-division multiplex signals.

Twinplex systems have been used in this manner to carry a four-channel time-division system on each of the twinplex channels, thus providing as many as eight channels, all at peak power, from one twinplex transmitter. It is important in synchronized twinplex working, when the synchronized terminal telegraph equipment is remote from the twinplex equipment, to arrange that the transmission times of the signals over the intervening links are equal, otherwise distortion will be caused from the slight lack of synchronism between the two sets of signals in the twinplex transmitter.

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CHAPTER 11

START-STOP TELEGRAPH INSTRUMENTS

THE principles of start-stop telegraphy have already been described in Chapter 2 and the reader is recommended to read pages 53 to 55 before studying the present chapter which describes in detail typical start-stop telegraph instruments.

The essential feature of start-stop telegraphy is that the signal code of each character is preceded by a "Start" signal and followed by a "Stop" signal. The function of the start signal is to start the receiving instrument from its rest position in readiness for the reception of the code signals, which bear the intelligence of each character: and the function of the stop signal is to stop the receiver after the reception of each character, in readiness for the start signal of the next character. The speed of the transmitter and the receiver are made nominally the same and a governor is fitted to each machine to maintain their speeds constant within close limits.

Telegraph signals are distorted during their transmission over a line and it is essential that the receiver should be capable of receiving and correctly interpreting these signals even when a high degree of distortion is present. It is therefore important that loss of margin caused by speed error should be kept to a minimum by close control of the speed tolerance. The C.C.I.T. has recommended that start-stop transmitters should have a character cycle of 150 msec (i.e. 20 msec start signal, five-code elements of 20 msec each and a stop signal of 30 msec) and that their speed tolerance should not exceed $\pm$ 0·75 per cent. Hence, if such a transmitter, when 0·75 per cent fast, is working to a receiver, which is 0·75 per cent slow, the result will be that the successive signal transits produced by the transmitter for each character will all occur 0·75 per cent early whilst the selecting instants in the receiver will all occur 0·75 per cent late compared with their nominal theoretical timings. It will therefore be clear that a cumulative speed discrepancy between the transmitter and receiver will occur throughout the cycle of each character. However, providing the receiver is stopped by the stop signal at the end of the character, the maximum speed discrepancy will be confined to that which can occur during one character only. This is the great advantage of start-stop telegraphy compared with synchronous telegraph systems.

The maximum theoretical margin a receiver could have if it were ideal, is 50 per cent, which means that the timing, with respect to the beginning of the start signal, of any of the signal transitions from marking to spacing, and vice versa, may be displaced by a time equal to 50 per cent of the transmitted signal element. Thus for a 20 msec signal element the maximum theoretical displacement permissible would be 10 msec. In practical teleprinter designs 40 to 45 per cent margin is the more usual figure of performance, so that in this case the maximum permissible displacement of the timings is 40 to 45 per cent of the transmitted signal element, i.e. 8 to 9 msec (early or late) for a 20 msec signal element.

To ensure a high degree of margin in the receiver, the operating time of the clutch which drives the receiving cam must be short and as uniform as possible to reduce errors in the timing of the selecting instants, and the receiving cycle for each character must be completed before the arrival of the next start signal. The most onerous conditions arise when the transmitter is operating at its maximum speed, i.e. corresponding to automatic transmission conditions, as the time interval between successive start signals is then a minimum. Let us assume that the cycle of the receiver is made nominally equal to that of the transmitter, i.e. 150 msec, and that the transmitter and the receiver are 0·75 per cent fast and slow respectively. The transmitter will therefore complete each cycle in 148·875 msec and the receiver in 151·125 msec. Thus, under automatic transmission conditions an error of $(151{\cdot}125 - 148{\cdot}875) = 2{\cdot}25$ msec will occur at the commencement of the second selection cycle and a progressive error will accumulate over succeeding characters which will soon cause misselections to occur. The transmitter and the receiver will, in fact, get completely out-of-step with each other. To avoid these effects it is obvious that the duration of the receiving cycle must be made less than that of the transmitter so that the receiver is in its stopped position when the next start signal arrives.

In deciding upon the optimum duration of the receiving cycle account must be taken of the operating time for the receiving clutch, speed errors in the transmitter and the receiver, and the effect of signal distortion in the line.

Fortuitous distortion in the line may cause the signal transition corresponding to some start

signals to occur early and others late so that if, due to this effect, one early start signal follows immediately behind one which has been made late, the receiver in this case will have less time in which to complete its receive cycle for the first character before it is released for the reception of the second character. Another important factor is that some teleprinters employ transmitters having a 140 msec character duration and it is necessary to permit interworking between these machines and those having a 150 msec transmitting cycle. In practice this problem is overcome by designing the receiver so that its cycle is completed in $6\frac{1}{2}$ unit signal elements. Thus in start-stop instruments employing 7 unit signals and in which the start and stop signals and the 5-code elements are each 20 msec, the receiver completes its receiving cycle in 130 msec compared with the transmitter cycle of 140 msec; whilst in $7\frac{1}{2}$-unit start-stop working in which the stop signal is $1\frac{1}{2}$ units in duration, the transmitter cycle is 150 msec compared with 130 msec for the receiver. The use of $7\frac{1}{2}$-unit transmitters and receivers having a receiving cycle of $6\frac{1}{2}$ units is obviously a more sound arrangement as it permits a time displacement of 20 msec between successive start signals without endangering the stopping of the receiver by the stop signals.

It should be noted that the question of the receiving cycle over-running the commencement of a second start signal is mainly of importance in the case of automatic transmission of signals since, when transmission is from a manual keyboard, the hesitation of an operator in the selection of the next key to be depressed has the effect of prolonging the stop-signal of the preceding character.

The Teleprinter

Various types of start-stop telegraph instruments are employed, the most important being the Teleprinter (known in the U.S.A. as the Teletypewriter). The teleprinter is a self-contained instrument having a typewriter type of keyboard which is used for sending and which automatically controls the transmission of the appropriate start-stop signal code for each character. The teleprinter also includes a receiving mechanism which translates electrical start-stop signals from line into the corresponding function or printed character on a roll of paper or on a paper tape. When the machine is being used for transmission it may be arranged so as to provide a local printed copy of the message.

Start-stop telegraph systems often employ automatic transmission methods by the use of perforated tapes in conjunction with automatic transmitters. The message to be transmitted is recorded in 5-unit code form by perforations in a paper tape which is then passed through an automatic transmitter which interprets the perforations and transmits the corresponding start-stop signals to line. The instrument used for preparing perforated tape can be either—

(*a*) a keyboard perforator having a typewriter keyboard;

(*b*) a special teleprinter fitted with a perforating or reperforating attachment which produces a perforated tape, as well as the normal printed record, when the keyboard is operated or signals are received from line; and

(*c*) a reperforator which converts received start-stop signals into a perforated tape record.

In addition, to facilitate the identification and checking of messages on perforated tape, increasing use has been made in recent years of Printing Reperforators (Typing Reperforators in the U.S.A.) which not only produce a five unit code perforated tape but also print the message on the same tape.

Detailed descriptions of typical instruments are given in the following pages.

The Codes used in start-stop telegraph systems have been described in Chapter 1. The code for each character consists of five equal elements each of which may be one of two signalling conditions, either marking (M) or spacing (S) and the combination of elements for each character is preceded by a "Start" signal and is followed by a "Stop" signal. The function of the "Start" signal is to start up the mechanism on the receiving machine and prepare it for reception of the character combination elements; the "Stop" signal causes the mechanism of the receiving machine to come to rest at the end of a character and before the reception of the "Start" signal for the succeeding character. The "Stop" signal is therefore of the same polarity as that used for the normal rest condition in a circuit, i.e. marking, whilst the "Start" signal is a spacing signal.

For international working with start-stop equipment, the use of a standardized alphabet has been agreed, viz. "International Telegraph Alphabet No. 2 (see Chapter 1, page 7), and the durations of the "Start" signal and the five code elements have been fixed at one unit each, the time of a unit element being 20 msec. The length of the "Stop" signal is indeterminate since it is affected by the speed of operation of the transmitter, which may be a manually operated keyboard, but the minimum length has been fixed at one unit.*

* At the VIIth Plenary C.C.I.T. Meeting, Arnhem, 1953, it was agreed that the minimum length of Stop Signal should be not less than 1·4 units (preferably 1·5 units) and Administrations have been recommended to adopt this standard as soon as possible.

The number of different combinations of elements possible with a five unit code and using either of two signalling conditions for each element is 2^5, i.e. 32. It is not usual to use the combination of five spacing elements for a character combination and therefore only 31 combinations are available for characters. This number is insufficient for normal commercial practice and so it is customary to include on teleprinters a "shift" device which makes it possible for each combination to be used for two characters, the character to be printed at the receiving machine being predetermined by special letter-shift or figure-shift signals. Thus, after receipt of a letter-shift signal, the receiving teleprinter will print letters (or primary characters) and will continue to do so until a figure-shift signal is received; after which the machine prints figures (or secondary characters) until the next letter-shift signal is received. Two combinations out of the available 31 are used for the letter-shift and figure-shift signals and thus only 29 are left for character combinations. Since each of the 29 may have a primary and a secondary character allotted to it, a maximum of 58 characters is possible but this number is never used in practice for printing characters since a number of combinations is required for functional purposes, e.g. carriage-return, line-feed, and space.

Since the English alphabet has 26 letters, it is possible to accommodate each letter in the primary shift and have three combinations for functional

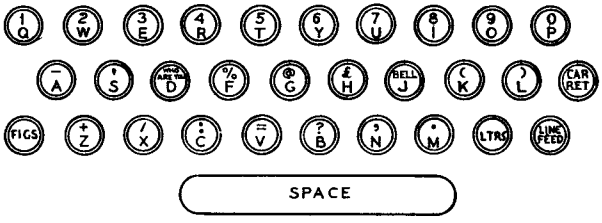


FIG. 11.1. TELEPRINTER NO. 7: KEYBOARD LAYOUT

signals other than letter-shift and figure-shift. These three combinations are most commonly used for "carriage-return," "line-feed," and "space."

The keyboards used on teleprinters resemble those used on commercial typewriters; in the British Post Office it is standard to have three rows (or banks) of keys but several other countries use a four row keyboard.

With the three row keyboard lay-out it is usual to have 10 keys in each row, giving a total of 30 keys, and a space bar (or space bars) which is situated in front of the lowest row of keys. This allows one key for each of the available 31 code combinations and, with the exception of certain keys which are allotted to functional signals, each key has a primary (letters) and a secondary (figures) character allotted to it. The functional signal keys have the same purpose in both the primary and secondary shifts. In addition, to enable the design of the transmitting mechanism to be as simple as possible, it is desirable that the secondary character should have the same code combination as the primary character associated

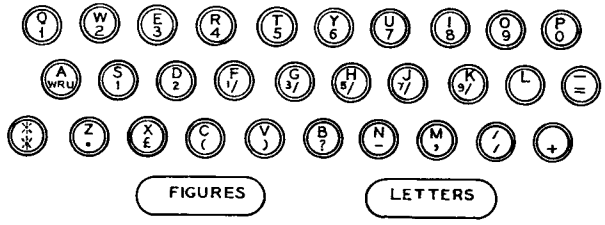


FIG. 11.2. TELEPRINTER NO. 3: KEYBOARD LAYOUT

with the same key and this is almost universally adopted.

Fig. 11.1 depicts the layout of the keyboard used on the Teleprinter No. 7 (which is employed on Private Wire and Telex Services) on which the allocation of the primary and secondary characters conforms to the International Telegraph Alphabet No. 2 (see Chapter 1). This teleprinter is primarily a page (column) printing machine and therefore, in addition to "Letter-shift" and "Figure-shift" keys, "Carriage-return" and "Line-feed" keys are provided. A single bar is provided for the "Space" function.

Fig. 11.2 shows the layout of the keyboard used on the Teleprinter No. 3. This machine is a tape-printing machine and was used extensively prior to 1954 on the British Post Office Inland (Public) Telegraph Service. "Carriage-return" and "Line-feed" keys are not provided and the allocation of the code combinations do not agree in all respects with the international standards. Also two space pads are provided and the "Letter-shift" function is associated with one whilst the "Figure-shift" function is associated with the other, no separate combination being allocated to "Space." Thus, whilst on a Teleprinter No. 7 it is possible to transmit and print a message of the form AB12CD34EF, on the Teleprinter No. 3 this could only be rendered as AB 12 CD 34 EF.

Fig. 11.3 shows the layout of the keyboard used on the Teleprinter No. 11 which is employed on the British Post Office Teleprinter Automatic Switching System for the Public Service. This teleprinter has now completely superseded the Teleprinter

No. 3 in the U.K. and like the Teleprinter No. 7 uses the International Telegraph Alphabet No. 2. The similarity of the two keyboard layouts will be seen by comparing Figs. 11.1 and 11.3. Three keys additional to those used on the Teleprinter No. 7 are provided. Two of these are located behind the third (top) row of keys, one at each end of the keyboard. The key at the left-hand side is used to the use of a d.c. or a.c. motor together with a governor which keeps the speed sensibly constant.

Direct current motors are preferable on performance and maintenance grounds and two types are employed, *viz.* (*a*) a shunt field motor, and (*b*) a series field motor. The principle and theory of these motors is described in many textbooks and therefore a detailed description will not be given.

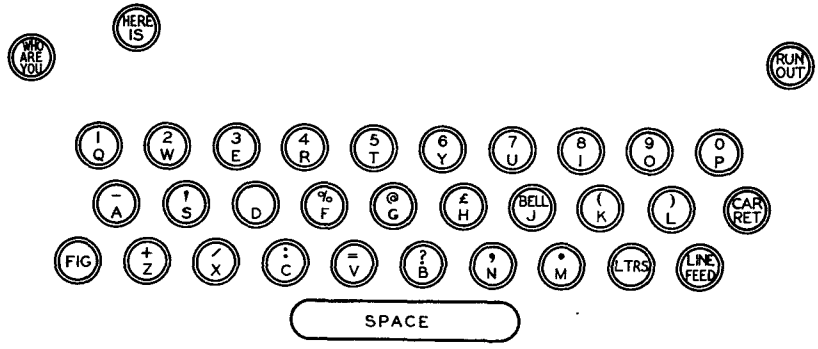


FIG. 11.3. TELEPRINTER NO. 11: KEYBOARD LAYOUT

send the "WRU" (D secondary) signal combination. The D key is not allocated any secondary character and, as will be explained later, arrangements are made to prevent its operation after the "figure-shift" key has been operated. Similarly the WRU key cannot be operated after the "letter-shift" key has been depressed.

The key at the right-hand side, called the "Run-out" key, when depressed results in the continuous transmission of the signal combination corresponding to the last key operated.

The third additional key, called the "Here is" key, is mechanically connected to the answer-back unit and is used to trip the unit and cause transmission of the home answer-back code as an identification signal.

Although the Teleprinter No. 11 is essentially a tape printing machine, "Carriage-return" and "Line-feed" keys are provided for use when the machine is worked to a page printing machine.

The Motor. To provide power for the operation of the mechanisms concerned with the transmission, reception and printing, teleprinters are provided with a motor. The primary consideration is constant and correct speed but it is necessary also that the motor should have a high starting torque and be capable of running for long periods with a minimum amount of maintenance attention.

Although synchronous motors can be used if reliable frequency controlled mains supplies are available, by far the most common arrangement is

However, the following paragraphs give sufficient information to enable the student to understand the operation of the motor in conjunction with the governor.

In the shunt wound motor the connexions of the armature and the field are as shown in Fig. 11.4. It will be seen that the field windings are connected directly across the voltage supply and as a result the current in the field windings is constant,

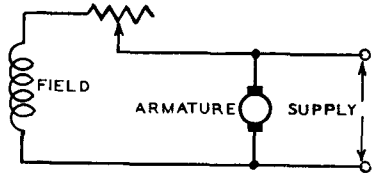


FIG. 11.4. SHUNT WOUND MOTOR CIRCUIT

resulting in a flux which is also constant except for the effect of armature reaction. Consequently the speed is almost uniform under all conditions of load; actually there is a small reduction in speed as the load increases, due to the increase in voltage drop in the armature resistance, as will be seen by reference to Fig. 11.5.

The connexions of the series wound motor are as shown in Fig. 11.6. The armature and field windings are in series and therefore any change in the load causes a change in both the armature and field current and thus causes a proportional variation in

the flux. At light loads the current is small, resulting in both a small flux and low voltage drop due to the resistance in the armature and field; the motor therefore runs at a high speed. As the load increases, the current increases thus causing an increase both in flux and voltage drop due to

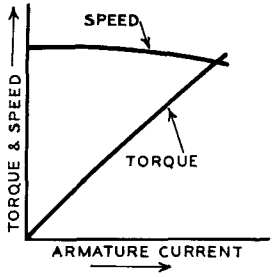


FIG. 11.5. SHUNT WOUND MOTOR: SPEED CHARACTERISTIC

armature and field resistance. Both these effects cause a reduction in speed and a typical load characteristic of a series wound motor is shown in Fig. 11.7.

It might be thought that the shunt wound motor with its constant speed characteristic is superior to the series motor for teleprinter use but it is also necessary to consider the relative merits of shunt and series motors from the point of view of starting torques since, in many applications of teleprinters in practice, the motor is constantly being started and stopped. In these circumstances it is essential that the motor, when started, should run up to governed speed as rapidly as possible.

The torque developed on the armature of a motor is proportional to the armature current $\times$ the flux. In a shunt motor, since the field current is approximately constant, the torque is therefore approximately proportional to the armature current, whereas in a series motor the torque will be proportional to the (armature current)^2. Thus a series motor has very much better starting torque characteristics than a shunt motor and enables a controlled running speed to be reached more rapidly. For this reason the series motor is usually favoured for use on teleprinters and is employed on B.P.O. Teleprinters Nos. 7 and 11. The Teleprinter No. 3 employs a shunt motor since in this case the teleprinter is kept running continuously for long periods of traffic and the balance of advantage is therefore clearly in favour of the improved speed characteristic of a shunt motor as the problem of starting is of less importance.

Speed Control. The accuracy of the various timing operations which have to be performed in a teleprinter transmitter and receiver are directly dependent upon the speed of the driving motor. Any inaccuracy of speed causes distortion of the transmitted signals and loss of margin in the receiving mechanism. For optimum performance it is necessary to maintain as high a degree of accuracy as possible in the speed of the motor. In practice limits of $\pm$ 0·75 per cent accuracy are normally set.

The mechanical load cycle of a teleprinter fluctuates widely when it is operating, especially

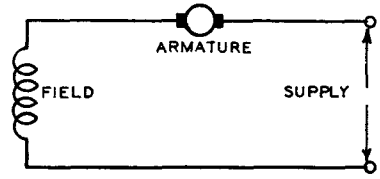


FIG. 11.6. SERIES WOUND MOTOR CIRCUIT

when it is printing, and voltage fluctuations in the mains supply also occur. If no special compensating steps were taken, the speed of the motor would vary prohibitively. In order to maintain sufficient accuracy of speed control it is necessary to employ a governor, unless a synchronous type of a.c. motor can be employed driven from mains having an accurately maintained frequency. In the majority of cases an electrical form of governing is employed and this is standard practice on British machines.

The governor is a centrifugal type and is mounted

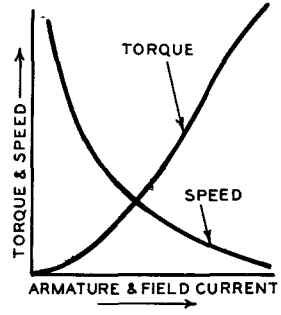


FIG. 11.7. SERIES WOUND MOTOR: SPEED CHARACTERISTIC

on an extension of the motor shaft. The action of the governor is to make, or break, a pair of electrical contacts in the motor circuit and thereby control the current flowing in the armature, and/or field circuit, by varying the resistance, and thus control the amount of electrical energy supplied to the motor. In certain cases known as "tapped field governing" the contacts control the insertion or short-circuiting of a tapped portion of the field winding.

The precise arrangements used vary in electrical detail depending upon whether a series or shunt motor is employed and whether, in the latter case, the governing is done in the armature or field circuit. The basic arrangement is, however, common and is as follows. The governor incorporates a fixed electrical contact with which a movable one makes contact, the latter being carried on a contact arm. The contact arm is constrained by a spring which is preadjusted so that, at the desired control

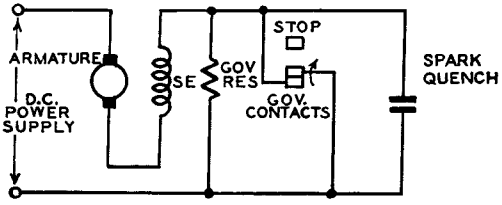


FIG. 11.8. SERIES WOUND MOTOR: NORMAL GOVERNING CIRCUIT

speed, the centrifugal force acting on the contact arm is just equal and opposite to the force exerted by the restraining spring.

Thus consider the motor at rest and the power is then switched on; the motor will immediately develop a torque and the armature will accelerate rapidly up to the desired speed and is designed so that it would, if not checked by the governor action, run up to a considerably higher speed.

Governing a Series Motor. Consider now the case of a series motor as is used for example on Teleprinters No. 7B and Teleprinters No. 11; the circuit arrangement is shown in Fig. 11.8. In this case the governor contacts are closed when the motor is at rest and, in this position, they short-circuit a resistance which is in series with the motor circuit. When the motor runs up to control speed, the centrifugal force on the movable contact arm is just equal to the restraining force of the governor spring. Thus, as the speed goes on increasing, the contacts break and immediately cause the governing resistance to be inserted in the series motor circuit. The current therefore falls, the fall being opposed by the inductive nature of the armature and field windings. The reduction in current reduces the motive torque and the speed is reduced until the governor contacts restore and close and so short-circuit the governing resistance again. When this occurs the current again begins to rise; hence the torque increases and so also the speed, thus causing the contacts to break again. Thus it will be seen that the pre-set governor spring can be adjusted to make the motor govern very closely between limits about the desired control speed.

Although in the foregoing description the action was described in relation to the running-up of the motor from a rest start, under a constant load condition, it will be clear that, if a sudden decrease in load occurs, the torque being developed by the motor at the time will be excessive and thus will cause the motor to accelerate rapidly above the control speed, whereupon the governor action again takes charge and reduces the electrical energy being supplied to the motor. Conversely, a sudden increase in load will cause a sudden fall of speed, below the control speed, and the governor contacts will close to allow the additional energy to be supplied to meet the load. The effect of rate of change of load and voltage determines the amount of over-shoot and under-shoot of the motor speed about the control speed and therefore the periodicity and duration of the operation of the governor contacts during the load cycle. The load and mains voltage changes, however, which can occur in practice are well within the scope of the governor and motor design, and speed control within limits of $\pm$ 0·75 per cent is readily secured.

Because the governor contacts have to make and break an inductive circuit, it is essential to fit a spark quench circuit to reduce the effect of arcing and hence wear on the contacts.

Governing a Shunt Motor—Armature Governing. Consider now the case of a shunt motor as for example was used on early models of Teleprinter No. 7A. The circuit arrangement is shown in Fig. 11.9. In this case the arrangement and action is generally similar to the series motor case already

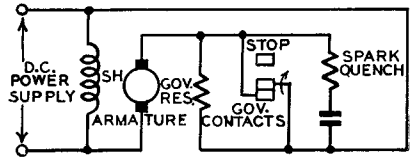


FIG. 11.9. SHUNT WOUND MOTOR: ARMATURE GOVERNING

described except of course that the governor contacts and resistance are only in the armature circuit. Thus apart from the effects of armature reaction and variation of the motor voltage supply the field current remains constant.

The action of the governor with increase of speed above the control speed is to cause the governor contacts to break and insert a resistance in series with the armature. This increases the resistance drop in the armature circuit and the armature current falls. This results in a fall in torque and a consequent reduction in speed until the governor contacts restore and close the short-circuit across the governing resistance in the

armature circuit. The speed then again rises and so on.

Governing a Shunt Motor—Field Governing. Another method of governing a shunt motor is by controlling its field current using a resistance in series with the field, operated in conjunction with centrifugal governor contacts. A typical circuit arrangement of this sort is shown in Fig. 11.10 and was used on Teleprinters No. 3. It will be noted that two sets of contacts are employed, namely the normal governor contacts and an auxiliary pair, called starting contacts, which are for the purpose of enhancing the starting torque. When the motor is at rest, the starting contacts are closed and in this state short-circuit a starting resistance in the field circuit; the main governor contacts are open but connected to operate across the same resistance. The resistance thus acts as a starting resistance and a governing resistance. The starting contact arm is a light cantilever spring. When the power is switched on to the motor at rest the short-circuited starting resistance increases the field current and enables a higher torque to be developed and thus increases the acceleration of the armature up to speed. The starting contacts are arranged so as to break by centrifugal action at a speed well below the control speed and, as soon as this occurs, the field current begins to fall and finally stabilizes at its new value determined by the total field circuit resistance and armature reaction. The reduced field current causes the back e.m.f. in the armature (which is proportional to speed and flux) to fall and hence the armature current will rise and the speed will continue to increase.

If not checked by the action of the main governor contacts the armature would finally reach a speed considerably higher than the desired control speed. When, however, the motor speed passes through the desired control speed the main governor contacts close and cause the governing resistance to be short-circuited again; thereupon the field current is increased and the back e.m.f. in the armature correspondingly increases so reducing the armature current. The fall in current is greater proportionately than the rise in field current and thus the torque is reduced and the speed falls back to the control speed at which the governor contacts re-open and so cause the governor resistance to be reinserted into the field circuit and allow the speed to rise again. The action will recur repeatedly and maintain the motor speed within close limits of the control speed.

Tapped Field Governing of Series Motors. Series connected motors are not inherently suitable for driving teleprinters on account of their torque-speed characteristics, but the use of a series motor is in many cases essential, in order to secure the high starting torque necessary on a teleprinter which is being repeatedly started and stopped, e.g. on switching services and private wire circuits. When series motors are used it is necessary in design to ensure that the speed of the motor driving the heaviest teleprinter load is above the speed, N r.p.m., which corresponds to the nominal baud speed, when the governor contacts are closed and taking into account the effect of voltage variation.

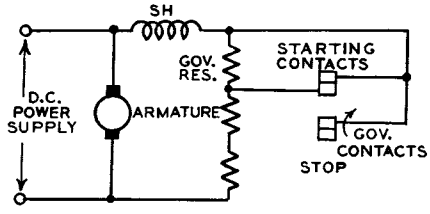


FIG. 11.10. SHUNT WOUND MOTOR: FIELD GOVERNING

The governor resistor is then fixed at such a value that when it is in circuit the speed of the motor is below N r.p.m., again taking into account the effect of supply voltage and load variations. In practice this results, in a typical case, in a motor which under average conditions would drive the teleprinter at about 5,000 r.p.m. when the resistor is short-circuited, and very nearly stops when it is in circuit. In this example the required governed speed which corresponds to the nominal baud speed of 50 bauds is 3,000 r.p.m.

The governing action necessary to control the motor speed throws a severe strain on the governor contacts, which control directly the whole of the power supplied to the machine in a highly inductive circuit. This has three undesirable effects—

1. The rate of governor contact wear is high, so reducing the life of the contacts and necessitating fairly frequent readjustment.

2. The wide and rapid fluctuations in the armature and field current causes poor commutation and in consequence shortens brush life.

3. The consequent heating of the governor alters the speed at which it operates, due to dimensional changes and alteration in the elasticity of the controlling spring in the governor.

To minimize these effects close attention is given to the design of the spark quench circuits but it will be appreciated that reducing the sparking on the governor contacts is a difficult problem, as in a typical practical case an instantaneous voltage of 500–600 V is developed across the governor contacts of a series teleprinter motor.

Very promising results have been obtained in

experimental trials by the use of a special series connected motor having a tapped field winding and in which governing is accomplished by short-circuiting a portion of the field winding. The circuit arrangement employed is illustrated schematically in Fig. 11.11. The results of tests indicate that this method of governing is considerably

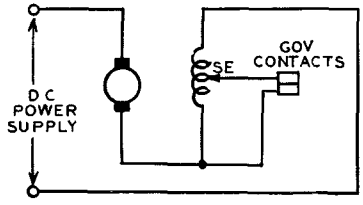


FIG. 11.11. SERIES WOUND MOTOR: TAPPED FIELD GOVERNING

better than the usual method of resistance governing. The method is however only suitable for d.c. motors as with a.c. supplies there would be a transformer action between the main field and the tapped field winding which is short-circuited when the governor contacts close. The short-circuiting action also occurs with the a.c. ripple of rectified a.c. supplies and the ripple must be reduced by suitable smoothing to reduce the short-circuit ripple current through the contacts when they make and break.

Using tapped field governing on series motors driven from d.c. mains, or a.c. rectified supplies, considerably reduces the instantaneous voltage developed across the contacts thus increasing contact life and reducing the speed variations which occur in service.

Speed Governors. Those on the motors of Teleprinters No. 3, 7, and 11 are similar in design. The governor is fitted at one end of the motor shaft and electrical connexion is made by two spring-loaded carbon brushes, mounted on an insulated block on the motor casting, bearing on two slip rings fixed to the rear of the governor base. The base is a bakelite disc on which the various parts are mounted under a metal dust cover. The arrangement of the parts is shown in Fig. 11.12.

The contact arm consists of a central portion of bent steel with a spring extension affixed to each end. The spring on the right hand end is used to anchor the contact arm to the contact arm block and also serves as a pivot for it. The spring at the other end carries the governing contact. The contact arm moves, as described below, between the points *A* and *B*. A contact or an insulating stud may be fixed in either of these points so that the contact assembly may be arranged as either a "make" or "break" arrangement to suit the motor concerned, i.e. shunt or series wound. The arrangement for a field-governed shunt-wound motor is shown in Fig. 11.12. The angle of the contact faces is such that a rubbing action is obtained during operation so helping to clean the surfaces.

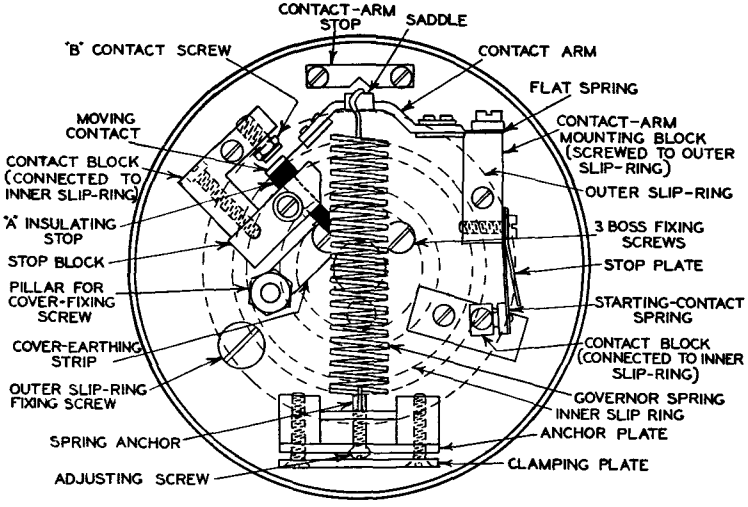


FIG. 11.12. GOVERNOR—MECHANICAL DETAILS

The governor spring lies along a diameter of the disc. It is fixed at one end to an adjustable anchorage and a loop at its other end embraces the contact arm. Thus, when the motor is at rest, the contact arm is pulled towards the centre and the governing contact is held against *A*. The adjustable anchorage

enables the tension of the spring to be varied for speed adjustment.

When the motor is running and the speed reaches a value at which the centrifugal force acting on the arm exceeds the force exerted by the spring, the arm moves outwards and the governing contact breaks with *A* and makes with *B*.

The design of the governor is such that it is quick to follow speed variations and governing of the motor speed is achieved as already explained.

unit, and not 7 unit, signals (the receiving cam sleeve makes one revolution in 140 msec). The speeds of the various shafts are shown in Fig. 11.13.

Teleprinter No. 7B. This is the later version of the Teleprinter No. 7 and is designed to conform to the standards laid down by the C.C.I.T. Also it incorporates a number of improvements in mechanical design as compared with the Teleprinter No. 7A.

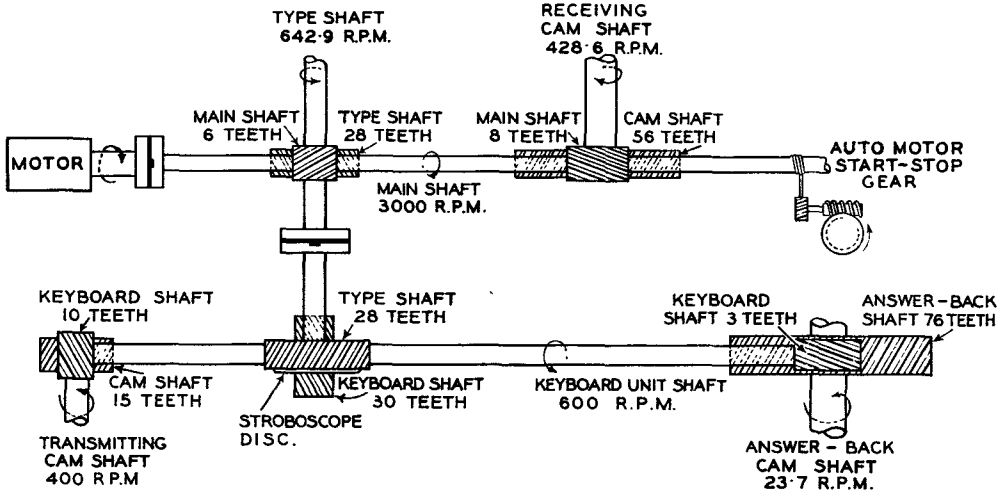


FIG. 11.13. TELEPRINTER NO. 7A: SHAFT AND GEAR DETAILS

The starting contacts are provided only when the governor is used with a field-governed shunt-wound motor and function as explained on page 375.

The contact material used is tungsten, chosen for its ability to withstand heavy duty without undue wear. When adjusted for a given value of input voltage, the governor will maintain the speed accurate to within $\pm$ 0·5 per cent for a $\pm$ 10 per cent variation of that voltage.

The Teleprinter No. 7

The Teleprinter No. 7, manufactured by Creed & Co., Ltd., Croydon, England, is designed primarily for page printing of the received message on a roll of paper although, by the substitution of a tape printing attachment for the page printing attachment, it can be adapted for reception of messages on a paper tape. It uses the International Telegraph Alphabet No. 2 and has a signalling speed of 50 bauds.

Teleprinter No. 7A. This was the earliest model of the teleprinter No. 7 introduced in 1930. It does not conform to C.C.I.T. requirements since its receiving mechanism was designed to receive 7½

Teleprinters No. 7B transmit 7½ unit signals and are therefore able to work to Teleprinters No. 7A which require a 7½ unit signal for the correct operation of their receiving mechanism. The 7½ unit signal of 150 msec is made up as follows—

Start element, 20 msec, five code elements, 20 msec each and stop element 30 msec.

To conform to C.C.I.T. standards, the receiving mechanism has been designed to receive either 7 or 7½ unit signals. The receiving cam shaft makes one revolution in 130 msec so that in the case of 7 unit transmission it will be brought to rest 10 msec before the end of the 140 msec signal and, in the case of 7½ unit transmission 20 msec before the end of the 150 msec signal, assuming in each case that the speed is correct and neglecting distortion. The speeds of the various shafts are shown in Fig. 11.14.

Since the general design of the Teleprinters Nos. 7A and 7B is similar, it is only necessary to give a detailed description of the 7B model and to point out those features which differ on the 7A model.

The Teleprinter No. 7B is illustrated in Figs.

11.15 to 11.20. The machine is designed in unit assemblies, each unit being self-contained and readily detachable from the main base of the machine without disturbing the adjustments of adjacent parts. This facility is provided by fitting to each unit abutment screws, which are put in standard adjustment during manufacture. To fit a unit to the main assembly it is only necessary to ensure that the abutments locate properly and then screw down the securing screws; by this means

The Teleprinter Sub-assembly comprises the following units—

Main Base	Starter Switch Control Unit
Combination Head	Motor Unit
Typehead	Governor Unit
Receiving Cam Unit	Mainshaft Unit
Typehammer Unit	Starter Switch Unit
Control Lever Unit	Ribbon Feed Brackets
Operating Electro-magnet	Cover.

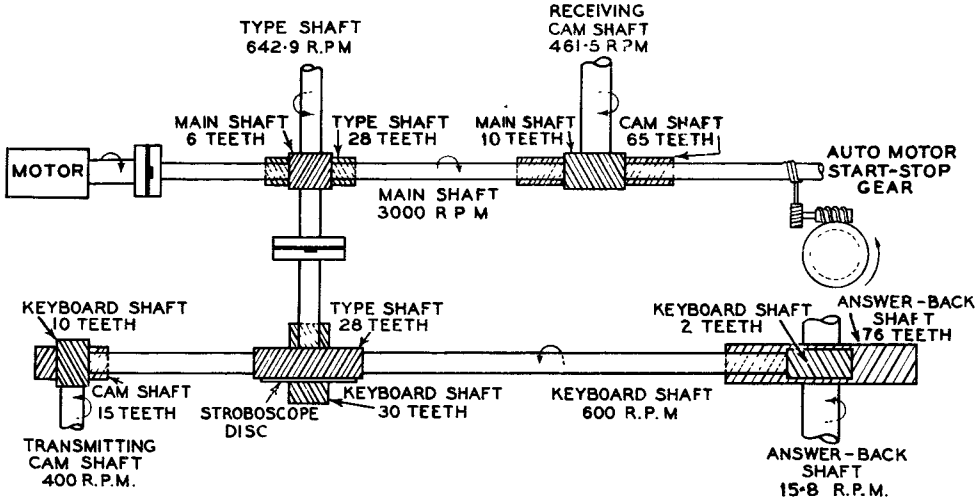


FIG. 11.14. TELEPRINTER NO. 7B: SHAFT AND GEAR DETAILS

correct engagement of interacting parts is ensured and means for the automatic connexion of the electrical circuit are also provided when necessary. The adoption of this method of unit construction greatly facilitates maintenance as it ensures strict interchangeability of parts.

All the units are fixed on the main machine base and the full space at the rear of the machine is available for the travel of the paper carriage which is always in view of the operator.

The dimensions of the machine with the standard dust cover in position are—

Width $23\frac{1}{2}$ in.
Depth $23\frac{1}{2}$ in.
Height 13 in.

The weight of the machine complete with a Page or Tape Printing Attachment is approximately 67 lb.

The machine may be divided into three main sections—

The Teleprinter Sub-assembly.
The Keyboard Unit.
The Page or Tape Printing Attachment.

The Keyboard Unit is attached to the Teleprinter Sub-assembly by two fixing screws and comprises the following units—

Keyboard Assembly.
Transmitting Unit.
Answer-back Unit.

The Printing Attachment may be either for page or tape printing, the two attachments being interchangeable. The page printing attachment can, if desired, be of a type employing sprocket feeding of the paper.

The motor speed is 3,000 r.p.m. and an automatic switch is provided for starting and stopping.

Wherever practicable ball bearings or self lubricating bearings have been used in the design of the mechanisms in order to eliminate the necessity for frequent lubrication. Those bearings which require more frequent lubrication are provided with small lubrication caps.

The normal dust cover, seen in Fig. 11.15, is a felt lined sheet-steel cover which fits over the main portion of the mechanism but leaves the keyboard unit and printing attachment exposed. A special sound reducing cover may be fitted if required.

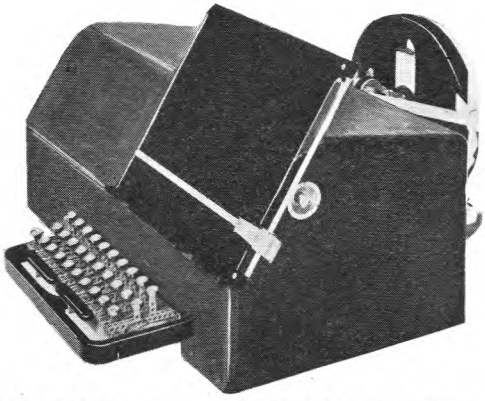


FIG. 11.15. TELEPRINTER NO. 7B: WITH TAPE ATTACHMENT AND DUST COVER
(By courtesy of H.M. Postmaster-General)

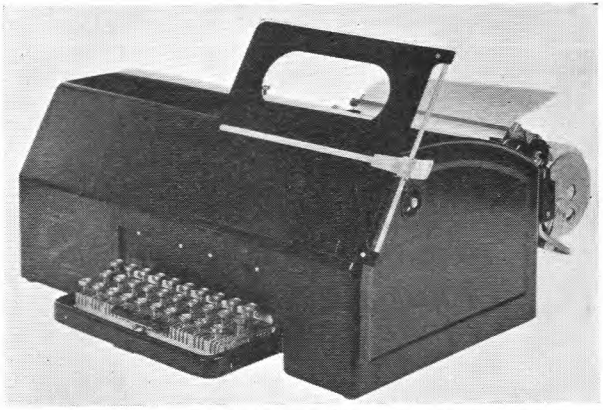


FIG. 11.16. TELEPRINTER NO. 7B: WITH PAGE PRINTING ATTACHMENT AND DUST COVER
(By courtesy of H.M. Postmaster-General)

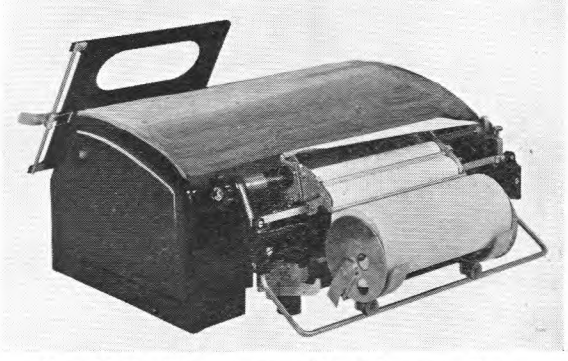


FIG. 11.17. TELEPRINTER NO. 7B: WITH PAGE PRINTING ATTACHMENT (REAR VIEW)
(By courtesy of H.M. Postmaster-General)

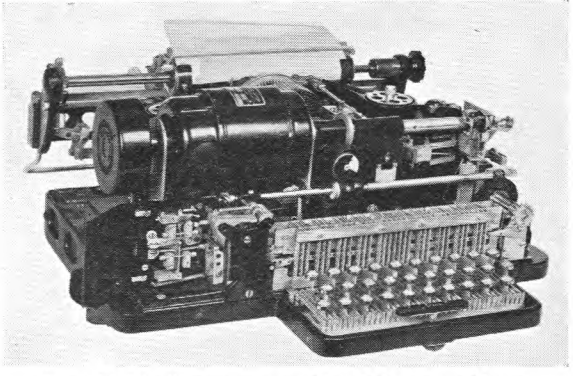


FIG. 11.18. TELEPRINTER NO. 7B: WITH PAGE PRINTING ATTACHMENT (VIEW FROM L.H. SIDE, DUST COVER REMOVED)
(By courtesy of H.M. Postmaster-General)

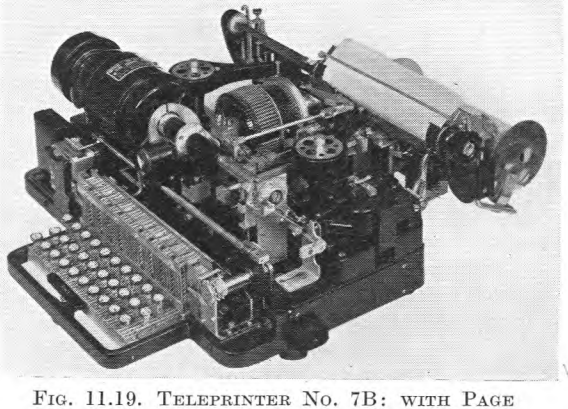


FIG. 11.19. TELEPRINTER NO. 7B: WITH PAGE PRINTING ATTACHMENT (VIEW FROM R.H. SIDE, DUST COVER REMOVED)
(By courtesy of H.M. Postmaster-General)

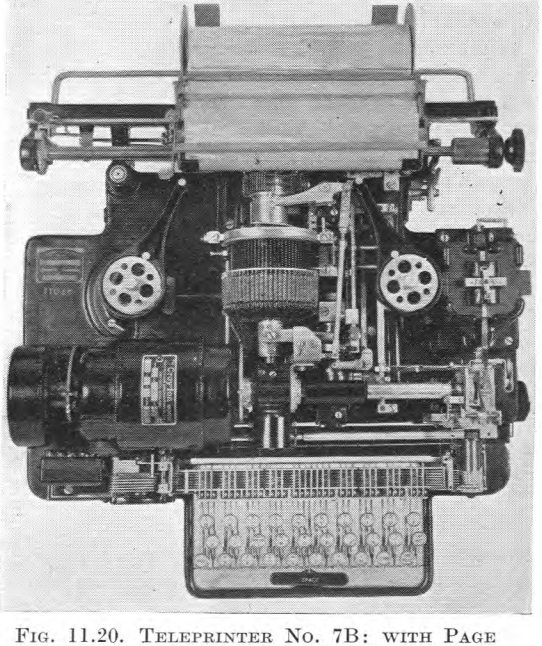


FIG. 11.20. TELEPRINTER NO. 7B: WITH PAGE PRINTING ATTACHMENT (PLAN VIEW, COVER REMOVED)
(By courtesy of H.M. Postmaster-General)

The various signalling connexions are brought out to a nine-way plug, the circuit arrangement being as shown in Fig. 11.166; the power connexions for the motor shown in Fig. 11.167, are connected via a three-way plug and cord, the third connexion being used to earth the frame (base) of the teleprinter.

Radio interference suppression components are fitted in the motor and signalling circuits as shown in Figs. 11.166 and 11.167.

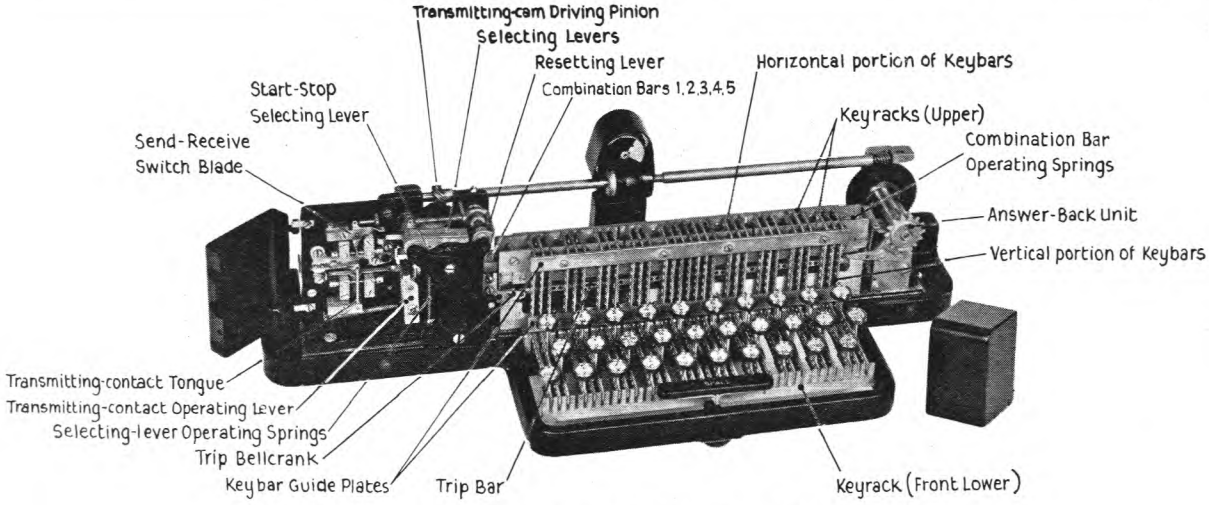


FIG. 11.21. TELEPRINTER NO. 7B: KEYBOARD AND TRANSMITTING UNIT
(By courtesy of H.M. Postmaster-General)

Transmitting Mechanism. The transmitting mechanism consists of the Keyboard Unit which, as has already been stated, is made up of the Keyboard Assembly, the Transmitting Unit and the Answer-back Unit, which is an auxiliary unit and will be described later. These units can readily be seen in Fig. 11.18 which also shows the complete machine with the cover removed and the cover of the transmitter open.

The Keyboard Unit detached from the main teleprinter assembly is shown in Fig. 11.21; this unit is attached to the main teleprinter assembly by two screws, the electrical connexions being completed via six connecting blades which fit into a jack on the main base. These blades can be seen in the rear view of the transmitting unit shown in Fig. 11.22.

There are two types of transmitting unit, one known as the Link Transmitter and the other, an improved type, known as the Striker Transmitter. Both of these types will be described in order to show the advantages of the latter.

The layout of the keys on the keyboard has already been described on page 371.

Fig. 11.23 shows a schematic representation of the whole of the mechanisms concerned in the transmission of signals and Fig. 11.24, shows the details of the keyboard mechanism.

The Keyboard. The keybars are free to move vertically between two pairs of guide plates, a pair of rollers being fitted to each key to reduce friction. The keys also pass through slots in each of four racks which prevent lateral movement. Each key is fitted with a restoring spring which resets it after operation. Two of the racks serve a double purpose as they also act as guide plates.

Supported by racks at each end, so that they lie immediately below the upper horizontal extensions of the keybars, are six bars. One of these is called Locking Bar No. 1 and, as will be shown later, serves to lock any depressed key during the transmission of the appropriate code combination. The remaining five bars are termed Combination Bars and each controls one element of every signal combination transmitted.

Each of the combination bars and locking bar No. 1 has a spiral spring fitted to its right-hand end, which tends to pull the bar towards the right-hand supporting rack. However, in their normal positions the bars are held to the left by the Resetting Lever (Fig. 11.25) and in this position the vertical extensions of the combination bars are immediately below the tails of the corresponding selecting levers on the transmitting unit.

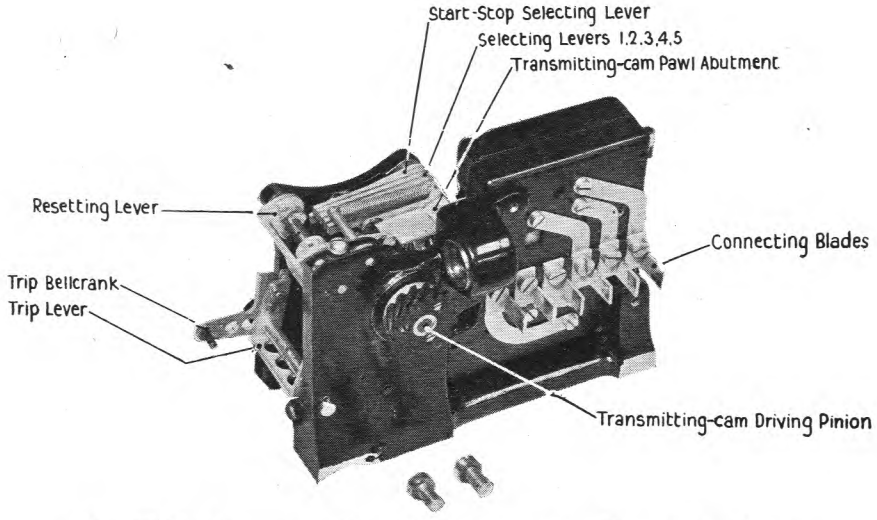


FIG. 11.22. TELEPRINTER NO. 7B: TRANSMITTING UNIT (REAR VIEW)
(*By courtesy of H.M. Postmaster-General*)

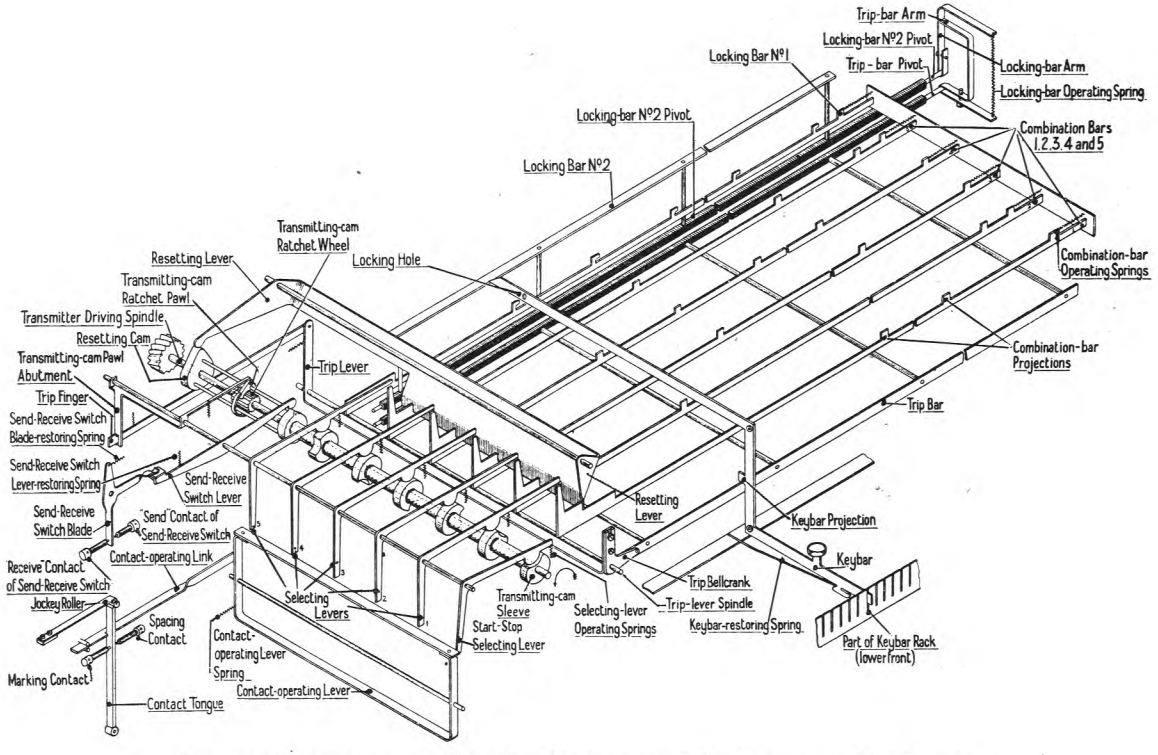


FIG. 11.23. TELEPRINTER NO. 7B: SCHEMATIC OF TRANSMITTING MECHANISM

On the top edge of each of the combination bars is a number of square projections corresponding to the spacing elements of the signalling code and positioned so that, with the combination bars in their normal position, the projections are immediately below and adjacent to the left-hand sides of it is necessary that the second and fourth combination bars must remain stationary whilst the first, third, and fifth must be free to move. Hence, at the positions corresponding to the *Y* keybar, projections are provided on combination bars two and four, but not on combination bars one, three, and

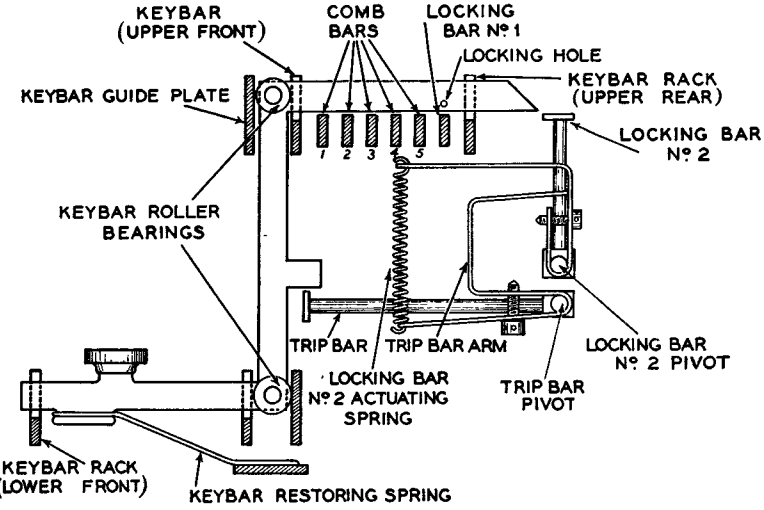


FIG. 11.24. TELEPRINTER NO. 7B: KEYBAR AND LOCKING MECHANISM

the corresponding keybars. Each of the five combination bars selects one element of the code and the keyboard is designed so that, when a combination bar moves, a "marking" element is

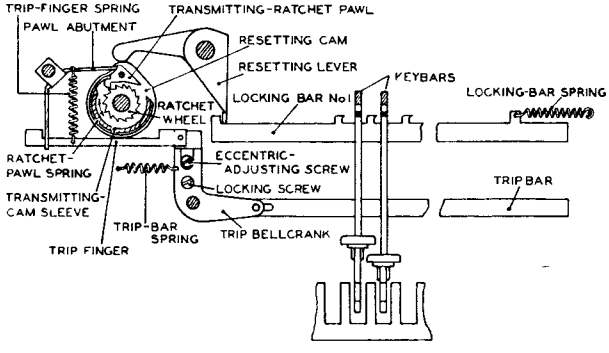


FIG. 11.25. TELEPRINTER NO. 7B: TRANSMITTING CAMSLEEVE, TRIP AND LOCKING BAR MECHANISM

transmitted and when a combination bar is held in its normal position due to its code projection engaging with the depressed keybar, a "spacing" element is transmitted.

For instance, the code combination for the character *Y* is first, third, and fifth elements marking, the second and fourth spacing. Therefore five. Consequently when the *Y* keybar is depressed and the operation of the resetting lever releases the combination bars, the projections on bars two and four prevent the movement of these bars whilst bars one, three, and five, move to the right under the tensions of the springs. Locking bar No. 1 moves to the right during the transmission of each character and one of the hooked teeth on its upper edge engages with the hole in the upper horizontal extension of the depressed keybar. Thus the key is locked in the depressed position until the transmission of the character is completed.

In addition to ensuring that a depressed keybar is not released until the appropriate code combination has been transmitted it is also necessary to prevent the operation of a second keybar before the first has been released. Locking bar No. 2 fulfils this function. It is situated immediately behind the upper horizontal extension of the keybars and is supported on a spindle which moves in bearings fitted at each end of the keyboard assembly. Mounted as an extension of the same spindle is an L-shaped locking-bar arm, whilst a trip-bar arm is fixed to the spindle of the trip bar assembly. A spiral spring is attached to the two arms and holds them in contact with each other.

Locking bar No. 2 is normally held away from the chamfered extremities of the keybars by the

thrust of the trip bar arm. When a depressed keybar moves the trip bar downwards, the trip spindle is rotated and, through the action of the trip bar arm and tension spring, causes locking bar No. 2 to move forward to a position above the chamfered end of the depressed keybar but beneath the ends of those keybars which have not been depressed. No other keybar can now be depressed until the first keybar is released after the transmission of the code combination is completed

Teleprinters No. 7; one known as the "Link" and the other as the "Striker" type.

A transmitting unit of the "Link" type is illustrated in Fig. 11.26 and is depicted schematically on the left-hand of Fig. 11.23.

The transmitting unit consists of a cam sleeve which, in conjunction with the combination bars on the keyboard unit, controls the movement of a set of code selecting levers which in turn control the movement of the transmitting tongue between

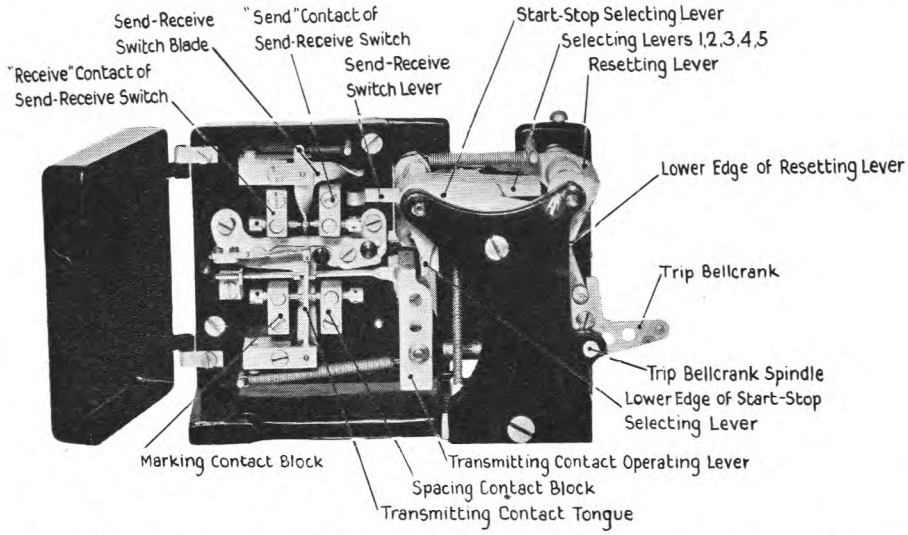


FIG. 11.26. TELEPRINTER NO. 7B: TRANSMITTING UNIT, LINK TYPE (FRONT VIEW)
(By courtesy of H.M. Postmaster-General)

and thus interference with the combination set up by the first keybar is not possible. It should be noted, however, that locking bar No. 2 does not prevent the depression of two or more keybars simultaneously.

A trip bar extends across the front of the keyboard behind the vertical portions of the keybars as shown in Figs. 11.23 and 11.24. The trip bar is rigidly attached by means of four rods to a spindle, which rests in bearings at each end of the keyboard assembly and is coupled to the locking bar No. 2 by means of the locking bar and trip bar arms as previously described. At its left-hand end the trip bar is coupled to the trip bellcrank. When a keybar is depressed, the projection on the vertical portion moves the trip bar downwards; this causes movement of the trip bellcrank which, as will be described later, causes transmission of the code combination to begin.

Transmitting Unit. As previously mentioned two types of transmitting units have been used on

a pair of contacts. The transmitting tongue is connected to the send line and the two contacts to the marking and spacing signalling supply respectively. The cam sleeve performs one complete revolution for the transmission of each character when a key is depressed. A "Send and Receive" switch is also operated by the rotation of the cam sleeve.

The cam sleeve is a hollow metal cylinder and is coupled, by a ratchet and pawl clutch, to the transmitting spindle which is driven from the teleprinter motor, see Fig. 11.14. Six cam tracks are cut in the periphery of the sleeve and serve as guides for the selecting levers. A portion of each of these grooves is cut away as shown schematically in Fig. 11.27 so that, when the cam sleeve is rotated the associated lever will, if permitted, be drawn inwards into the recess.

The transmitting cam sleeve rotates at 400 r.p.m., i.e. it makes one revolution in 150 msec, and thus it will rotate 48° in 20 msec. The track nearest to the front of the machine controls the sending of the

start and stop elements of the character combination. It is cut away between 300° and 12°, i.e. 72° representing 30 msec, for the stop element. When the transmitter is at rest, the start-stop selecting lever is resting in this recess and causes the transmitting tongue to be held on the marking contact. The start element (space) is sent during the interval from 12° to 60° during which none of the cam tracks are cut away. Cam tracks 2 to 6 control the transmission of the five code elements and are cut

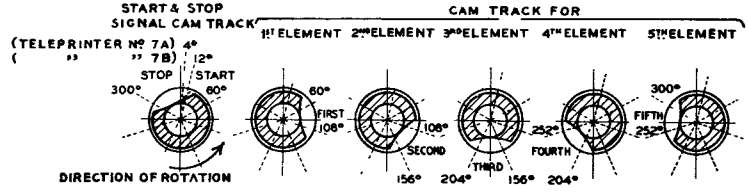


FIG. 11.27. TELEPRINTER NO. 7B: TRANSMITTING CAMSLEEVE TRACKS

away for 48° arcs successively between 60° and 300°, see Fig. 11.27. Thus the code selecting levers will ride into the cut-away portions successively for 20 msec periods provided they are permitted to do so by the setting of the combination bars.

In addition to the selecting lever cam tracks, the cam sleeve also has two cams which control the operations of the send and receive switch and the resetting lever respectively. The send and receive switch lever is operated from a cam which lies between the rear selecting lever track and the pawls, whilst the operation of the resetting lever is controlled from a cam formed on the rear end of the cam sleeve which also serves to disengage the trip finger from the pawl abutment, as will be described later.

The transmitting cam sleeve has a single revolution clutch of the ratchet and pawl type. Passing through the centre of the cam sleeve is the transmitter driving spindle which carries two ratchet wheels. The ratchet wheels are fixed side by side, with their teeth staggered half a tooth pitch. This arrangement gives the advantage of a robust ratchet with fine pitch and ensures a quick engagement between the pawls and the ratchet. The two pawls are pivoted on the cam sleeve and each has one leaf of a spring tending to force the hooked head of the pawl into engagement with the ratchet teeth. In the rest position this movement is prevented by the counter-thrust of the transmitting cam pawl abutment. The arrangement is shown in Fig. 11.25, only one ratchet wheel and pawl being shown for the sake of simplicity.

The trip finger is attached at right angles to the trip lever and is connected to the pawl abutment by means of a spiral spring. The free end of the finger carries a projection which is located in the forked end of the vertical extension of the pawl abutment. When the trip bellcrank is moved by the depression of a keybar and the trip bar, the trip finger is moved to the right and causes the pawl abutment to be raised out of engagement with the pawls which are free to engage with the teeth of the ratchets on the transmitting spindle. One of the pawls engages with its ratchet, under the influence of the pawl spring, and the cam sleeve commences to rotate.

Half way through each revolution of the cam sleeve, the hump on the resetting lever cam engages with the trip finger and thrusts it downwards sufficiently to free it from the forked lower end of the pawl abutment. The pawl abutment is pulled back into the path of the pawls by its spring and is thus in readiness to trip the pawls from engagement with the ratchets at the end of the revolution of the cam sleeve. The trip finger, however, is not reset in the forked end of the pawl abutment until the depressed key is released. Therefore, the cam sleeve will make one revolution only for each depression of a keybar irrespective of the length of time during which a key is held depressed.

The resetting lever can be seen in Figs. 11.23 and 11.25. Its upper part normally rests on the top of the hump of the resetting cam surface on the cam sleeve and its lower extremity is a plate which engages with the vertical projections formed on the left-hand ends of each of the combination bars and locking bar No. 1. The resetting lever fulfils the following functions—

(*a*) To hold the combination bars and locking bar No. 1 towards the left-hand side of the keyboard assembly, against the tension of their controlling springs, when the transmitting cam is in its rest position.

(*b*) To release the combination bars and locking bar No. 1 after the trip mechanism operates as the result of the operation of a keybar. This is achieved as the resetting lever rides off the hump on the cam.

(*c*) To restore the combination bars and locking bar No. 1 to their rest positions, after the signal combination has been transmitted.

The selecting levers, see Fig. 11.23, are six in number and are freely pivoted side by side on a common spindle, in such a way that the five levers corresponding to the code elements are in alignment with their associated combination bars. The sixth lever, which does not function in conjunction with a combination bar, is the start-stop selecting lever and, as its name implies, controls the transmission of the start and stop signals for each combination.

On the lower edge of the horizontal portion of each selecting lever is a hump which is pulled downwards by a spring on to the surface of one of the tracks in the transmitting cam sleeve. The vertical part of each lever engages on the contact operating lever, which in its rest position is held against the levers by the action of its spring. When the cam sleeve rotates, the selecting levers will, if permitted, enter in sequence into the cut-away portions of the cam tracks which they are traversing. If in the case of the five code selecting levers, the combination bars are positioned for the transmission of spacing elements, this movement is prevented by the vertical extensions of the combination bars which have been restrained from moving by the action of the depressed keybar. Those selecting levers which are not restrained, owing to their corresponding combination bars having been allowed to move, ride downwards into the recesses in their cam tracks. This imparts a clockwise movement to the selecting levers which cause the top of the contact operating lever to move to the left against the tension of its spring and the contact tongue will be moved to the left hand (marking) contact.

The selecting levers are so arranged that, during the transmission of consecutive marking elements, each lever enters its recess before the preceding lever completes its upward movement. This prevents the contact operating lever from moving sufficiently to cause the contact tongue to break away from the marking contact. In the case of consecutive spacing elements, the selecting levers concerned are held in the rest position and the contact operating lever, under the tension of its spring, holds the contact tongue firmly against the spacing contact.

The start-stop selecting lever is situated in the front track of the transmitting cam sleeve. It is similar in construction to the five code selecting levers but its action differs in the following respects—

(*a*) In its normal position it is held down with its hump fully bedded in the recess of its cam track. Thus the contact operating lever is held to the left against the action of its spring and the contact tongue is held against the marking contact.

(*b*) It is not associated with a combination bar and its operation occurs in conjunction with every combination set-up on the keyboard. Its function is to transmit the start (spacing) element preceding each five-unit code combination and a stop (marking) element immediately following the five-unit code combination.

As already described, the hump on the start-stop selecting lever in the rest position is fully bedded in the recess in its cam track and the contact tongue is held against the marking contact. As the cam sleeve commences to rotate, the start-stop lever, which is the first to be operated, rides out of the recess in its cam track and the vertical portion of the lever moves to the right. The contact-operating lever, following up this movement, causes the contact operating link to move the contact tongue to the spacing contact for the start signal. Following the transmission of the five code elements, the start-stop lever rides fully into the recess in its cam track; this causes the contact tongue to move over to the marking contact and thus the stop signal is transmitted.

The contact operating lever and link are shown in Figs. 11.23 and 11.26 and the method of transferring the operations to the contact tongue can readily be followed.

The contact tongue is pivoted at its lower end and is positioned in a slot in the contact-operating link so that, as it is moved, its electrical contacts move between two adjustable screw contacts. The contact material on the tongue and screw contacts is platinum.

The top end of the tongue is bevelled to form a knife edge on which operates a jockey roller which is pivoted on a bias spring, the pressure of which can be adjusted. When correctly adjusted for neutral signal output, i.e. no bias, the jockey roller is positioned so that the force it exerts on the tongue is equal for both positions of the tongue.

The jockey roller is normally held, by the bias spring, against one or the other side of the knife edge on the contact tongue. When the contact operating link begins to move, it exerts a force on the contact tongue which is at first opposed by the pressure of the bias spring on the jockey roller. As the contact operating link completes its movement the jockey roller is forced to ride up the bevelled surface to the tip of the tongue; it then snaps down the opposite side of the knife edge thus accelerating the transit of the tongue to the contact and then holds it firmly against the contact. By this action the jockey roller enables the following conditions for satisfactory transmission to be fulfilled—

(*a*) Transit time of the contact tongue must be small.

(*b*) Contact tongue pressure on the contacts must be adequate.

(*c*) Contact tongue must not bounce or chatter on the contacts nor break away from the contacts when the contact operating lever is partially operated during the transmission of succeeding elements of the same polarity.

Originally the send and receive switch was provided primarily for the purpose of automatically changing the teleprinter connexions from a receiving

to a sending condition, and vice versa, when operating a teleprinter over a single wire line. The switch is arranged so that it can be set in the send position immediately prior to the transmission of each code combination and returned to the receive position at the end of transmission of each character. The send and receive switch may also be used for obtaining a local record in certain instances or made use of in the operation of circuits as explained in Chapter 7.

The send and receive switch blade is controlled by the send and receive switch lever, which is normally held in contact with a cam on the transmitting cam sleeve. A spring normally holds the blade against the receive contact but, immediately the cam sleeve commences to rotate, the send and receive switch lever rides off the hump of the cam surface and turns on its pivot under the tension of its operating spring and the blade is moved to the send contact. It remains in this position until the cam sleeve has completed one revolution when the send and receive switch lever is raised by the hump on the cam and the blade is pulled over to the receive contact by its restoring spring.

It is difficult to obtain a distortionless signal output from a transmitting unit of the link type because—

(*a*) the contact operating lever is moved from *M-S* by spring tension whilst it is moved in the opposite direction, *S-M*, by the selecting levers which are in turn operated from the cam tracks and

(*b*) since the cam tracks and selecting levers are directly concerned in the movements of the transmitting tongue, the characteristics of the signals sent for the individual elements of the combination will be effected by manufacturing tolerances or wear of individual cam tracks or selecting levers.

To overcome these difficulties a greatly improved design of transmitter, known as the striker type, was introduced; it is illustrated in Fig. 11.28.

The transmitting cam sleeve is similar to that of a link type transmitter except that a timing cam, which is shown in Fig. 11.29, is provided at its front end. This has seven indentations cut accurately

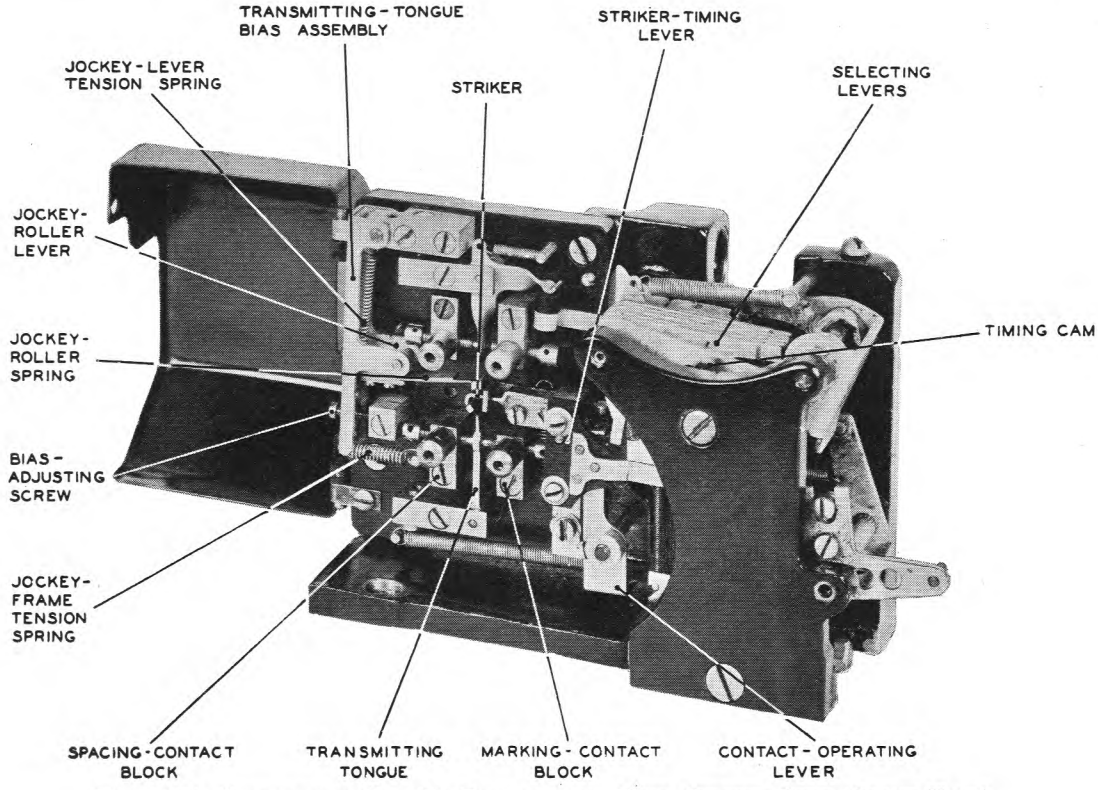


FIG. 11.28. TELEPRINTER NO. 7B: TRANSMITTING UNIT, STRIKER TYPE (FRONT VIEW)

(*By courtesy of H.M. Postmaster-General*)

in its periphery and is fixed to the cam sleeve so that the indentations are in correct phase relationship to the operating portion of each signalling cam track.

The selecting levers, in conjunction with the transmitting cam sleeve and the keyboard combination bars, are used to determine only the sense of the signals to be transmitted, i.e. *M* or *S*, and a striker, operated from the timing cam is used to effect the movements of the transmitting tongue from *M* to *S* and vice versa. The timing cam is accurately cut so that movements of the tongue occur at precise 20 msec intervals for the start signal and code elements and 30 msec for the stop signal. Moreover the timing cam is made from hardened material and suffers little from wear which will, in any case, be uniform and have only a small effect on the timing of the signals. Thus it will be seen that the transmitter will produce accurately timed signals independent of wear on individual selecting levers or cam tracks.

The contact operating lever is similar to that used on the link type transmitter but, instead of being associated with a contact operating link, it operates in conjunction with a striker and striker timing lever, which determine the position to be occupied by the contact tongue.

The striker mechanism, Fig. 11.29, comprises two

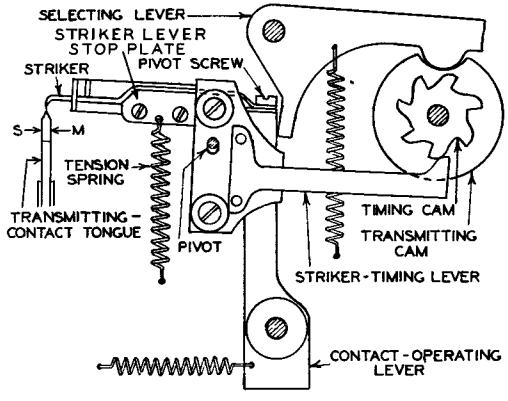


FIG. 11.29. TELEPRINTER NO. 7B: SCHEMATIC OF STRIKER TYPE TRANSMITTER

horizontal members, viz. a striker timing lever and a striker lever, mounted on an insulating plate. The complete assembly is pivoted on an adjustable metal block. The nose of the striker timing lever is held in engagement with the periphery of the timing cam by the action of a tension spring. The striker lever, or left hand member, has a slotted guide which controls the vertical movement of the striker. The timing lever, in conjunction with the timing cam, functions first to raise and then to lower the striker seven times during the transmission of each code combination. The cycle of movements is timed to correspond accurately to the changeover periods required by the individual elements of the code combination.

The striker is flexibly mounted, at its right hand end, on the top surface of the contact operating lever and its left hand end is supported in the slot

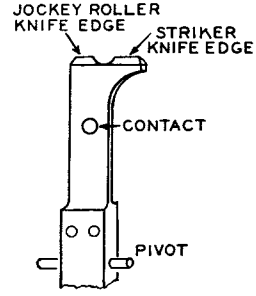


FIG. 11.30. TELEPRINTER NO. 7B: TRANSMITTER CONTACT TONGUE

in the striker timing lever. The left hand end of the striker is bent downwards and is shaped to the form of a knife edge, which acts on a similar knife edge on the tip of the contact tongue and, during the "pecking" action of the striker timing lever, it strikes on one or the other side of the contact tongue knife edge, depending upon the position occupied by the contact operating lever. This operation, provided the position of the contact operating lever is changed between two successive code elements, results in the contact tongue being moved from one contact to the other.

The striker is moved to the left for marking elements and to the right for spacing elements; consequently, for marking elements the downward movement of the striker will cause the tongue to be moved to the right-hand contact, and it will be moved to the left-hand contact for spacing elements. These conditions result in the positions of the marking and spacing contacts being reversed as compared with those on the link type transmitting unit.

The contact tongue is similar to that used on link type transmitting units except that the tip is provided with two knife edges as shown in Fig. 11.30, one for the striker and the other for the jockey roller.

The jockey roller mounting has been improved to give a more stable pressure and a simplified adjustment for correcting bias. The arrangement is shown in Fig. 11.31 and comprises a jockey frame, which is pivoted to a bearing block, and a jockey roller lever assembly which is pivoted near the centre of the frame. The pressure for the jockey roller is provided by means of a tension spring. A

bias adjustment screw and a tension spring enable the position of the jockey frame to be adjusted so

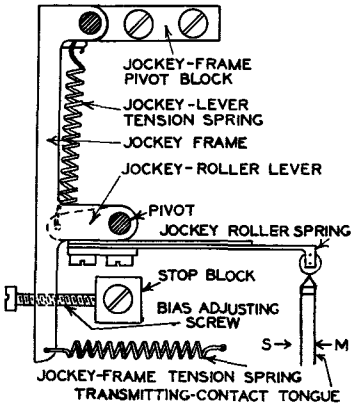
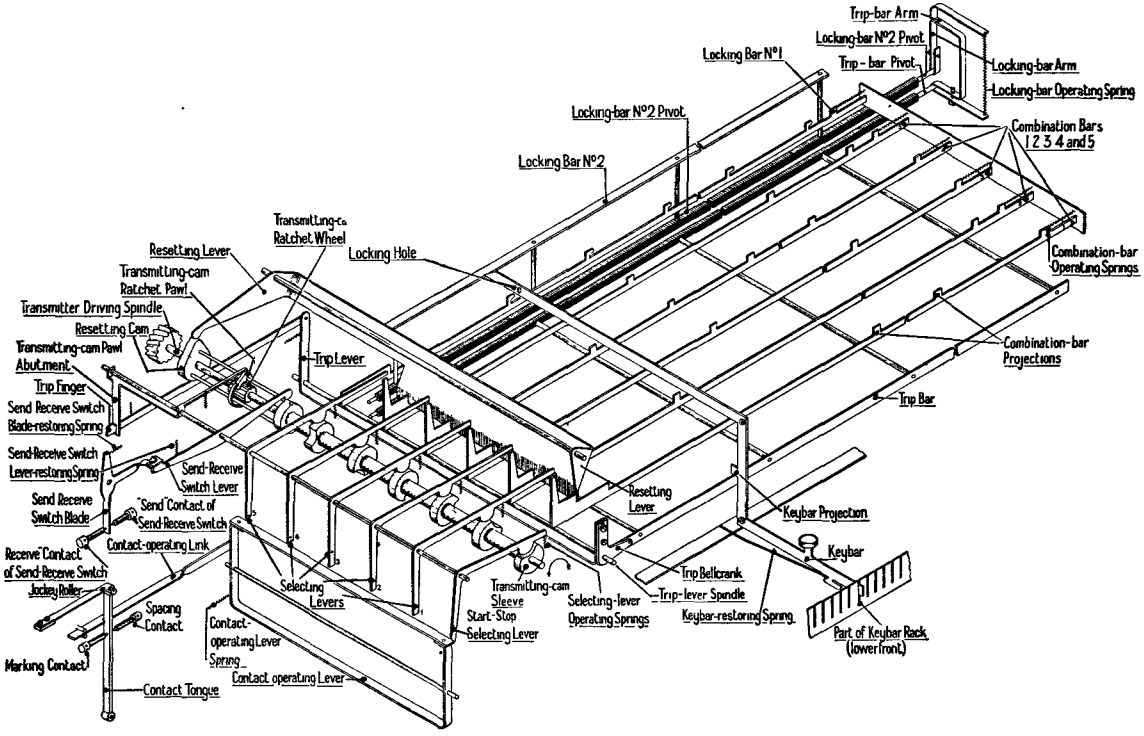


FIG. 11.31. TELEPRINTER NO. 7B: JOCKEY ROLLER MECHANISM FOR STRIKER TYPE TRANSMITTER

that the jockey roller is central in respect to the contact knife edge.

is proposed to follow the complete sequence of mechanical operations necessary for the transmission of a signal combination. The operation of the striker type of transmitting unit will be described. For the purpose of these considerations the transmission of a letter "*Y*" will be described in particular although the description applies in principle to the transmission of any character, except for the obvious changes which have to be made in respect of the selection of the code combinations for individual characters.

As frequent reference to Fig. 11.23 will be necessary, it is reproduced here. As previously explained, the position occupied by the projections on the combination bars determines the sense (marking or spacing) of each of the elements transmitted in the signal combination for the particular character concerned. For example, the signal combination for the letter *Y* is marking for the first, third, and fifth code elements and spacing for the second and fourth elements. It is therefore necessary to allow the combination bars one, three and five to move to the right whilst bars two and four must remain stationary.



Operation of Transmitting Mechanism. Having described in detail the various parts comprising the transmitting portion of the Teleprinter No. 7B, it

Hence projections are provided immediately to the left of the "*Y*" keybar on combination bars two and four but not on bars one, three, and five.

When the *Y* keybar is depressed the projection on the vertical member of the keybar engages with the trip bar and depresses it. The upper horizontal extension of the keybar is moved downwards across the combination bars between the projections. At the same time, locking bar No. 2 moves forward between the upper (chamfered) end of the depressed keybar and the undersides of the other keybars, thus preventing a second key from being depressed. Simultaneously, the trip bar causes the trip bell-crank to turn slightly on its pivot which results in the trip finger being moved to the right and the pawl abutment is raised out of engagement with the pawls. The pawls are thereby released and move inwards under the action of the pawl spring; one pawl engages with the ratchet on the driving shaft and the cam sleeve commences to rotate.

Immediately the cam sleeve commences to rotate, the upper arm of the resetting lever rides down the side of the hump on the resetting cam and, as a result, the lower part of the resetting lever moves to the right, yielding to the pull of certain of the combination bar springs, depending upon the key depressed, and locking bar No. 1 spring. Under the control of the springs, the released combination bars and locking bar No. 1 move to the right. For the transmission of the letter "*Y*", as described above, combination bars one, three, and five move.

As locking bar number one moves to the right the hook on it which is located on its upper edge adjacent to, and on the left hand side of, the upper horizontal extension of the depressed keybar, enters the small locking hole in the keybar. This maintains the keybar depressed until the resetting lever restores the locking bar near the end of the transmission of the signal and thus avoids the necessity for the operator to hold the key depressed until transmission of the signal has been completed.

The start-stop selecting lever is not associated with a combination bar and therefore is free to move each time the cam sleeve revolves. The lever normally rests with its hump fully bedded in the recess in the cam track and its vertical portion engaged with the contact operating lever, holding it to the left against the pull of its spring. Under these conditions the contact tongue is held to the marking contact. The timing cam rotates with the cam sleeve and, the first projection on the timing cam depresses the striker timing lever causing the striker to be raised clear of the contact tongue. As the cam sleeve continues to rotate the hump of the start-stop lever rides out of the recess in the cam track and the vertical portion moves to the right allowing the contact operating lever to move also under the influence of its spring. The combined effect is that the striker is raised by the striker timing lever and is then moved to the right by the contact operating lever (Fig. 11.29).

Immediately after the start-stop selecting lever completes its upward movement, the projection on the timing cam passes the nose on the striker timing lever which rides into the first depression. This causes the striker to be lowered and the left hand side of the striker knife edge is brought into engagement with the right hand side of the transmitting tongue knife edge and moves the tongue to the space (left hand) contact screw to commence transmission of the start element. The jockey roller functions to hold the contact tongue firmly against the contact screw.

For the letter *Y* the first code element is marking and the first combination bar will have moved to the right. The continuing rotation of the cam sleeve causes the second projection of the timing cam to again depress the striker timing lever and the striker is again raised clear of the contact tongue, which however remains in position due to the pressure of the jockey roller. The first code selecting lever is then allowed to enter its recess, since the first combination bar has moved, and the movement of its lower end moves the contact operating lever which causes the striker to take up a new position to the left of the contact tongue. At the required instant, i.e. 20 msec from the commencement of the start element, the nose on the striker timing lever enters the second indentation on the timing cam and the striker is lowered. The right hand side of the striker knife edge engages on the left hand side of the tongue knife edge and forces the tongue against the pressure of the jockey roller, over to the marking (right hand) contact screw to commence transmission of the first code element.

This cycle of operations continues for each marking code element. In the case of spacing elements, for the letter *Y*, elements two and four, the selecting levers are prevented from falling into the recesses in their cams as the associated combination bars have not moved and the vertical extensions on their left hand ends support the selecting levers in their normal position. Under these conditions the contact operating lever is allowed to move to the right and, acting in conjunction with the striker timing lever and timing cam, causes the tongue to be moved to the spacing contact.

At the conclusion of the transmission of the code elements, the start-stop selecting lever rides back into its recess and this, in conjunction with the timing mechanism, results in the tongue being moved to the marking contact and the stop element is transmitted.

If the code of the letter being transmitted is such

that consecutive elements are of the same polarity, the position of the contact tongue is not changed. The striker, however, is raised and afterwards lowered but the movement occurs on the same side of the contact tongue which therefore remains in the same position under the influence of the jockey roller.

Just prior to the end of one revolution of the cam sleeve the resetting lever again rides on to the hump on its cam surface and the lever is turned in a clockwise direction. The lower portion of the lever causes locking bar number one and the combination bars one, three, and five, to be retracted to the left. The hooked projection on locking bar number one is thus withdrawn from the depressed keybar, which is restored by the upward pressure of its restoring spring and the trip bar rises. The movement of the trip bar is communicated to locking bar number two which is also restored to its normal position.

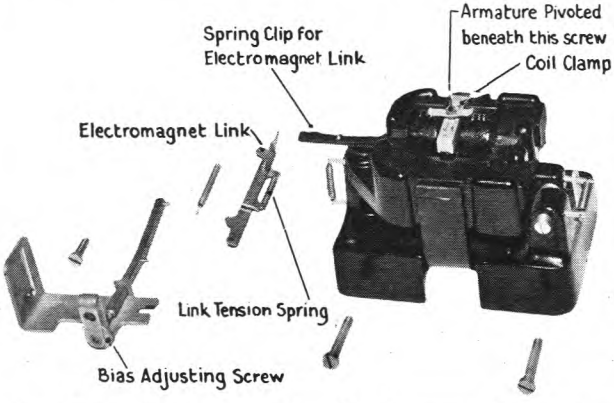


FIG. 11.32. TELEPRINTER NO. 7B: RECEIVING ELECTROMAGNET

(By courtesy of H.M. Postmaster-General)

The pawl abutment was released during the rotation of the cam sleeve, since after approximately 180° revolution the hump on the resetting cam surface engaged the trip finger and forced it downwards and freed it from the forked end of the pawl abutment. Since the pawl abutment is released, it will again engage the pawls after the cam sleeve has completed one revolution and will force them out of engagement with the ratchet. The cam sleeve, therefore, comes to rest in readiness for the transmission of the succeeding character.

Also at the commencement of rotation of the cam sleeve (i.e. at 9°) the send-receive switch is operated and remains so until it is restored (i.e. at 357°) at the end of one revolution.

Teleprinter No. 7B—Receiving and Selecting Mechanism. The signals received on a teleprinter are employed to operate a polarized electromagnet and the resulting movements of its armature produce the following effects—

(*a*) Set in motion the selecting and printing mechanisms.

(*b*) Select the character required to be printed.

(*c*) Bring the mechanism to rest at the end of a signal.

The movement of the electromagnet armature also controls an automatic switch for starting and stopping the motor.

Figs. 11.18 and 11.19 give general views of the teleprinter with the cover removed and the receiving and selecting mechanisms can be readily seen.

The electromagnet, shown in Fig. 11.32, is situated on the main base at the right hand side. It comprises two U-shaped permanent magnets mounted side by side with their like poles adjacent and having laminated pole pieces which are shaped so that they embrace the coils. Later models are fitted with an improved electromagnet unit of the type used on Teleprinters No. 11 and this is described on page 439. The armature which is constructed of laminated soft iron, is pivoted at its centre and is enclosed by the coils as shown in Figs. 11.32 and 11.34. It is provided with an armature extension which is made of non-magnetic steel alloy so as to reduce the leakage flux from the armature. The armature extension moves within the gap of a stop plate which prevents the armature coming into physical contact with the pole pieces. The laminated pole pieces and coil assembly are contained in a moulded frame which is provided with a cone pivot at its front end. This pivot fits into a bearing hole in the moulded base which is secured to the main base of the teleprinter; thus the whole of the coil and armature assembly can be pivoted about this point, its position being controlled by the bias adjusting screw and spring which can be seen on the right-hand side of Fig. 11.32. This alters the position of the armature relative to the pole pieces when it is hard up against the stop plate and thus corrections for bias on the armature can be made. (*Note.* The bias adjusting screw shown on the detached assembly to the left of Fig. 11.32 is used for biasing the armature in single-current working only.)

The electrical connexions from the coils to the main wiring of the teleprinter are made via pins on the moulded magnet base to springs located on the base of the machine.

The principles of operation of the electromagnet follow closely those of the Creed relay which has a magnetic circuit similar to that shown and

described on page 92, Chapter 4. Referring to Fig. 11.33, which shows the magnetic circuit in schematic form, the magnetic flux between the

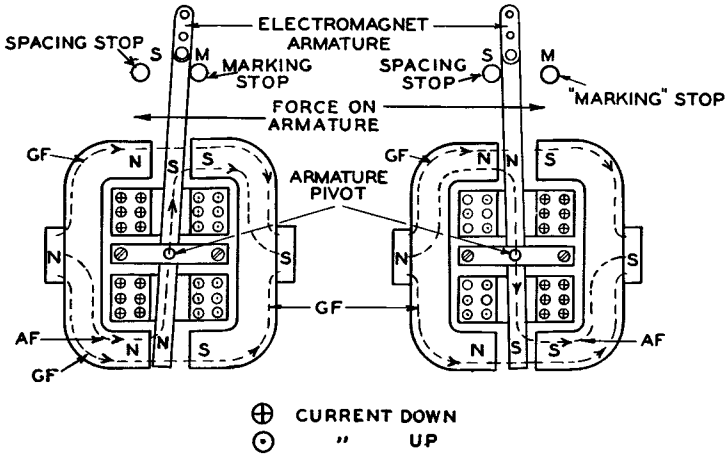


FIG. 11.33. TELEPRINTER NO. 7B: PRINCIPLE OF RECEIVING ELECTROMAGNET

pole pieces is shown by the dotted lines. With no current passing through the windings a portion of the flux, represented by the lines GF, passes directly across the air gaps but the major portion is concentrated through the soft iron armature as indicated by the line AF. The flux passing through the armature holds it firmly against the stop to which it has been moved by a current flowing through the windings and it remains in that position after the current has ceased to flow. The armature is limited in its deflexion by two stops shown in the figure as S and M. A current passing through the windings in the direction shown in Fig. 11.33 (a) makes the upper end of the armature of south polarity and it therefore moves over to the stop S. The path of the flux between the poles is now deflected as shown in Fig. 11.33 (b), the flux in the armature having been reversed, and the armature is held firmly against stop S until a current in the reverse direction passes through the windings; the armature is then moved over to stop M.

The windings consist of two coils each having a resistance of 100 Ω and when connected in series the windings have an inductance of the order of 8 Henries. Since the armature is mechanically coupled to the starting and selecting mechanisms in the teleprinter, it is required to perform an appreciable amount of mechanical work during each deflexion; hence the operating current required is fairly high and the armature travel is large, about 20 mils. When the coils are connected in series a steady state current of the order of 16 mA is usually employed. As the armature travels across the air gaps, a back e.m.f. is generated in the windings which will cause some interference to the incoming signal and produce some distortion to the shape of the signal applied. At the same time it will give rise to high frequency interfering currents in the receiving line which will affect other circuits. This effect can be minimized by connecting a capacitor across the windings; this provides a path for the surge voltages generated in this way.

The electromagnet link is fitted, by means of a spring clip, to the end of the armature extension which protrudes beyond the stop plate as shown in Fig. 11.34. This link couples the armature to the trip shaft and also engages with the starter trip lever which will be described later.

A bias adjusting spring, the tension of which can be adjusted by a knurled nut, is provided to give a spacing bias when the electromagnet is operated from single-current signals. Under double-current signalling conditions,

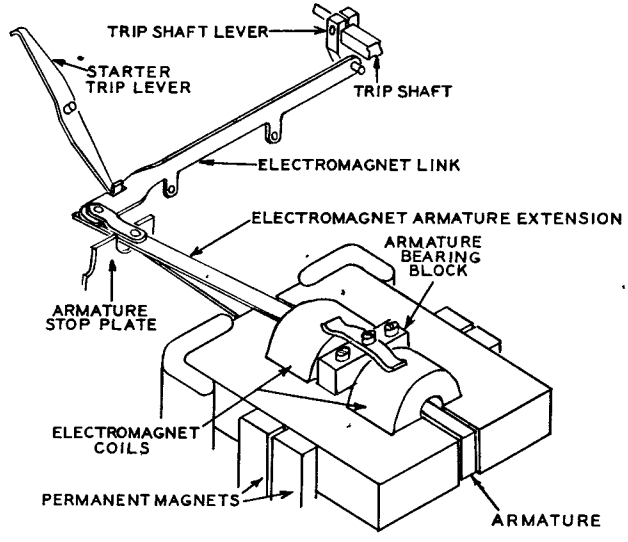


FIG. 11.34. TELEPRINTER NO. 7B: RECEIVING ELECTROMAGNET LINK

which are standard in the British Post Office, the electromagnet has optimum sensitivity when it is adjusted for neutral bias; therefore the bias adjusting spring is not required and is not fitted.

The receiving mechanism is shown schematically

in Fig. 11.35 whilst Fig. 11.36 illustrates the receiving cam unit. As the electromagnet armature moves in response to the incoming signals, it causes the trip shaft to take up one of two positions depending upon whether the received signal is marking or spacing. The trip shaft has cone bearings at each end which are supported in bearing blocks mounted on the base of the receiving cam unit.

Referring to Fig. 11.35, it will be seen that, at one end, the trip shaft is fitted with two levers, one of which is used to effect the coupling to the electromagnet link and the other is mechanically connected to the receiving cam sleeve pawl abutment. At the other end of the trip shaft, it is fitted with two slotted rods which act as guides for the finger setting blades.

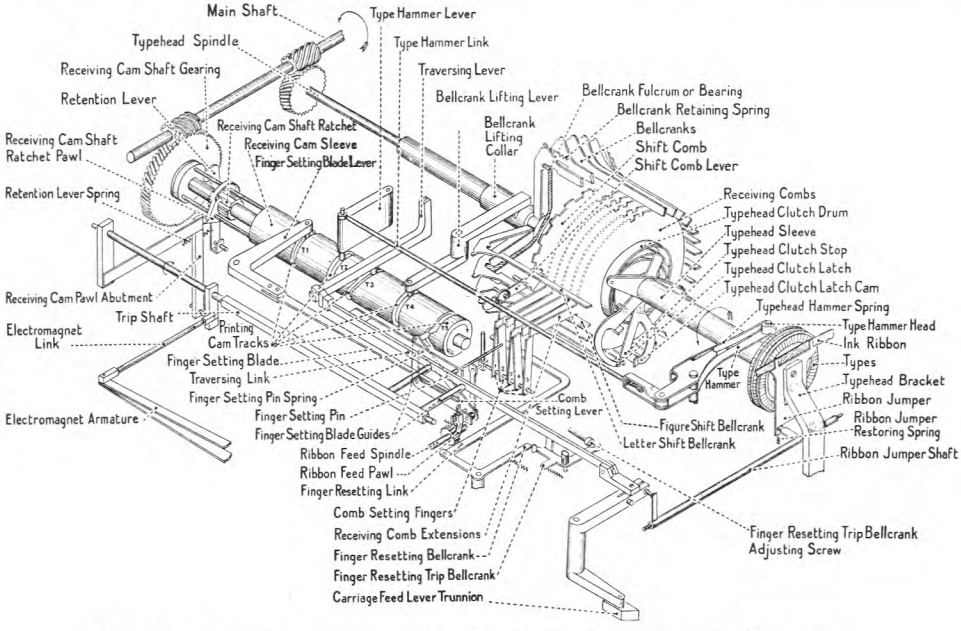


FIG. 11.35. TELEPRINTER NO. 7B: SCHEMATIC OF RECEIVING MECHANISM

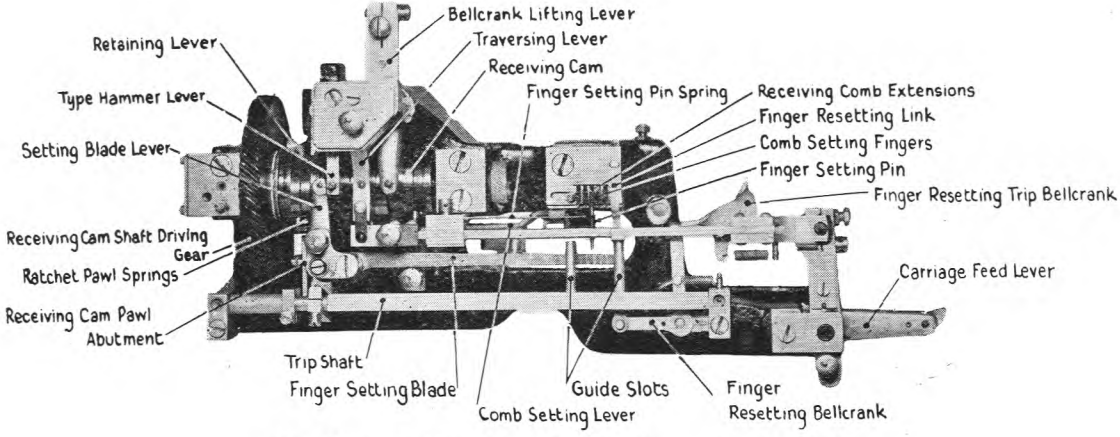


FIG. 11.36. TELEPRINTER NO. 7B: RECEIVING CAM UNIT

(By courtesy of H.M. Postmaster-General)

The trip shaft performs two functions—

(*a*) It controls the starting and stopping of the

receiving cam sleeve by engagement and disengagement of the pawls through the action of the pawl abutment, and

(*b*) It controls the deflexion of the finger setting blade in accordance with the incoming signals and thus translates the signal code combination into a corresponding setting of the five comb setting fingers.

The receiving cam sleeve is driven by means of a clutch consisting of a ratchet and pawls similar to those employed on the transmitting cam sleeve. A pawl abutment pivoted vertically on the base of the unit, and coupled by a link to the trip shaft, normally holds the pawls from engagement with the ratchet whilst the electromagnet armature is in the rest or marking position. On receipt of incoming signals, the first spacing impulse, i.e. the start signal, causes the electromagnet armature to move thus causing the trip shaft to turn in such a direction that the link attached to the pawl abutment moves the abutment from the path of the ratchet pawls. The pawl spring forces the head of one of the pawls into engagement with the rotating ratchet and the cam sleeve begins to rotate. The time taken for a pawl to engage a ratchet tooth is slightly variable as it obviously depends upon the relative position of the ratchet teeth and the pawls at the instant when the latter are released for action by the start signal. The time taken to engage will cause a corresponding error in the timing of the selecting instants in the receiver and hence a loss of margin. It must therefore be kept as small as possible and this is done by having two sets of ratchet teeth staggered by half a tooth pitch.

The cam sleeve is required to make one complete revolution for the reception of each signal combination. To ensure that this is done the speed of rotation of the ratchet shaft, which drives the cam sleeve, is designed so that each revolution is completed during the last impulse of the combination, i.e. the stop signal, which is always in a marking direction and causes the pawl abutment to be reset in the path of the ratchet pawls to disengage them from the ratchet and so bring the cam sleeve to rest until the start signal of the next combination is received. Although, during the reception of a signal combination, the pawl abutment moves in and out of the path of the pawls it does not engage them, because the pawls accompany the cam sleeve in its rotation and only approach the pawl abutment again just as the cam sleeve is completing its revolution.

As already stated the receiving mechanism of the Teleprinter No. 7B is arranged for the reception of 7 unit (140 msec) signals and the time of rotation of the receiving cam sleeve is 130 msec. On the Teleprinter No. 7A, which is designed for the reception of 7½ unit (150 msec) signals the time of rotation of the receiving cam sleeve is 140 msec. Thus, neglecting the effects of distortion and speed error, the receiving cam sleeve of the Teleprinter No. 7B is brought to rest for a minimum of 10 msec between successive signals when receiving seven unit signals or for 20 msec when receiving 7½ unit signals. Similarly the receiving cam sleeve of the Teleprinter No. 7A is stationary for a minimum of

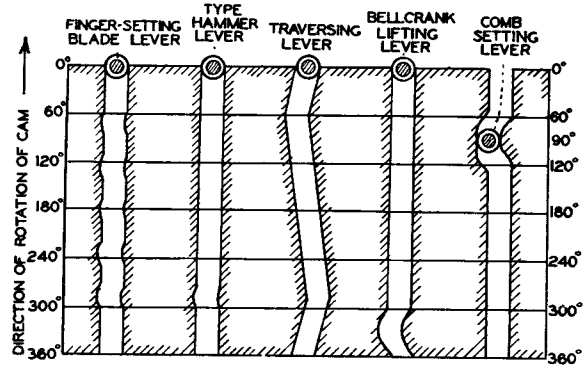


FIG. 11.37. TELEPRINTER NO. 7B: RECEIVING CAM TRACKS

10 msec when receiving 7½ unit signals. This ensures that the receiving cam sleeve is at rest when the start signal of the succeeding character combination is received even if the transmitter, from which the signals are being sent, is running a little fast and appreciable signal distortion is present. By this means slight speed errors are prevented from becoming cumulative. The gearing and speeds of the various shafts from which the receiving cam is driven have already been shown in Figs. 11.13 and 11.14.

A retention lever is provided to hold the receiving cam sleeve stationary whilst the clutch is disengaged.

The receiving cam sleeve, Fig. 11.36, is a hollow steel cylinder which has five cams cut in its surface in the form of grooves; the cam shapes and their respective phase positions, which are shown schematically in Fig. 11.37, control the sequence of movement of levers which are actuated via cam rollers which ride in the grooves and control the various operations required for the selection and printing of the required character.

The operation of each of these levers during one complete revolution of the cam sleeve will now be considered.

Attached to the finger setting blade lever is a flexible steel blade, the finger setting blade, which

at its extremity is lightly embraced by the two slotted guide rods fixed to the trip shaft; the blade is free to move laterally in the slots of the guides, towards or away from the selecting fingers. The associated cam track has five cams, see Fig. 11.37, which cause the finger setting blade to be moved five times, inwards and outwards, during each revolution of the cam sleeve, the movement being timed to occur 30, 50, 70, 90, and 110 msec from the commencement of the start signal, i.e. at the centre of the duration of distortionless signals. Incoming signals, by the action of the electromagnet armature and the trip shaft, cause the blade to be deflected downwards or remain in the up position according to whether a spacing or marking signal is being received. As will be described later, these operations result in the required combination being set up on the comb setting fingers.

The traversing lever is coupled to the traversing link which, by reason of the shape of the operating cam track, is given a reciprocating movement. The link carries a spring blade and both are drilled to accommodate the finger setting pin, one end of which passes through the link and the other end protrudes through the spring, see Fig. 11.35. The tension of the spring blade normally holds the pin against the traversing link but allows it to be moved away from the link whenever it is struck by the finger setting blade during the selection operations. When the receiving cam is at rest, the finger setting pin is also at rest and is positioned opposite and in line with the third comb setting finger.

When the receiving cam sleeve rotates, the traversing link is operated and causes the finger setting pin to traverse the upper ends of the five comb setting fingers; from its normal position opposite the third finger it is first moved until it is opposite the first finger, then past each of the five fingers in turn and finally to its rest position opposite the third finger whereupon the cam sleeve completes one revolution and stops. The cam track is designed so that as the pin moves from the first to the fifth finger, it is brought opposite each finger at the correct time for selection to take place. The sequence of operations for selection will be described more fully later.

In addition to controlling the traverse of the finger setting pin, the traversing link has the following functions—

(*a*) Its extremity engages with the carriage feed lever and provides the effort required to feed the paper carriage and also operate the ribbon jumper mechanism.

(*b*) It carries the finger resetting trip bellcrank which, during the initial movement of the link, strikes the finger resetting bellcrank. It turns this on its pivot and causes the finger resetting link to reset the comb setting fingers, from the last selection set up on them, in readiness for the selection cycle.

The names of the remaining three levers operated from the receiving cam are self-explanatory and detailed explanations of the operations which they perform will be given when describing the parts which they control.

The five comb setting fingers, Figs. 11.35 and 11.36, are supported by friction springs, in guide slots in the finger setting block. At their lower ends they are pivoted on a spindle which is mechanically coupled to the comb setting lever. Any finger may be pushed beneath the corresponding comb extension by the finger setting pin which is itself pushed inwards for marking signals but not for spacing signals.

The comb setting lever is operated from a track on the receiving cam sleeve. Immediately after the resetting of the fingers by the finger resetting link, the end of the lever to which the spindle carrying the fingers is coupled is depressed as the roller on the lever rides on to the hump in the cam track and the fingers are lowered into a position such that the finger setting pin, during its movement, traverses the upper ends of the fingers. Subsequently, after the combination has been set up on the fingers, the lever moves upwards raising the fingers so that those which have been pushed inwards by the setting pin engage with the extensions on the receiving combs concerned and lift them slightly.

The receiving (or selecting) combs are employed to select the bell-crank which will cause the typehead to be positioned so that the character corresponding to the incoming signal combination may be printed. The combs are part of the combination head unit which is shown in Fig. 11.38 with certain of the bell-cranks removed so that the combs can be seen. There are five receiving combs mounted on a drum through which the typehead spindle passes. The receiving combs are free to rotate slightly and are positioned by collars of suitable width. Each comb has a flat coiled spring which restores it to the normal position of rest after a character has been printed and also has a horizontal extension piece which extends above the upper end of the corresponding selecting finger.

Indentations are cut into the periphery of each of the receiving combs and they are so arranged that, for each one of the 32 combinations of positions into which the five combs can be moved by the comb setting fingers, certain indentations on the five combs are brought into alignment and a slot is provided beneath one pair of adjacent bellcranks depending upon the character combination.

One bell-crank of each pair corresponds to a "letters" or primary character and the other to the "figures" or secondary character for the same signal code combination. Which bell-crank of a

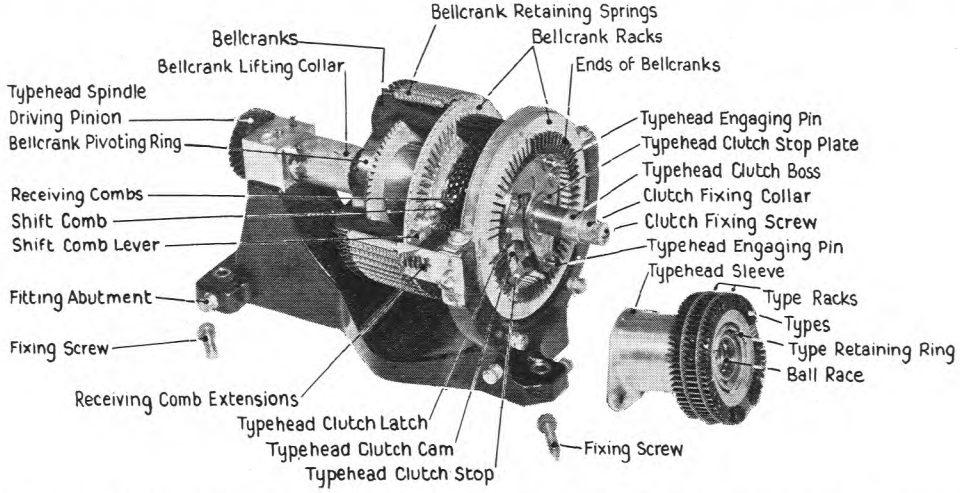


FIG. 11.38. TELEPRINTER NO. 7B: COMBINATION HEAD UNIT (THE TYPEHEAD IS REMOVED TO SHOW THE TYPEHEAD CLUTCH)

(By courtesy of H.M. Postmaster-General)

pair shall drop into the prepared channel is determined by a sixth comb, known as the shift comb, which is similar to the receiving combs except that it is not provided with an extension and the indentations are equally spaced, the distance apart, or pitch, of the indentations being twice the basic pitch of those on the receiving combs.

The shift comb is free to move on the drum similarly to the receiving combs and its movement is limited to the distance of one bell-crank spacing. Thus, whichever position the shift comb occupies, it permits only one of a pair of adjacent bell-cranks to be drawn inwards into the channel prepared by the selecting combs being moved in accordance with the signal combination. Therefore, for each combination received, only one bell-crank is operated, the position of the shift comb determining whether a bell-crank in the "letters" or "figures" group is brought into action.

The shift comb is operated by the shift comb lever shown in Fig. 11.39 which is mounted on a pivot on the bell-crank rack, in a position such that it can be operated by the inward pressure on either of its shoulders by the figure shift or letter shift bell-crank. The lever is held firmly in either of its two operated positions by means of the toggle action of the shift comb lever spring. Thus when the shift comb has been set for "letters," all characters printed thereafter will be in the "letters" case until the receipt of a figure-shift combination causes the figure shift bell-crank to be operated; the shift comb is then moved to its alternative position after which only bell-cranks in the "figures" group can be selected until the letter shift combination is again received.

The bell-cranks control the positioning of the

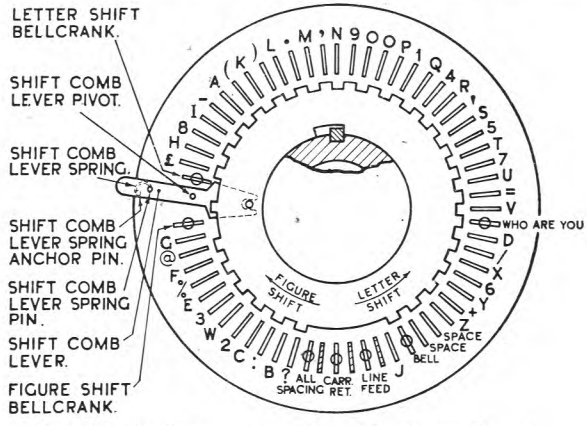


FIG. 11.39. TELEPRINTER NO. 7B: SHIFT COMBS AND LEVER OF COMBINATION HEAD UNIT

Note: The bell-cranks marked with a circle are functional bell-cranks; those which are cross-hatched are cut-away bell-cranks.

typehead. They are mounted around the periphery of the receiving combs and are carried on an annular ring, called the comb rack, as shown in Fig. 11.39 which also shows the disposition of the bell-cranks

for the various characters; it should be noted that the bell-cranks corresponding to the primary and secondary characters for each combination are mounted adjacent to each other. Each bell-crank is normally held by a spiral controlling spring, anchored to the comb rack, so that its inner edge rests on the outer edges of the receiving and shift combs. When, as already described, a slot is exposed by alignment of a series of indentations in the combs, the bell-crank concerned is moved into

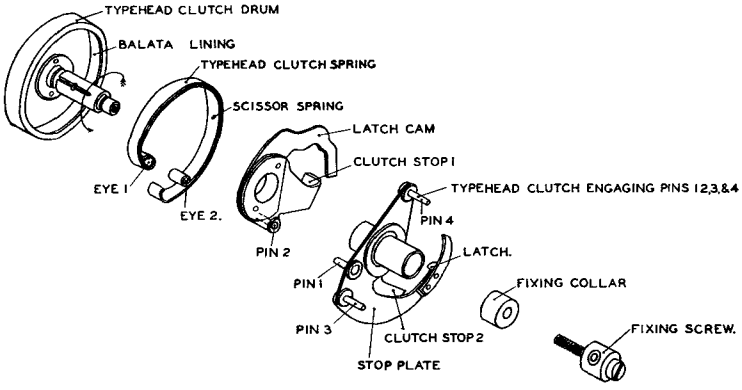


FIG. 11.40. TELEPRINTER NO. 7B: EXPLODED VIEW OF TYPEHEAD CLUTCH

the slot by the pull of its spring. The letter-shift and figure-shift bell-cranks are provided with springs stronger than the remainder since more force is required to enable them to actuate the shift comb lever.

The horizontal extremity of each bell-crank protrudes through the combination head so that when a bell-crank is operated into a slot, its extremity forms an obstruction in the path of the rotating typehead and arrests it in the appropriate position in readiness for the printing operation as will be described later.

It is necessary for the line feed and carriage return bell-cranks to be operated by the reception of the appropriate code combination whether the shift comb is in the "letters" or "figures" position and, in order to allow this, the projections on the shift comb are cut away so that both bell-cranks of the pair are allowed to drop when the corresponding selection is set up, irrespective of the position of the shift comb. So that the action of the typehead clutch may not be interfered with by the presence in its path of two bell-crank ends simultaneously, special bell-cranks having cut-away ends are fitted in the secondary positions of these pairs.

One end of the bell-crank lifting lever rides in its cam track and the other end is coupled to the bell-crank lifting collar. The shape of the cam track causes the lever to move inwards towards and then outwards from, the combination head once during each revolution of the receiving cam sleeve. As the lever moves towards the combination head, the lifting collar is pressed against the cranked end of each of the bell-cranks thus causing the bell-cranks to be lifted clear from the receiving combs; the bell-crank employed for the previous selection is thus withdrawn from engagement with the stop arm of the typehead clutch and the typehead is free to rotate. The receiving combs are restored to normal by their springs. These actions occur immediately prior to the instant when the comb-setting fingers are raised by the comb setting lever. The receiving combs are set for the new character combination whilst the bell-cranks are still lifted and the bell-crank lifting collar is then moved away from the bell-cranks by the lever, thus allowing all the bell-cranks to be drawn inwards by their springs. The bell-crank selected for the new combination is drawn into the slot prepared for it.

Printing Mechanism. Whilst the teleprinter motor is running, the typehead spindle is rotated continuously via the gear wheel which can be seen in Fig. 11.38 in which the typehead can also be seen. The spindle passes through the body of the combination head and, at the end remote from the driving gear wheel, it carries the clutch drum which is rigidly fixed to it. The inner surface of the clutch drum is lined with a strip of balata which has a high coefficient of friction and a long life.

The component parts of the typehead clutch are shown in Fig. 11.40. The clutch spring and the scissors spring are connected together at one end by their looped ends and are inserted into the clutch drum so that the free end of the clutch spring is pointing in the direction opposite to the direction of rotation of the typehead. The latch cam and clutch stop are riveted together and their boss fits over the sleeve of the stop plate which in turn is fitted on to the clutch drum spindle so that pin No. 1, on the stop plate, engages with eye No. 1 formed by the clutch and scissors springs and pin No. 2, on the latch cam, engages with eye No. 2 of the scissor spring. The assembled clutch is shown in Fig. 11.41; it is held on to the typehead spindle by a fixing screw and collar. Pins No. 3 and 4, on the stop plate, engage in bushes on the typehead which is thus carried with the clutch as it is rotated.

During the periods when the bell-cranks are

raised by the operation of the lifting collar, the clutch spring is free to expand until it engages with the balata lined inner surface of the clutch drum;

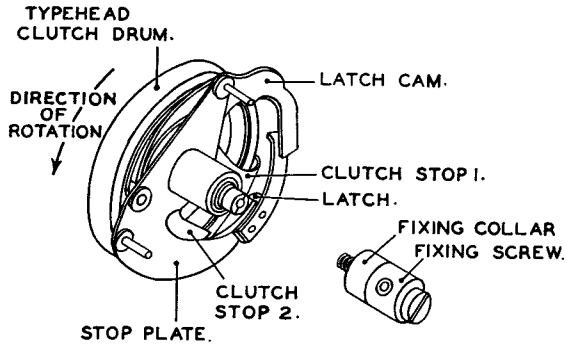


FIG. 11.41. TELEPRINTER NO. 7B: TYPEHEAD CLUTCH ASSEMBLED

thus the turning movement of the drum is communicated by friction to the clutch assembly which rotates in the direction shown by the arrow in Fig. 11.40. When a selected bell-crank moves into the slot prepared for it, its extremity obstructs the path of the rotating clutch stop No. 1 and arrests its movement. The typehead is fixed to the stop plate and its angular momentum causes the stop plate movement to continue, thus contracting the scissor spring and, in this way, the speed of the stop plate and the typehead is gradually reduced to rest.

After a small amount of independent movement of the stop plate and typehead, clutch stop No. 2 abuts against the back edge of clutch stop No. 1 and the typehead is brought to rest. Just prior to this taking place, the scissor spring is flexed to such an extent that eye No. 2 is brought into contact with the curved free end of the clutch spring, which is thereby contracted, and the friction between the clutch spring and the balata lining of the clutch drum is reduced until, when the typehead reaches the desired position and is at rest, the clutch is completely disengaged. Simultaneously, the clutch latch moves in behind the latch cam and its hooked end is thrust behind the selected bell-crank thus locking the clutch on the desired bell-crank in readiness for printing. This ensures correct alignment of the type and prevents any backward movement of the typehead due to the tendency of the springs to expand. When the selected bell-crank is reset, the clutch is unlocked and the typehead is again rotated for selection of the next character to be printed.

Later Teleprinters No. 7 are fitted with an improved clutch similar to that used on the Teleprinter No. 11 and which is described on page 445.

The construction of the typehead may be seen from the sectional view given in Fig. 11.42. The type bars are carried in slots formed in a light-weight type rack; the slots permit movement of the types parallel to the axis of the typehead. The type retaining plate is held in position by three springs and exerts a pressure on all the types, thus normally keeping them in contact with the back stop. The ballrace, fitted in the front of the typehead, engages with an end thrust bearing, mounted on a bracket, see Fig. 11.35, which retains the typehead in engagement with the pins on the clutch stop plate.

The typehammer is operated from the receiving cam sleeve and is moved forward so that it strikes one of the types according to the position in which the typehead has been brought to rest. The type is moved forwards, carrying one edge of the type retaining plate with it, and when the typehammer is withdrawn the retaining plate, under the influence of its springs, restores the type to its normal position. A special loaded typehammer is used when manifolding paper is used to obtain more than one printed copy.

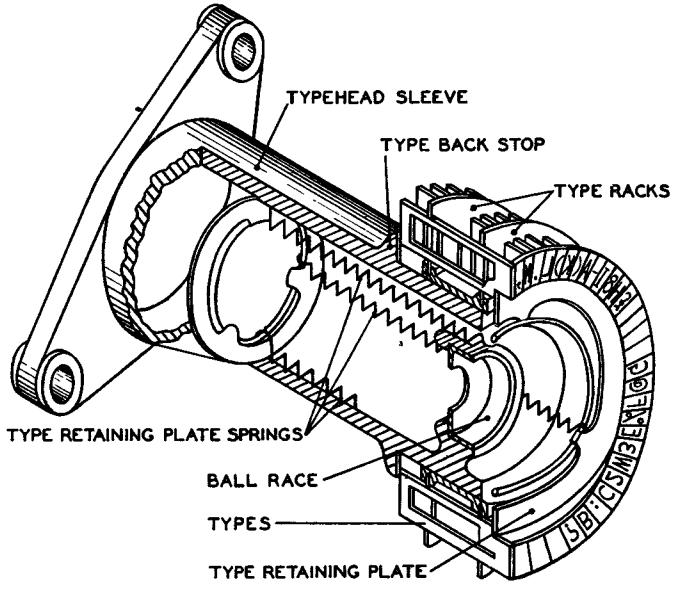


FIG. 11.42. TELEPRINTER NO. 7B: SECTIONAL VIEW OF TYPEHEAD

An ink ribbon, similar to that used on a commercial typewriter, is used. To enable the printed

characters to be visible to the operator as they are printed, the ink ribbon is interposed between the type and the paper only when the type is being struck by the hammer. This is effected by means of a ribbon jumper through which the ribbon is threaded and which is free to move vertically in slots on the typehead support bracket, see Fig. 11.35. A spring holds the ribbon jumper against an arm on the ribbon jumper shaft, see Fig. 11.35, which is operated by the traversing link via

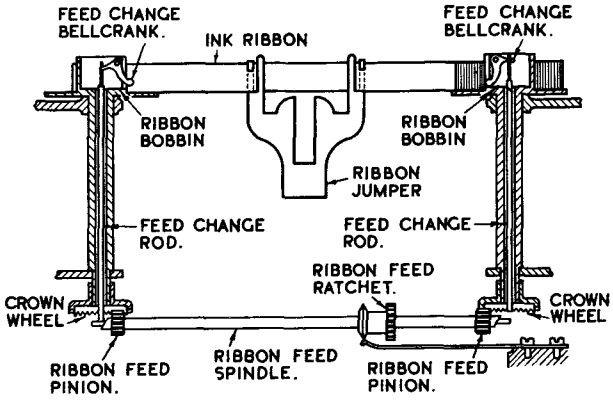


FIG. 11.43. TELEPRINTER NO. 7B: RIBBON FEED MECHANISM

the feed lever. It will be seen that, as a result of the reciprocating movement of the traversing link, the ribbon jumper is moved up and down once per rotation of the cam sleeve; the ribbon jumper is at its maximum height when the type-hammer strikes the typebar.

The ribbon is accommodated on two bobbins, Fig. 11.43, and, by means of a ribbon feed mechanism, is fed forward each time a character is printed; the direction of feed is reversed each time the ribbon on one of the drums reaches the end of its effective length.

The ribbon feed mechanism is shown schematically in Fig. 11.43. The ribbon feed spindle has a ratchet which is driven one tooth, for each revolution of the receiving cam sleeve, by a pawl which is fitted to the comb setting lever, see Fig. 11.35. The spindle is free to move longitudinally and is retained, by a jockey spring, in the position to which it was last moved. The spindle carries two pinions, one of which engages with a crown wheel on one of the ribbon bobbin extensions in either position of the spindle; thus only one bobbin is driven at a time.

Each of the ribbon bobbins has, passing through its centre, a feed change rod which is suspended from the horizontal arm of a feed change bell-crank which it tends to turn about its pivot and thus cause the other end to protrude through a slot in the side of the ribbon bobbin. Normally this action is prevented by the ribbon with which the end of the bell-crank comes into contact through the slot. As the last turn of ribbon is unwound from a bobbin, the slot is uncovered and the bottom end of the feed change bell-crank moves into the slot and the feed change rod is thereby lowered. The pinions on the ribbon feed spindle have obliquely cut faces with one of which the end of a lowered feed change rod engages and thus, as the spindle rotates it is thrust to the left or the right, as the case may be, thus throwing one pinion out of engagement with its crown wheel and causing the other pinion and crown wheel to engage. Thereby the direction of feed of the ribbon is reversed.

As already stated, the teleprinter may be fitted with either a page or a tape printing attachment which is easily fitted to the machine. The operations of the mechanisms of these units are controlled from the movements of the traversing link via the feed lever which operates in conjunction with other levers on the Control Lever Unit, as follows—

(*a*) To provide a means whereby the line feed and carriage return movements of the page printing attachment are effected.

(*b*) To provide for letter feed of the paper to be effected.

(*c*) To suppress the operation of the letter feed mechanism whenever the functional signals, viz. figure- and letter-shift, carriage return, line feed and bell signal, are received.

The *Control Lever Unit* is illustrated in Fig. 11.44 and is shown schematically in Fig. 11.45. The various control levers are pivoted on a common spindle and, with the exception of the feed throw-out lever, are held by means of springs so that their inner ends bear on the outer edges of the bell-cranks which correspond to the code combinations of the functional signals. When any one of these functional bell-cranks is selected, the appropriate control lever follows the inward movement of the bell-crank, thereby causing the free end of the control lever to be moved downwards so effecting operation of the page or tape printing attachment as will be described later. The feed throw-out lever, in its normal position, is held so that its bent end rests on the horizontal arms of the figure and letter shift levers and the spindle on its other end rests on the underneath edges of the other control levers. Thus, whenever a control lever or a shift lever is operated, the free end of the throw-out lever will be operated which results in the letter feed mechanisms on the page or tape printing attachment being rendered inoperative.

The bell control lever engages on a plunger fitted in the main casting and when operated depresses the plunger and causes a pair of electrical contacts to be closed. The contacts when closed cause a bell in the external circuit to be energized.

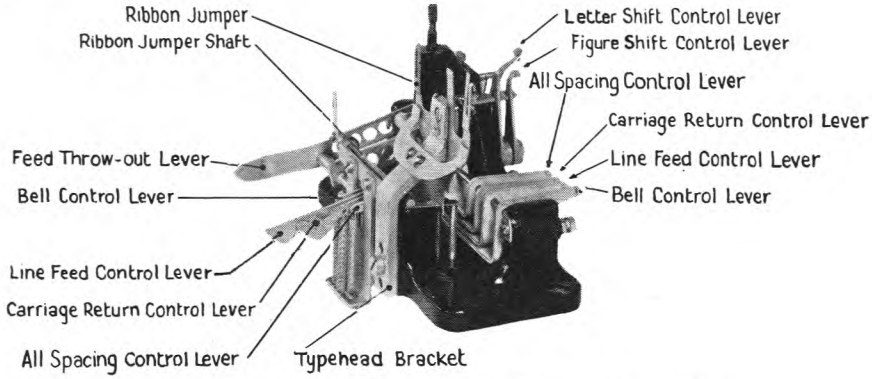


FIG. 11.44. TELEPRINTER NO. 7B: CONTROL LEVER UNIT
(By courtesy of H.M. Postmaster-General)

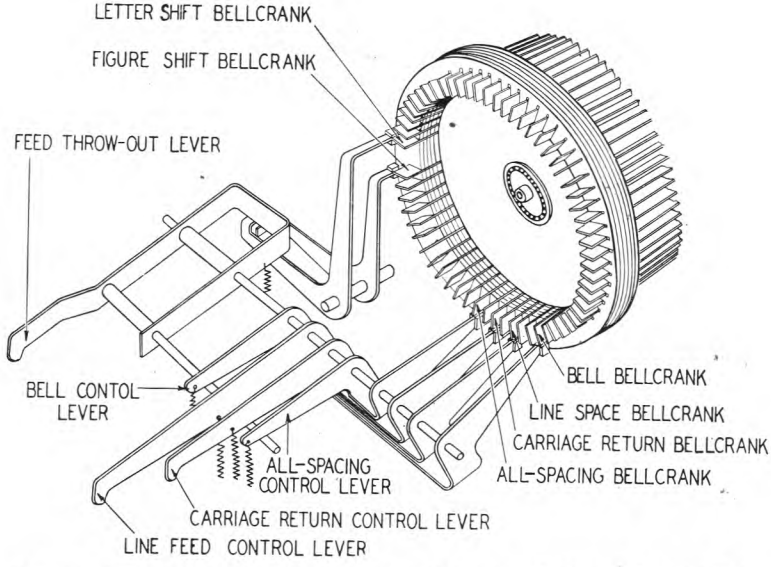


FIG. 11.45. TELEPRINTER NO. 7B: SCHEMATIC OF CONTROL LEVER UNIT

Page Printing Attachment. The page printing attachment consists of a main casting which carries guide rods on which the paper carriage moves; the casting also serves as a mounting for the mechanisms required for feeding the paper and effecting the return of the carriage.

Fig. 11.17 shows a rear view of the teleprinter fitted with a page printing attachment and Fig. 11.46 shows a view with the attachment opened outwards on its pivot. An underside view showing the platen and the paper feed mechanisms is given in Fig. 11.47.

To remove the attachment from the machine it is only necessary to raise the latch, swing the attachment outwards and then lift it from its pivot.

The platen, Fig. 11.47, is a metal roller, covered with compressed cork (langitex), over which the paper is passed; the right hand end of the roller acts as a dash-pot for the carriage shock absorbing

piston. The platen spindle passes through the centre of the platen, friction to traverse movement being reduced by pairs of roller bearings which

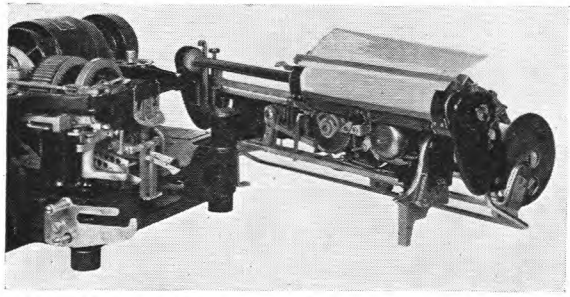


FIG. 11.46. TELEPRINTER NO. 7B: PAGE PRINTING ATTACHMENT SWUNG OUTWARDS ON ITS PIVOT AT REAR OF TELEPRINTER

(By courtesy of H.M. Postmaster-General)

engage a spline on either side of the platen spindle, see Figs. 11.48 and 11.49, which give an end view

end of the spindle a knob for manual rotation of the platen is provided.

The platen is accommodated in the paper carriage, Figs. 11.48 and 11.49, the principal components of which are—

(*a*) The paper carriage casting.

(*b*) The two end plates, which also act as bearings for the platen.

(*c*) Two pressure rollers, covered with compressed cork, which are held in contact with the platen by pressure springs. Each pressure roller extends practically half the length of the platen; their purpose is to ensure that the paper is held with uniform tension throughout the width of the platen. The rollers may be lifted from the platen by means of the pressure roller release lever so as to facilitate insertion of the paper on the platen.

(*d*) Two paper holding clips, one at each end, to ensure that the paper is held in close contact with the platen during printing.

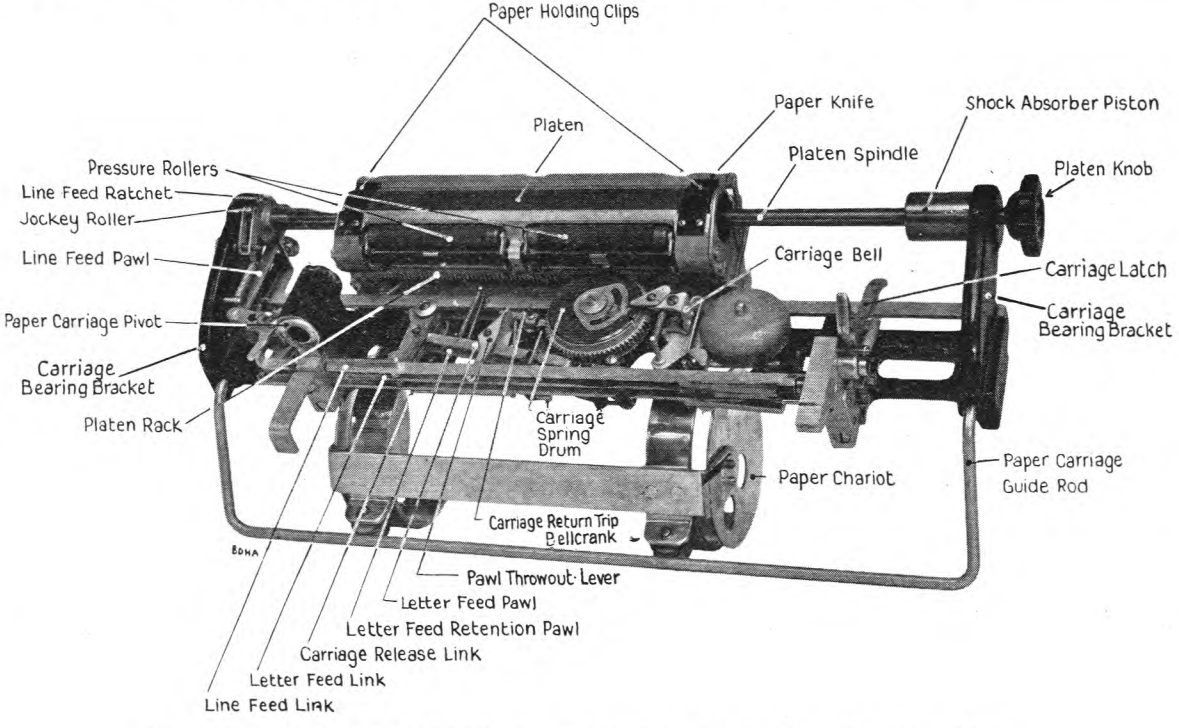


FIG. 11.47. TELEPRINTER NO. 7B: PAGE PRINTING ATTACHMENT (UNDERSIDE VIEW)

(By courtesy of H.M. Postmaster-General)

and a sectional view respectively. At the left hand end of the platen spindle is a ratchet which is acted upon by the line feed pawl so causing rotation of the spindle and the platen. At the right hand

(*e*) A paper knife, by means of which the printed message can be torn neatly from the paper roll.

(*f*) A tension roller mounted on arms pivoted on the end plates and held in its normal position by

two springs. Its function is to ensure an even feeding of the paper round the platen.

(*g*) The platen rack is a toothed rack which engages with a gear wheel associated with the letter feed mechanism.

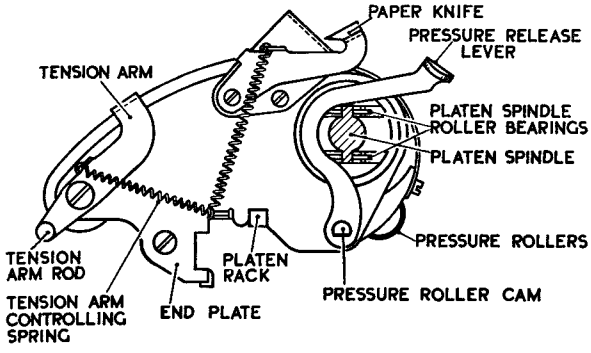


FIG. 11.48. TELEPRINTER NO. 7B: PLATEN AND CARRIAGE (END VIEW)

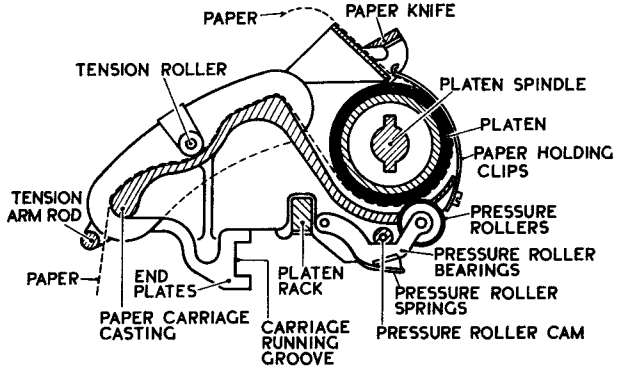


FIG. 11.49. TELEPRINTER NO. 7B: PLATEN AND CARRIAGE (SECTIONAL VIEW)

The paper chariot for accommodating a roll of paper is attached to the paper carriage casting by pivot screws one at each end; fixed to its base are two rollers which ride along the paper carriage guide rod during movement of the chariot in unison with the platen.

The method by which the paper is fed round the platen is shown in Fig. 11.49. The dotted line shows the path of the paper as it leaves the paper roll which is placed in the chariot so that the paper unrolls from the inside.

The carriage operating mechanism, controlling the movement of the paper carriage, is mounted on the main casting of the page printing attachment and consists of three main sections—

(*a*) the letter feed mechanism

(*b*) the carriage return mechanism and

(*c*) the line feed mechanism.

The reciprocating movement of the traversing link is transmitted to the carriage mechanism, through the carriage feed lever trunnion (refer to Fig. 11.35), which slides in the groove in the clutch cross-head. The cross-head is common to each section of the carriage mechanism and makes one complete oscillation for each revolution of the receiving cam sleeve. It is normally in its mid-position and its first movement is to the left; it next moves to the extreme right and finally back to its mid-position again. The movement of the cross-head provides the power for the operation of the various mechanisms under the control of the levers on the control lever unit, as will now be described.

The letter feed mechanism, Fig. 11.50, functions to propel the paper carriage from the right to the left hand side of the machine, one letter space for each character printed. The letter feed dog, which is pivoted to the letter feed link, is normally held in engagement with the claw on the under surface of the cross-head by its controlling spring. The letter feed link restoring spring is fixed at the other end of the letter feed link and is anchored to the main casting. Thus, as long as the letter feed dog

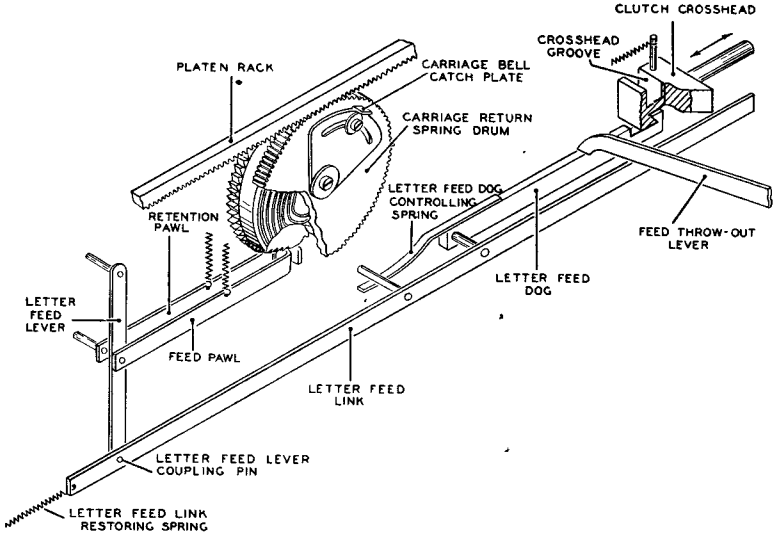


FIG. 11.50. TELEPRINTER NO. 7B: LETTER FEED MECHANISM

is engaged with the cross-head, the feed link will follow the movements of the cross-head.

The letter feed lever, the upper end of which is pivoted to the main casting, is attached to the letter feed link and carries the feed pawl. As the letter feed link follows the movements of the cross-head, the feed pawl is moved first to the left so that its tip engages with the next tooth of the ratchet wheel; then the pawl is moved to the right and

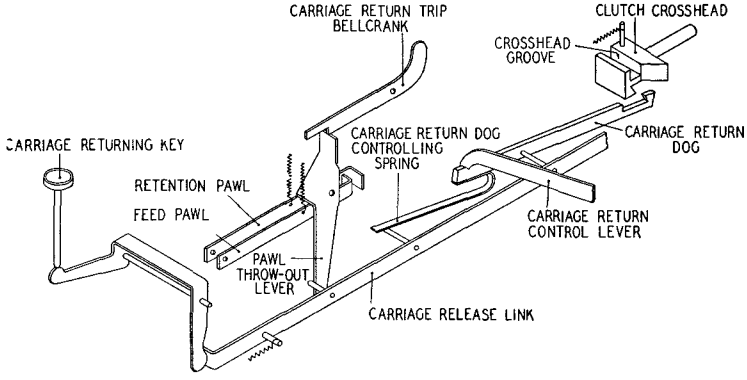


FIG. 11.51. TELEPRINTER NO. 7B: CARRIAGE RETURN MECHANISM

causes the ratchet to rotate one tooth and the retention pawl engages with the next tooth on the ratchet and holds it in position; on the same spindle as the ratchet is the gear wheel which engages with the platen rack and thus the paper carriage is carried forward one letter space. The ratchet carries a spring drum housing the carriage return spring and, as the ratchet is rotated, the spring is wound up and prevented from unwinding by the action of the retention pawl.

Certain signals, e.g. letter- and figure-shift, carriage return, line feed and bell signal, do not require the carriage to move forward or a character to be printed, and therefore it is necessary to render the line feed inoperative when these signals are received. This is effected by the action of the feed throw-out lever which, as already explained, is operated whenever one of the levers on the control lever unit is operated. The feed throw-out lever, when operated, depresses the letter feed dog, so that it is disengaged from the cross-head and consequently the letter feed link is not operated and the paper carriage is not moved for these signals.

The function of the carriage return mechanism, Fig. 11.51, is to move the carriage from the left hand to the right hand side of the machine at the end of a line of printed characters. The carriage is normally returned mechanically by the action of the carriage return mechanism after the receipt of a carriage return signal combination; but in order that the carriage may be returned manually if required, a carriage return key is fitted at the left hand side of the unit.

The carriage return dog, which is pivoted to the carriage release link, is normally held out of engagement with the clutch cross-head by its controlling spring. When a carriage return signal is received, the carriage return control lever on the control lever unit is operated and causes the carriage return dog to engage with the cross-head. Whilst it is thus engaged, the carriage release link will follow the movements of the cross-head.

The pawl throw-out lever is pivoted near its upper end and, at its lower end, engages with a pin on the carriage release link. As the cross-head moves to the right, the bottom end of the throw-out lever is deflected and the upper end depresses the feed and retention pawls, disengaging them from the ratchet. This permits the carriage return spring to unwind thus rotating the gear wheel and the paper carriage is returned in readiness for the next line of print.

The time occupied by the paper carriage in returning exceeds the time occupied by the operation of the carriage release link and, therefore, to ensure that the pawls are disengaged from the ratchet for a time sufficient to allow the paper carriage to complete its return movement, a trip bell-crank is provided. When the throw-out lever has been operated. the top end falls behind the shoulder of the trip bell-crank which prevents its return and re-engagement of the pawls until, when the carriage is completely returned, a projection on the carriage engages and raises the detent on the trip bell-crank, thus allowing the pawls to re-engage the ratchet.

To minimize the impact and eliminate bounce when the paper carriage is returned, a shock absorber is fitted at the end of the platen spindle, Fig.

11.52. This consists of a small piston, which enters the dashpot in the platen. A small air outlet is drilled through the piston to permit the escape of air from the cylinder. The speed at which the air

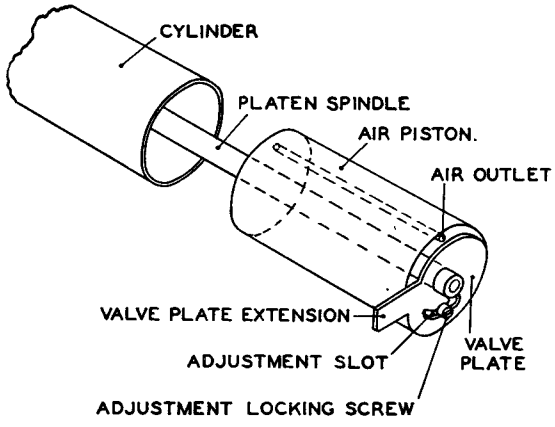


FIG. 11.52. TELEPRINTER NO. 7B: PLATEN SHOCK ABSORBER

is permitted to escape can be controlled by an adjustable valve plate which is slightly elliptical and, as it is turned, the extent to which the air outlet is covered is varied. By this means it is possible to regulate the amount of cushioning obtained with the shock absorber. *Note.* Teleprinters No. 7 manufactured in recent years have an improved form of shock absorber which employs a large independent dashpot, the piston of which is actuated by the platen via a lever.

The line feed mechanism, Fig. 11.53, functions to rotate the platen, on completion of each line of printed characters, in readiness for the next line. The line feed dog and line feed link are similar in construction and operation to the corresponding carriage return parts and are brought into operation, on receipt of a line feed signal, by the operation of the line feed control lever which causes the dog to engage with the cross-head. The line feed bellcrank, on which is pivoted the line feed pawl, is fixed to the left hand end of the line feed link. As the line feed link is moved to the right by the action of the cross-head, the pawl is operated and engages with the ratchet on the platen spindle and causes the spindle and platen to rotate. As the paper is held against the platen by the pressure rollers it is also rotated with the platen. The travel of the pawl is controlled by an eccentric by means of which either single or double-line spacing can be obtained. Back-lash on the platen is prevented by a jockey roller, which rides on the platen ratchet, and thus uniform spacing between lines is obtained.

In order that the operator shall receive warning that the end of a line is approaching, a bell is provided which rings at a point adjustable between 5 and 15 characters from the end of a line.

The bell, and the manner in which it is operated by a catch plate fixed to the spring drum, is shown in Fig. 11.54. As the catch plate engages the hammer pawl, the striker is withdrawn from the bell and then, as the drum continues to rotate, the catch plate is carried beyond the pawl and the tension of the spring causes the striker to strike the bell.

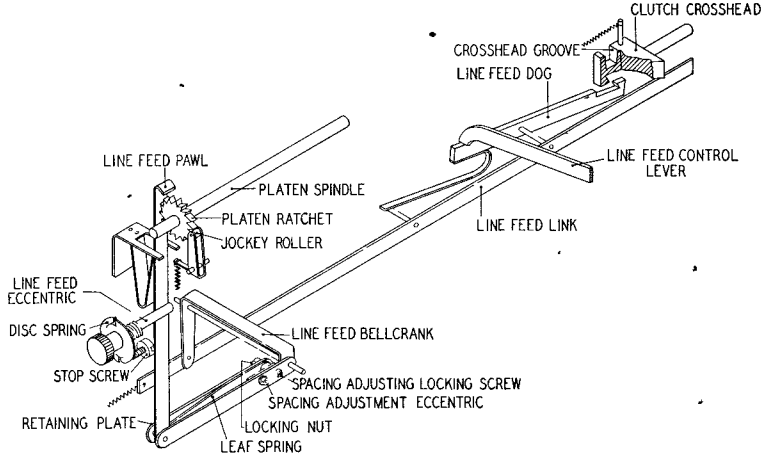


FIG. 11.53. TELEPRINTER NO. 7B: LINE FEED MECHANISM

Sprocket-feed Page-printing Attachment. The normal form of page-printing attachment is suitable for use when single-ply paper is used or when plain multi-ply paper either interleaved with

carbon sheets or made of special carbon-backed paper, in roll form, is used. However when a teleprinter is used for order writing or similar work in which printed stationery is used, it is essential that

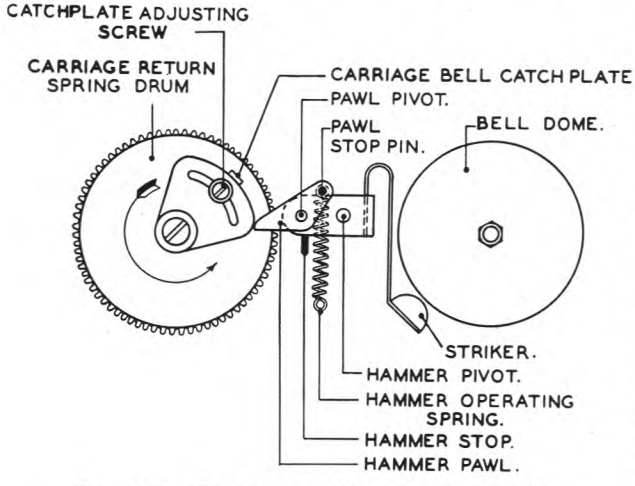


FIG. 11.54. TELEPRINTER NO. 7B: END OF LINE BELL MECHANISM

the typed characters should occupy a precise position on the stationery and a sprocket feed attachment is necessary to ensure accurate registration between the paper used on the machines at each end of a circuit.

The sprocket feed attachment is shown in Figs. 11.55 and 11.56. It is similar in most respects to the normal attachment, the main differences being—

(*a*) The pressure roller method of friction feeding the paper is replaced by a more positive paper driving arrangement in which a number of feed pins are spaced equidistant around the metal platen at each end and

(*b*) A paper chariot is not provided.

The feed pins engage in holes positioned near the edges of the special stationery which is required for this method of working. The special stationery is unsuitable for winding in rolls and is supplied in pack form; the pack is located in a separate container behind the machine or in a special chariot designed for the purpose.

Tape Printing Attachment Unit. The tape printing attachment unit is illustrated in Fig. 11.57 and the principal components of the unit are indicated in Fig. 11.58.

Fitted on the rear of the main casting of the unit is the tape roll holder which accommodates the roll of message tape. The main casting is similar to the paper carriage casting employed for the page printing unit. At one end, the casting is supported on a single pivot, whilst the other end carries a locking lever by means of which it is locked to the teleprinter base.

The platen consists of a small rubber covered metal drum. It is rotated by a friction drive from the feed spindle. At one end, the feed spindle is driven through the worm gear of the platen driving shaft and at the other end it is retained by a spiral spring so that pressure is exerted between the milled surface of the paper feed spindle and the rubber covering of the platen. The platen is held to the left by a spring which exerts an end thrust on the spindle.

The platen driving shaft is shaped like a crank at its upper end, opposite the platen spindle, so that the portion immediately below the milled boss at the top of the shaft is eccentric, relative to the

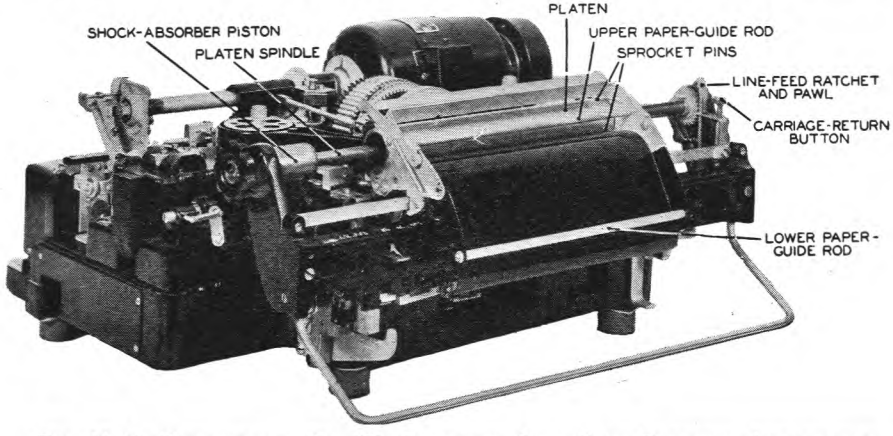


FIG. 11.55. TELEPRINTER NO. 7B: SPROCKET FEED PAGE PRINTING ATTACHMENT
(*By courtesy of H.M. Postmaster-General*)

rest of the shaft. When the driving shaft is rotated, this crank formation causes the platen to move from side to side under the action of the end thrust spring and the crank. In this way the wear on the

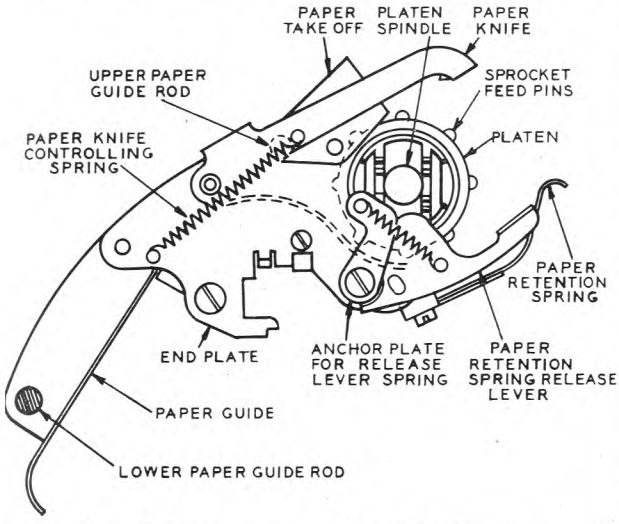


FIG. 11.56. TELEPRINTER NO. 7B: SPROCKET FEED PLATEN (END VIEW)

rubber surface of the platen due to blows from the type bars during printing is more equally distributed over the full surface of the platen.

platen, guided by the rectangular shaped guides situated on each side of the platen and on the right of the roll holder. A paper knife is provided, see Fig. 11.57.

The platen driving ratchet (feed ratchet) is fixed at the lower end of the driving shaft, and is driven by the feed pawl. The feed pawl is pivoted to the feed pawl pivot plate which rides freely on the lower end of the platen driving shaft and engages with the feed link. The feed link lever, which is pivoted to the main casting carries the left hand end of the feed link, the other end of which, when the unit is in position, hooks in behind the carriage feed lever trunnion (refer to Fig. 11.35). The feed link is normally held to the left by a tension spring. The reciprocating motion of the traversing lever is transmitted through the carriage feed lever trunnion and an oscillating motion is thus given to the feed link, except when the feed throw-out lever is operated. A rocking motion is thus imparted to the feed pawl pivot plate, and this causes the feed pawl to be thrust into the teeth of the driving ratchet; in this manner the platen driving shaft is continuously rotated while signals are being received. Back-lash on the driving ratchet is prevented by means of a jockey roller.

When a Teleprinter No. 7 fitted with a tape printing attachment is sending to a Teleprinter No. 7 equipped for page-printing, it is necessary that the sending operator shall have some reminder that the

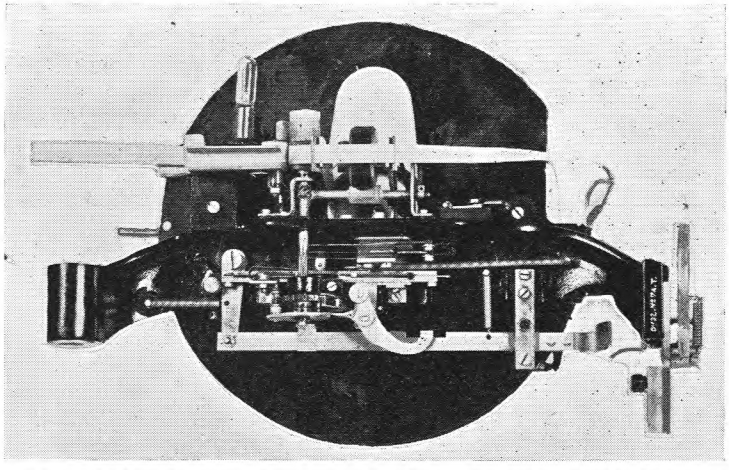


FIG. 11.57. TELEPRINTER NO. 7B: TAPE PRINTING ATTACHMENT
(By courtesy of H.M. Postmaster-General)

The pressure roller, which is mounted vertically on the pressure roller lever, exerts a pressure on the paper tape as it passes over the knurled boss located at the top of the platen driving shaft. By this means the message tape is drawn across the paper carriage on the receiving teleprinter is approaching the end of a line of printing and, therefore, that a carriage return signal followed by a line feed signal must be sent. This is provided by the "carriage return indicator" consisting of a

switch which is employed for operating an alarm, either audible, visual or both.

The mechanism which operates the switch consists of the carriage return indicator spur wheel which is driven through a pinion cut on the platen driving shaft; this wheel is held downwards against the carriage return indicator switch lever by the carriage return indicator spur wheel engagement

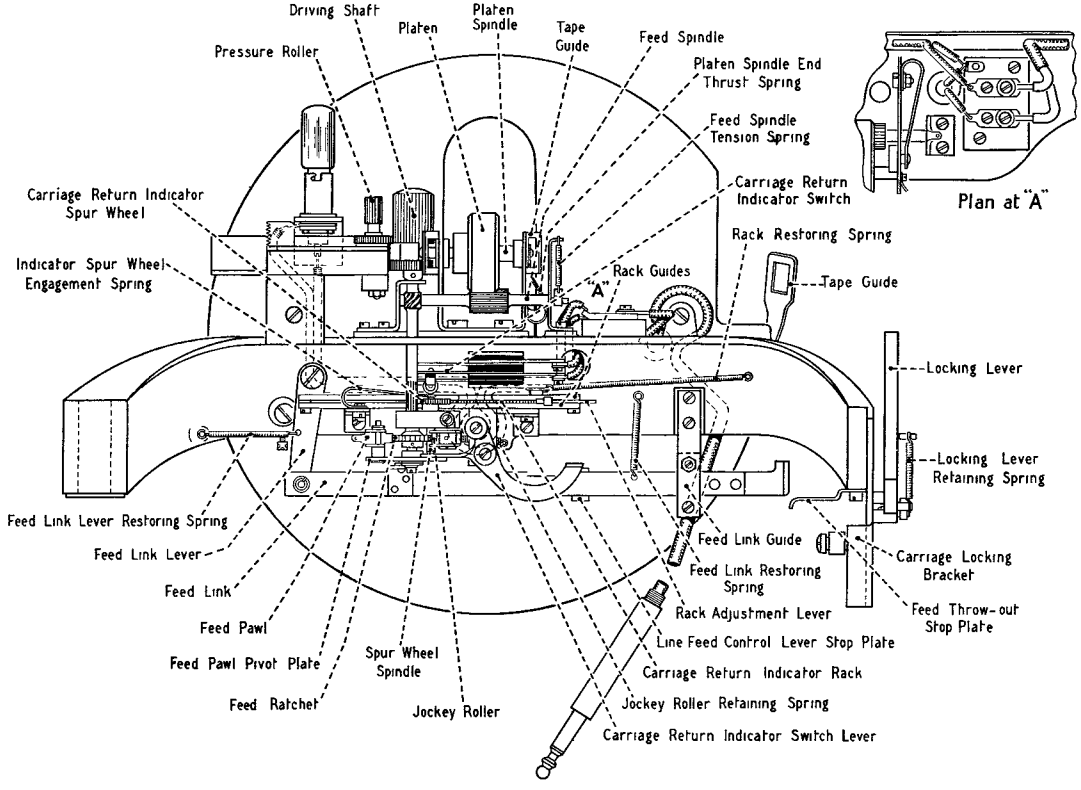


FIG. 11.58. TELEPRINTER NO. 7B: SCHEMATIC OF TAPE PRINTING ATTACHMENT

spring. This spur wheel is pivoted to the feed pawl pivot plate bearing bracket and engages with a small toothed rack, which is free to move to the left when engaged by the spur wheel. As the spur wheel rotates, the rack is drawn from its normal position on the right against the tension of the rack restoring spring, to a position on the left. At its extreme right-hand end the rack carries a small projection, which is employed to deflect the indicator switch springs as the rack reaches the extreme left-hand limit of its travel; the end-of-line alarm is thus operated.

For the purpose of giving a visual alarm, a lamp jack and six volt lamp are fitted on the tape roll holder on the left-hand side of the platen. The supply for lighting this lamp is obtained from a jack fitted near the teleprinter and connected by means of a cord and plug as shown in Fig. 11.58.

When the alarm lamp glows, the operator will depress the "carriage return" key and then the "line-feed" key. These signals cause the paper carriage on the Teleprinter No. 7 at the receiving end to be returned and rotated one line space in readiness for the next line to be printed. This sequence of operation is repeated by the sending operator each time the carriage return indicator alarm lamp glows. The indicator rack is restored to its normal position by the depression of the carriage return indicator switch lever. This is controlled by the carriage return control lever, associated with the printing attachment control unit, when a "carriage return" signal is received. The carriage return indicator spur wheel is thereby thrust out of engagement with the indicator rack. This permits the rack to be restored immediately, under the control of the rack restoring spring, to its normal position on the right of the mechanism.

When a tape teleprinter is only required to work

to other tape teleprinters, the carriage return indicator facilities are unnecessary and an adjustment is therefore provided by which the indicator rack may be moved so far to the right that it is not engaged by the indicator spur wheel.

The line feed control lever stop plate is a small bracket fitted on the front of the tape roll holder. It is employed to ensure that a space shall occur on the tape when a "line feed" signal is received. This is effected as follows: The end of the line feed control lever rests on the stop plate and is thus prevented from operating. Consequently upon the receipt of a "line feed" signal (this signal is transmitted after "carriage return" at the end of a line, when the message originates at a page printing teleprinter) the feed throw-out lever is not operated. This results in the tape being fed forward for a "line feed" signal, and a space is left on the tape between the two words which, on a page printing teleprinter, would have been the last word of one line and the first word on the succeeding line respectively.

When signals are received which do not require the tape to be fed forward, such as "bell," "letter shift" or "carriage return," the feed throw-out lever is operated, and this depresses the feed link out of engagement with the carriage feed trunnion; consequently a space is not caused to appear on the tape between the characters preceding and following the signal received.

Automatic Start-stop Switch. The automatic start-stop switch is an arrangement by which the teleprinter motor is automatically started by the reception of signals at the commencement of a transmission and is automatically stopped at the end of the transmission, thus economizing in power and reducing wear and tear of parts since the teleprinter is only running during periods when traffic is passing.

The switch is operated and starts the motor as a result of the movement of the electromagnet armature in response to the first "start" (spacing) signal of an incoming message and is so arranged that it restores to normal, and switches off the motor, approximately 90 seconds after the reception of signals has ended. To enable the motor to be started ready for the transmission of a message, a small press button is inset into the left hand side of the teleprinter cover so that, when depressed by the operator, it trips the starter switch control mechanism.

The switch and the control mechanism associated with it, are shown schematically in Fig. 11.59 which indicates the position of the mechanism when the machine is at rest.

The spindle is free to move longitudinally through a worm wheel. One end of the spindle carries the starter boss and at the other is fixed the weight lifting arm. Fixed at the end of the weight lifting arm is the weight lifting pin which is

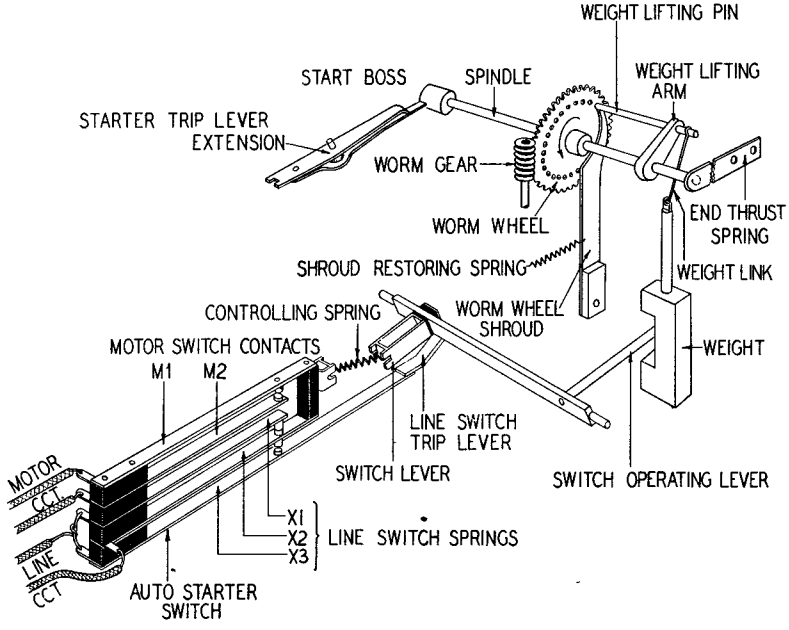


FIG. 11.59. TELEPRINTER NO. 7B: STARTER SWITCH

normally held in engagement with one of a series of holes in the worm wheel by the inward pressure of the end thrust spring acting on the spindle. The weight is attached to the pin by a link.

When the machine is at rest, i.e. the electromagnet armature is operated to marking, the flexible extension of the starter trip lever is out of engagement with the starter boss but, on receipt of the first "start" (spacing) signal of an incoming message, the electromagnet armature moves the starter trip bar and the extension is thrust against the boss and moves the spindle against the tension of the end thrust spring. This causes the weight lifting pin to be withdrawn from the hole in the worm wheel and the weight is allowed to drop forcibly on to the switch operating lever. This lever operates the switch which is mounted in the base of the machine. The motor contacts close and complete the motor circuit.

The worm wheel shroud is mounted against the side of the worm wheel, its function being to prevent the pin re-engaging with the worm wheel during the fall of the weight to its lowest position, i.e. to the left of the bottom of the worm wheel shroud. The upper end of the shroud is chamfered to allow the pin to ride easily on to it as the weight falls.

The worm wheel has teeth, cut round its edge, which engage with a worm gear by which it is rotated continuously whilst the motor is running. If no signals are being received, the electromagnet armature is on the marking side and the pin is allowed to engage with a hole in the worm wheel and it is rotated with the worm wheel thus causing the weight to be raised. After a period of approximately 90 seconds, the position shown in Fig. 11.59 will be reached and the starter switch will be switched off and the motor circuit disconnected. As the weight is lifted the shroud is displaced by the pin, but it is restored to its normal position by its restoring spring just before the motor is brought to rest.

The starter boss is slotted longitudinally, the slot being in such a position that when the weight has dropped it is opposite the extension of the starter trip lever, which consequently enters the slot each time it is actuated until the spindle has rotated approximately 10°. This arrangement ensures that, during the reception of signals, the switch imposes an occasional load only on the electromagnet and does not require to be tripped whenever the electromagnet armature moves to the spacing side. Normally, at the end of a signal combination, the electromagnet armature is restored to the marking stop and the starter trip lever extension is moved clear of the end of the starter boss. If the electromagnet armature stays on the spacing stop, for example, due to a fault in the line causing a continuous spacing signal, the end of the extension is firstly engaged in the slot in the boss. Under this condition, the weight lifting arm will be raised and switch the motor off as previously described, but the turning movement of the boss causes the end of the flexible extension to be forced out of the slot so that it rests upon the under surface of the boss. To restart the motor with the control mechanism in this position, a spacing element preceded by a marking element will be required. The marking element is necessary in this case to move the starter trip lever extension clear of the end of the boss so that the next spacing element (i.e. a start signal) will cause the weight lifting pin to be withdrawn from the worm wheel and result in switching the motor on.

The Answer-back Unit. The answer-back unit enables an operator to confirm that the machine at the distant end of a circuit is ready for reception and, in the case of switching systems in which a teleprinter may be connected to any one of a number of circuits, to verify that the correct connexion has been established. The answer-back can be, and is often, used at the end of a message also to confirm that the connexion is still properly established and thus enables a message to be transmitted with confidence to a subscriber who is temporarily absent. The answer-back unit on the teleprinter at the distant end is brought into action from the transmitting end by the sending of the "Who are You?" signal, which is the secondary of the letter D, and is sent when the D key is depressed after a "figure shift" has been sent.

The unit is located at the extreme right hand side of the keyboard unit and can be seen in Fig. 11.21 while a schematic illustration is given in Fig. 11.60. The drum spindle is mounted at right angles to the keyboard combination bars and at its forward end carries the ward barrel in which are fitted the answer-back wards, each representing one character. The character corresponding to each ward is determined by the projections on its outer edge, which engage with the ends of the combination bars. A projection prevents the corresponding combination bar from moving and thus a spacing signal is transmitted; where there is no projection the combination bar is allowed to move and a marking signal is transmitted.

The answer-back driving gear wheel is driven continuously through a worm gear whilst the motor is running and engages with a friction clutch. The drum spindle is prevented from revolving, however, by the detent which is normally held by its spring in engagement with a notch in the drum spindle.

The detent link is pivoted at one end to the detent and is supported in a guide so that the answer-back release shaft engages with the shoulder at its other end. When a "Who are You?" signal is received, the relative bell-crank on the combination head unit is drawn inwards and the answer-back release shaft follows its movement. The tension of the release shaft operating spring exceeds that of the detent restoring spring and thus the detent is

answer-back unit is prevented when the "Who are you?" key is depressed although the "Who are you?" bell-crank is operated by the local record.

An alarm signal cam, fitted on the rear of the drum spindle, engages with a plunger whilst the drum is off normal and a pair of contacts is closed. These contacts may be used to operate a visual or audible signal for the purpose of indicating that a message is about to be or has been received.

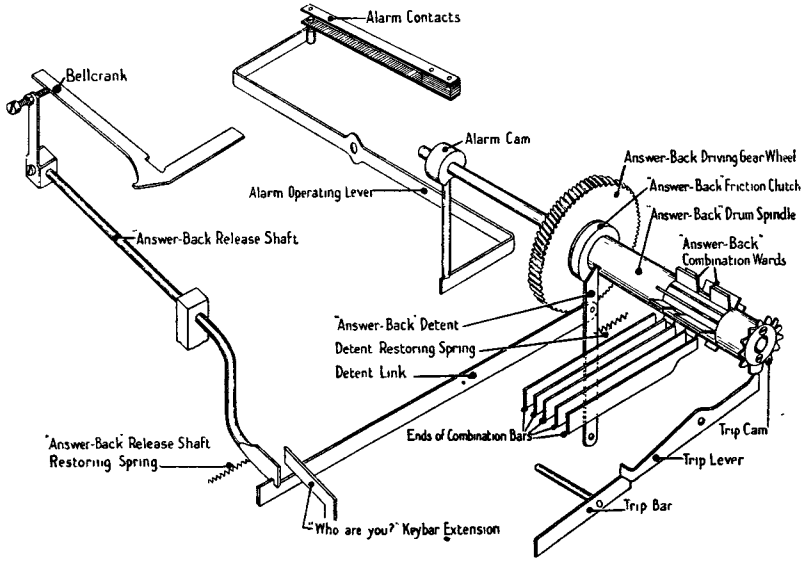


FIG. 11.60. TELEPRINTER NO. 7B: SCHEMATIC OF ANSWER-BACK MECHANISM

withdrawn from the notch in the drum spindle and the spindle commences to rotate.

The trip cam fixed to the end of the spindle has notches round its circumference, one for each ward, and a blank space for the normal rest position. A trip lever is pivoted so that when one end drops into a notch on the cam the other end depresses the keyboard trip bar. As the drum revolves, the trip lever depresses the trip bar as each ward arrives opposite the ends of the combination bars, thus releasing the transmitting cam sleeve for each character to be transmitted. The combination bars are controlled by the projections on the wards, instead of by the keybars as in normal transmission. The positions of the wards on the barrel are so arranged that, in the normal position of the drum, a blank space is left opposite the combination bars and their normal operation is not affected.

The "Who are you?" key is fitted with an extension which prevents the movement of the detent whilst this key is depressed, thereby retaining the detent in engagement with the notch in the drum spindle. By this means operation of the local

Two types of answer-back units, which are interchangeable, have been fitted to Teleprinters Nos. 7B, one having 13 wards (characters) and the later model having a larger drum with 20 wards.

In either case the first four wards are allocated as follows—

Ward No.	*Character Combination*
1	Letter shift
2	Carriage return
3	Line feed
4	Letter shift

and the final ward is always a letter-shift combination. Thus on the 13 character unit 8 wards are available for the answer-back code proper and on the 20 character unit 15 wards are available. (*Note.* The figures quoted include any wards required for shift combinations.)

The use of the letter-shift ward in the first position ensures that the combination head on the receiving teleprinter is in the letter-shift condition before the answer-back code proper is received. The carriage return and line feed wards in the second and third positions ensure that, when working to a page

printing machine, the paper carriage of the receiving teleprinter is in the correct position for printing of the answer-back code.

The letter-shift ward in the fourth position is included as an extra precaution to ensure that the receiving teleprinter is in the letter-shift condition before the answer-back code is received and also to make certain that, even under adverse conditions, the paper carriage on a page printing machine is fully returned.

End of Line Indicator on a Teleprinter Keyboard. Teleprinters No. 7 may require to be worked on a duplex basis or on other circuit arrangements which do not provide for a local copy of the transmitted message and under such conditions it is necessary to provide the operator with an indication when the end of a line of printed characters is approaching. The End of Line indicator described on page 406 operates from the receiving mechanism and is therefore not applicable in this case.

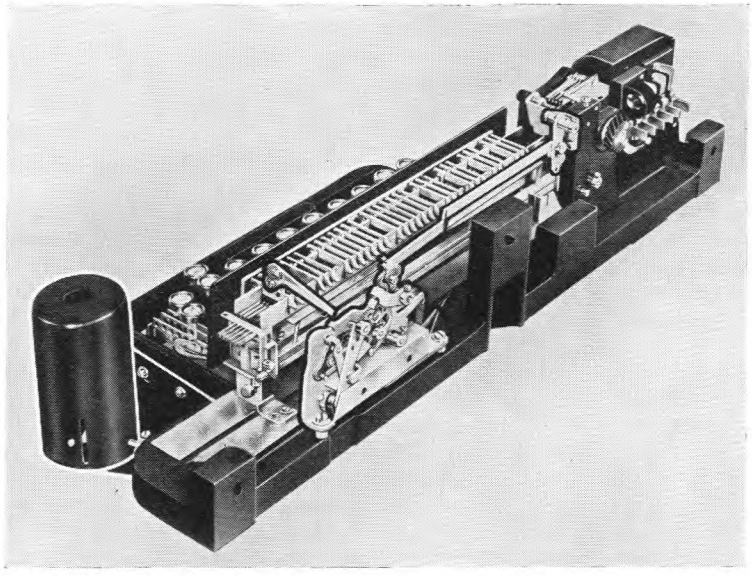


FIG. 11.61. TELEPRINTER NO. 7B: LETTER COUNTING DEVICE AND KEYBOARD
(By courtesy of H.M. Postmaster-General)

The letter-shift ward in the final position is provided to operate the printing mechanism for the last character of the code. Where the full number of ward positions available for the answer-back code are not required the spare positions are left blank; this results in the sending of a letter-shift combination.

There is an initial delay from the commencement of rotation of the answer-back drum to the commencement of transmission of the character combination of the first ward (letter-shift). On the 13 character unit this delay is 170 milliseconds and on the 20 character unit it is 540 milliseconds; the purpose of this delay is to allow for the hangover time of echo suppressors when working single-tone V.F. channels over repeatered trunk circuits and thus avoid mutilation of the transmission.

The wards are held in position on the drum by means of a slotted ring, which can be rotated so that the slot is opposite any ward which it is desired to remove, and a clamping nut.

To give this facility, therefore, a letter counting device is fitted to the teleprinter keyboard; the counting mechanism is stepped forward each time a key is depressed and, after approximately 55 characters have been transmitted, a pair of contacts are closed and complete a circuit for a warning lamp which glows to indicate to the operator that the "Carriage Return" and "Line Feed" keys must be depressed within the next 14 characters (69 characters represents a full line of printing).

The mechanism of the letter counter is incorporated at the rear of the keyboard, see Fig. 11.61, whilst the warning lamp and its mounting are fixed to the right hand side of the keyboard guard. The counting mechanism is operated from the transmitting cam sleeve and is released by the depression of the "Carriage Return" key. A close up view of the actual mechanism is given in Fig. 11.62(*a*).

Referring to Fig. 11.61, pivoted to the main casting of the transmitting unit is a lever carrying a link on which is mounted a cam roller which rides on the

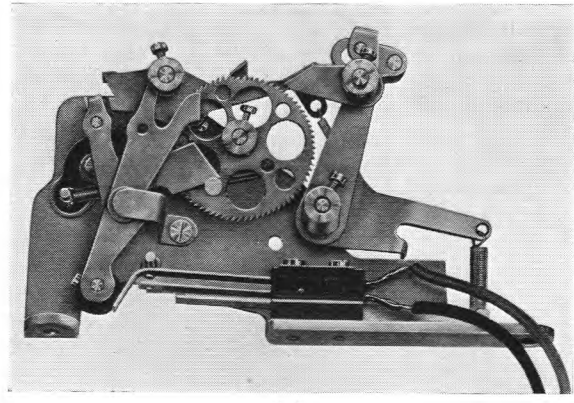
resetting cam of the transmitting cam sleeve. Also attached to the lever is the counter link which, at its other end, is connected to the operating lever of the counter unit. The counter link is normally held to the left by spring tension through the operating lever of the counter and thus holds the cam roller against the resetting cam. The counter operating lever carries the pawl which is held in engagement with the teeth of the ratchet by a spring.

During each revolution of the transmitting cam sleeve, the raised portion of the resetting cam moves the roller and therefore the counter link to the right. This movement causes the counter operating lever, Fig. 11.62(*b*), to be rotated on its pivot and the pawl steps the ratchet round one tooth. A pivoted retention pawl is held into the ratchet teeth by a spring and holds the wheel in position when the cam roller rides off the raised portion of the resetting cam and the pawl is moved backwards one tooth in readiness for the next feeding operation.

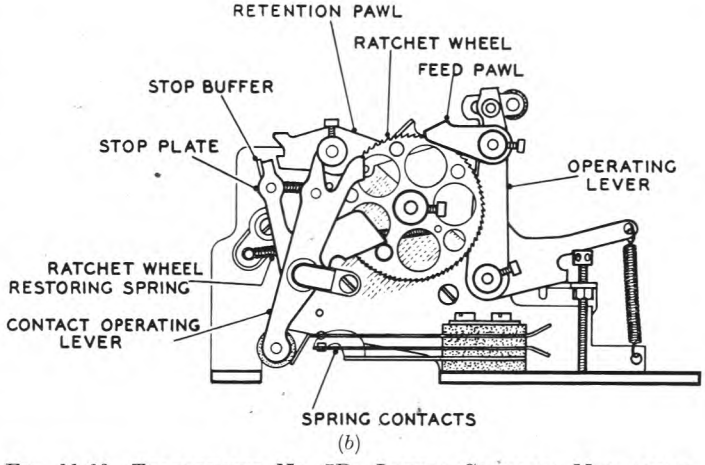
As the ratchet wheel rotates, the restoring spring is wound upon its boss, and, after approximately 55 characters from the zero position, a stud on the ratchet wheel bears against one end of the contact operating lever. The other end of this lever carries an ebonite roller which operates the spring contacts and completes the circuit for the warning lamp. When this has occurred, the feed pawl rides on a smooth arc (i.e. without teeth) of the ratchet wheel and further rotation of the wheel with possible overwinding of the restoring spring is prevented.

When the "Carriage Return" key is depressed, an extension on the key engages with the retention pawl and trips it out of engagement with the teeth of the ratchet wheel. An extension of the retention pawl moves the feed pawl so that it also is disengaged from the ratchet wheel which returns to its zero position under the action of the restoring spring. Whilst the ratchet wheel is restoring, the feed and retention pawls are locked out of engagement with it by an extension on the stop plate which engages with the latch at the end of the retention pawl. When the ratchet wheel reaches its normal position, the stud on it strikes the stop plate thereby unlocking the pawls.

Actions of Receiving, Selecting and Printing, (*Refer to Fig.* 11.35.) The construction and the functions of the mechanisms concerned with the reception of signals and the selecting and printing of the characters have been described and, to enable the student to obtain a thorough grasp of the functioning of the machine during reception of a message, it is now proposed to describe the complete sequence of operations. For this purpose, the operations which occur during the reception of the combination code for the letter Y and its translation into a printed character will be described.



(*a*)



(*b*)

FIG. 11.62. TELEPRINTER NO. 7B: LETTER COUNTING MECHANISM
(*By courtesy of H.M. Postmaster-General*)

The description will be based upon the Teleprinter No. 7B, and it will be assumed that the motor has already been started, as described on page 407, and that the character previously received was one in the letters group since the functioning of the shift mechanism has already been fully described. Therefore the shift comb will be in the position

for the selection of a bell-crank in the letters group.

The five unit combination for the letter Y consists of a marking element followed successively by spacing, marking, spacing and marking elements. The character combination is preceded by the start signal (spacing) and is terminated by the stop signal (marking).

It should be borne in mind that all the mechanical operations described occur during the period of one revolution of the receiving cam sleeve, i.e. for each character combination received, and that the instants of selection are arranged to be in unison with the operation of the transmitting mechanism on the sending machine.

The receiving cam sleeve is in the rest position at the commencement of the reception of the signal combination for each character and thus the following conditions exist—

(*a*) The electromagnet armature is held on the marking side.

(*b*) The pawl abutment is held against the pawls, keeping them out of engagement with the ratchet on the revolving receiving cam shaft.

(*c*) The bell-crank selected for the previous character combination is resting in the slot in the aligned selecting combs, and is holding the typehead in readiness for the printing operation.

(*d*) The setting fingers are in the raised position, to which they were moved for the preceding selection.

(*e*) The finger setting pin is at rest opposite finger No. 3.

On receipt of the start (spacing) element, the electromagnet armature moves to the spacing side and this causes the trip shaft, which is coupled to the armature, to be turned slightly. As a result the following actions occur—

(*a*) The pawl abutment is disengaged from the ratchet pawls, thus permitting the pawl springs to force one of the pawls into engagement with the ratchet wheel; hence the cam sleeve commences to rotate.

(*b*) The trip shaft, as it turns, deflects the finger setting blade downwards.

During the interval between the commencement of the start element and that of the first element of the character combination, the following actions occur—

(1) As the traversing lever operates, the traversing link carries the finger setting pin from its rest position opposite finger No. 3 to a position opposite finger No. 1.

(2) The finger resetting link, operating under the control of the finger resetting trip bell-crank and the finger resetting bell-crank, causes those fingers which were displaced during the previous selection to be withdrawn from beneath the extensions of the selecting combs.

(3) Immediately after the fingers have been withdrawn, the comb setting lever is moved downwards and lowers the fingers until their upper ends are on a level with the finger setting pin.

The traversing link is then moved in a backward direction so that the finger setting pin is carried progressively from finger No. 1 to finger No. 5 and, as the pin is opposite each finger in turn, the finger setting blade is moved inwards by the action of its lever in the cam track.

The first combination element for the letter Y is marking and, due to the movement of the armature from the spacing to the marking side, the trip shaft is turned so that the finger setting blade is restored to its horizontal position. As the pin is opposite finger No. 1 the blade is moved inwards and strikes the pin which pushes the finger inwards beneath the extension of its corresponding receiving comb.

The second combination element is spacing, and the trip shaft is again turned so that the blade is deflected downwards as in the case of the start signal. Consequently, when the pin is opposite finger No. 2, the blade, as it is moved inwards, does not strike the pin but passes below it and the finger is not displaced.

Similar actions take place for the third, fourth and fifth combination elements. The third and fifth elements are marking and so the corresponding fingers are pushed beneath the extension of the combs; the fourth element is spacing and the corresponding finger is not displaced.

Thus the combination corresponding to the character Y is set up on the comb setting fingers.

During the movement of the traversing link so far the feed lever has been operated and the functions of the page or tape printing attachment performed; thus the paper is in a position ready for the printing of the character now stored in the combination and typehead, i.e. *the character selected during the preceding revolution of the cam sleeve.*

Just prior to the selection of the fifth element of the character combination (in the case of the Teleprinter No. 7A it is just after, see Fig. 11.63 for a comparison of the timing of the operations on the two types of machine), the ribbon jumper is fully raised and therefore the ribbon is between the typehead and the paper on the platen. The typehammer is then operated and the stored character is printed.

Immediately after the operation of the typehammer, the bell-crank lifting lever is operated and

moves the bell-crank lifting collar inwards towards the cranked ends of the bell-cranks; this causes the bell-cranks to be raised from the edges of the receiving combs and thus the bell-crank employed for the selection of the character just printed is withdrawn from engagement with the receiving combs and the typehead clutch. As a result of these operations—

(*a*) those receiving combs concerned with the selection of the preceding character combination are reset to their rest position by their restoring springs and

(*b*) the typehead is freed from restraint, its clutch re-engages and the typehead commences to rotate.

Next, the comb setting lever moves upwards causing the fingers to be raised. The fingers corresponding to marking elements, viz. Nos. 1, 3 and 5, which have been moved inwards by the setting pin, are pushed against the extensions of receiving combs Nos. 1, 3 and 5 which are thereby rotated a small amount. This results in a channel being aligned across the edges of all five receiving combs and the shift comb which is in the letters position. The bell-crank lifting lever now moves outwards from the ends of the bell-cranks and the bell-cranks are lowered on to the combs again; the bell-crank for the letter Y is drawn by its spring into the channel provided by the setting of the combs. (*Note.* The selected fingers remain in the raised position until the commencement of the next revolution of the cam sleeve, when they are lowered by the comb setting lever and, at the same time, are reset by the finger resetting lever as described above.)

The outer end of the Y bell-crank is thus introduced into the path of the stop arm of the clutch on the rotating typehead. As a result, the clutch is disengaged and the typehead is arrested in a position such that the typebar for the letter Y is brought in front of the typehammer in readiness for printing during the succeeding revolution of the cam sleeve. Because of this feature of storing one character in the combination and typehead, it is always necessary to transmit an additional character, say letter-shift, at the end of a message so that the last character of the message itself shall be printed.

By reference to Fig. 11.63, it will be seen that the setting of the combination on the receiving combs, i.e. the raising of the fingers, overlaps into the stop signal. The stop signal is always marking so that the position of the trip shaft is such that the pawl abutment is placed in the path of the cam sleeve pawls. Thus, as the cam sleeve completes its revolution, the pawl abutment engages with the pawls, causing them to be disengaged from the ratchet and the cam sleeve is brought to rest in its normal position and the retention lever engages in the recess on the cam sleeve.

The timing of the operations concerned in the selection of a character will be understood more fully by a comparison of the receiving cam sleeve tracks on the Teleprinters Nos. 7A and 7B.

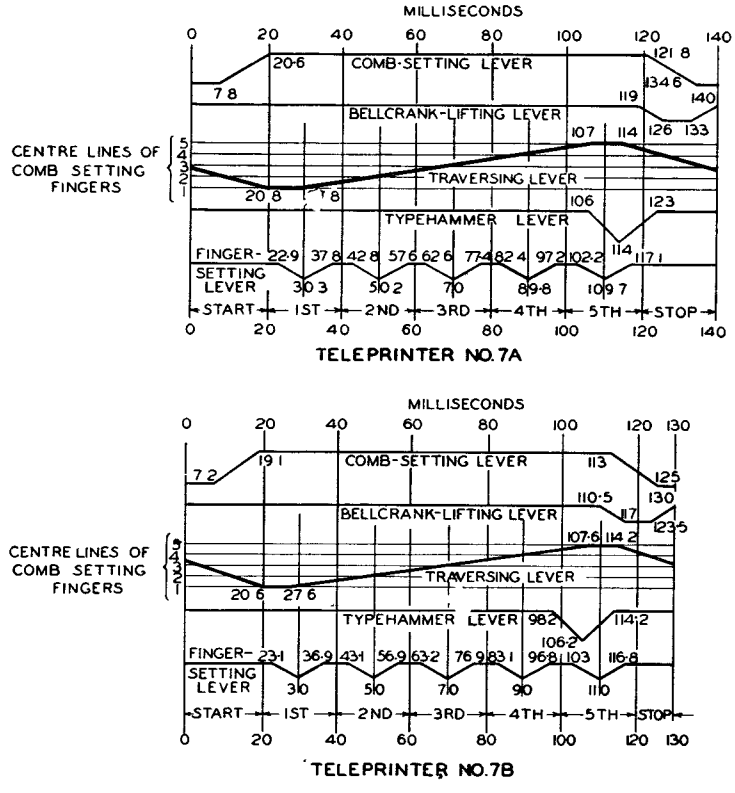


FIG. 11.63. TELEPRINTER NO. 7A AND 7B: RECEIVING CAM TIMING DIAGRAM

Fig. 11.64 shows the receiving cams of the two types of machine as they would appear if laid out flat whilst Fig. 11.65 shows schematically the angular positions in which the cam tracks are cut on the circumference of the cam sleeve. It will be seen that those tracks which control purely mechanical functions, e.g. comb setting, bell-crank lifting and type-hammer, are the same for the 7A as for the 7B but that the traversing lever and finger setting lever tracks differ.

Fig. 11.63 shows the timing of the various

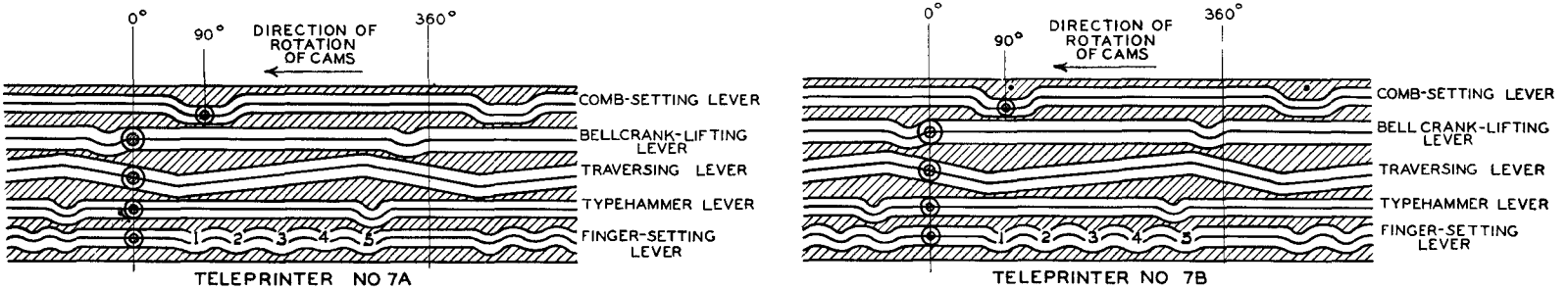


FIG. 11.64. TELEPRINTER NO. 7A AND 7B: RECEIVING CAM DEVELOPMENTS

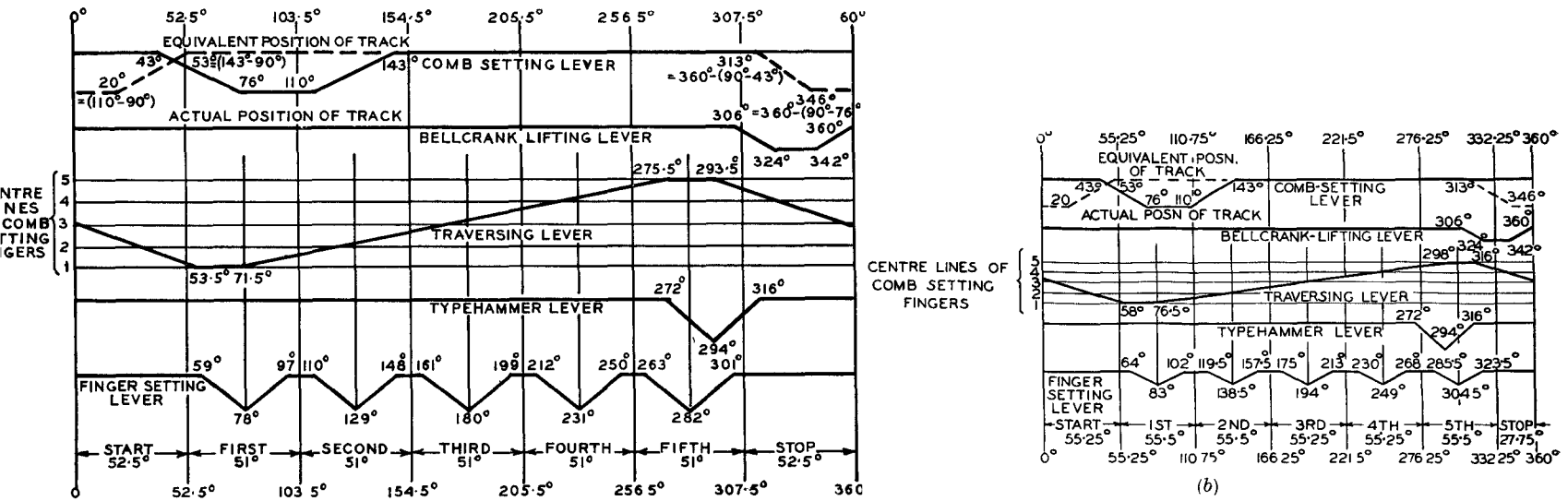


FIG. 11.65. SCHEMATIC OF RECEIVING CAM TRACKS

(*a*) Teleprinter No. 7A. (*b*) Teleprinter No. 7B.

operations controlled by the cams. It will be seen that the increased speed of rotation of the cam sleeve on the Teleprinter No. 7B obviously has the effect of speeding up the purely mechanical functions. The timing of the operations concerned with the selection of signals remains similar to that of the Teleprinter No. 7A with the result that the time allowed for the arrival of the stop element to actuate the receiving cam pawl abutment and so stop the cam is shortened to 10 milliseconds.

Fig. 11.66 shows the relationship between two successive revolutions of the cam sleeves and how the operations for the selection and printing of a character are spread over two revolutions of the cam sleeve, so that one character is always stored in the combination and type-head, and printing lags one character behind keyboard operation.

Fig. 11.66 also shows how the shorter time of revolution of the Teleprinter No. 7B cam sleeve allows it to be brought to rest for a minimum of 10 milliseconds when receiving perfect 7 unit (140 milliseconds) signals, or for 20 milliseconds when receiving $7\frac{1}{2}$ unit (150 milliseconds) signals. This ensures that the cam sleeve is at its normal position before the commencement of the succeeding signal thus allowing a margin for distortion of the signals or a speed error. This, of course, is the basic principle of the start-stop system of working.

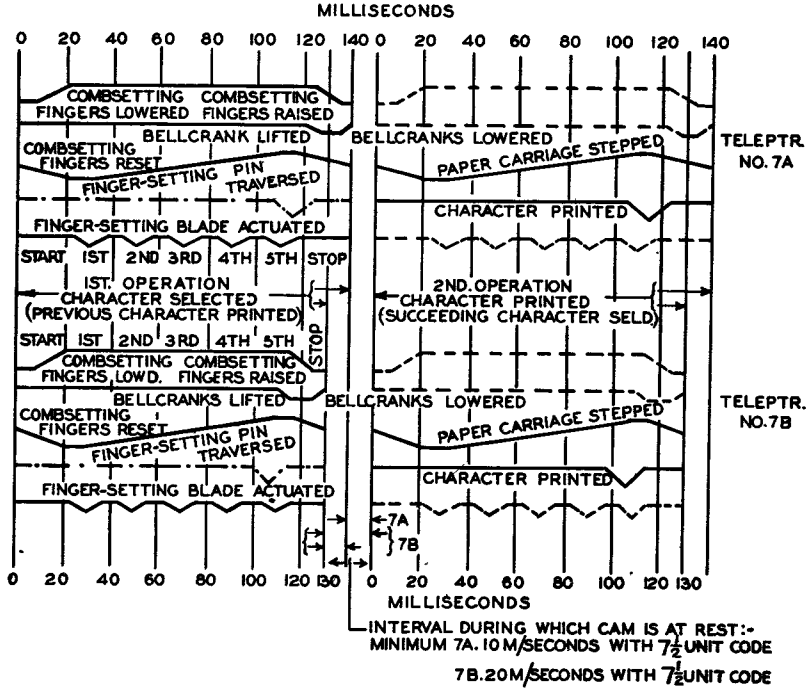


FIG. 11.66. TELEPRINTER NO. 7A AND 7B: TIMING DIAGRAM FOR TWO CONSECUTIVE REVOLUTIONS OF RECEIVING CAM

Referring to Figs. 11.64 and 11.65 it will be seen that the comb setting lever is physically positioned so that it is actuated from a point in its cam track 90° in advance of the operating points of the other levers. However, in order that the relative timing of the various tracks may be seen more readily, it may be assumed that the comb setting lever is displaced from 90° to 0° and the cam track displaced likewise. The equivalent position of the comb setting lever track from a timing point of view in relation to the other tracks would then be as indicated in Fig. 11.65 by the dotted lines. The timing (see Fig. 11.63) is calculated with reference to this equivalent position.

It has already been stated that the motors used on Teleprinters No. 7A and 7B have a working speed (governed) of 3,000 r.p.m. and that a centrifugal type of governor is employed to retain the speed steady at this value. On the earlier models of the Teleprinter No. 7A a direct current shunt wound motor with armature circuit governing was used whilst the later models of the Teleprinter No. 7A and all Teleprinters Nos. 7B employ series wound motors. The principles of operation of these types of governed motors have already been described on pages 372 to 377.

The series wound motor is suitable for mains voltage supplies from 100 to 110 V and from 160 to 250 V by adjustment of the field tappings on a specially provided block. It has a rated output of $\frac{1}{25}$ h.p. (30 W). In the case of the earlier shunt wound motor three separate types of motors covering the voltage ranges 110 V; 200–220 V and 230–250 V are available.

The motor, together with the governor which is fitted to the motor shaft, is assembled as a self contained unit which can readily be detached from the teleprinter base when required to do so for maintenance purposes. The motor shaft is coupled to the main driving shaft and thence through a system of gears to the transmitting and receiving mechanisms. Electrical connexions to the motor

are provided by four pins which engage with corresponding springs on the teleprinter base. The types of centrifugal governors used with these motors are described on page 376.

The Teleprinter No. 3

Teleprinters No. 3 gave long and robust service in the B.P.O. Inland service but they have now been superseded by Teleprinters No. 11 with the completion of the Teleprinter Automatic Switching System in 1954. Until the introduction of the Teleprinter No. 11 in 1949 the Teleprinter No. 3 was the standard machine used on the British Post Office Inland Telegraph Service for point to point and manual switching circuits. It is a tape printing teleprinter, the layout being designed so that the printed tape is ejected at the left-hand side of the instrument, which is the most convenient position for the operator.

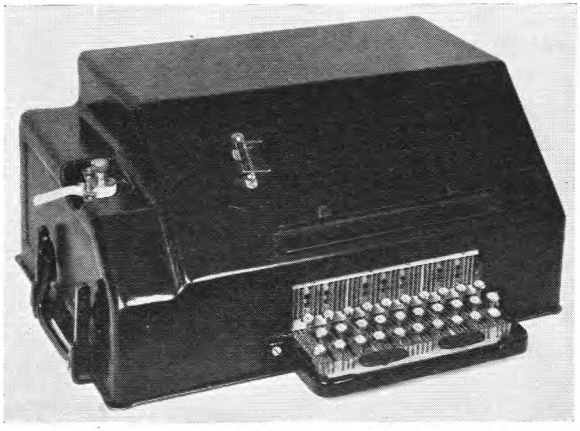


FIG. 11.67. TELEPRINTER NO. 3X: COVER ON
(By courtesy of H.M. Postmaster-General)

Several models of the Teleprinter No. 3 have been produced by the manufacturers Creed & Co. Ltd., as follows—

Teleprinter No. 3A. This is the basic type of Teleprinter No. 3. The signalling speed is 49 bauds and thus the length of a unit element is $\frac{1}{49} \times 1{,}000 = 20{\cdot}61$ milliseconds. The transmitting mechanism is arranged to transmit a start signal equal to one unit element, five code elements each equal to one unit and a stop signal equal to one and a half units; thus the time occupied by the $7\frac{1}{2}$ unit signal is 153 milliseconds approximately. The receiving mechanism is arranged for the reception of $7\frac{1}{2}$ unit signals, the receiving cam sleeve making one complete revolution in the space of approximately 143 milliseconds.

The alphabet and code allocations, see Fig. 11.2 on page 371, do not conform in all respects with C.C.I.T. standards.

Teleprinter No. 3W. This model incorporated several improvements over the Teleprinter No. 3A, and in particular was fitted with an answer-back unit.

Teleprinters Nos. 3Y and 3Z. These models included still further improvements; in particular these relate to the type-head clutch and lubrication facilities.

Teleprinter No. 3X. This was the latest pattern of the Teleprinter No. 3 and included still further improvements in design.

Teleprinters Nos. 3B–3E. These models are Teleprinters No. 3X adapted for working at 50 bauds and use the International Telegraph Alphabet No. 2. They have been used to a limited extent on overseas circuits where conformity to C.C.I.T. standards is essential.

The general principles of the design of all these teleprinters are similar and, as the Teleprinter No. 3X was the latest and most widely-used model, it is described as typical of the series of machines. Moreover, since many of the principles of design and operation are similar to those of the Teleprinter No. 7B, detailed descriptions will be given only where major differences exist.

The Teleprinter No. 3X is illustrated in Figs. 11.67 and 11.68. It consists of a main base casting on which are mounted the various mechanisms necessary for transmission and reception. Apart from the paper mechanisms, which are of course designed for tape working, the mechanisms serve similar functions to those of the Teleprinter No. 7B but they are disposed differently on the base so as to locate the printing point on the left-hand side of the machine.

A sheet metal base plate, with carrying handles, is provided with each machine and, in order to reduce noise, a thick felt pad is used between the base plate and the base casting of the machine. The arrangement can be seen in Fig. 11.68.

A removable metal cover, lined with felt, is attached, by hinges, to the base plate and encloses all the machine parts with the exception of the printing platen and the keyboard. The cover is hinged so that it can be either laid back or removed completely as required.

The dimensions of the machine, with the dust cover and base, are—

Width	$20\frac{1}{2}$ in.
Depth	$14\frac{1}{2}$ in.
Height	10 in.

The weight of the complete assembly is approximately 60 lb.

The motive power for the teleprinters is supplied by a shunt wound d.c. motor with a rated output of $\frac{1}{27}$ h.p. (27·5 W) which is available in four voltage ranges, viz. 100/110 V, 150 /170 V, 200/220 V and 230/250 V. The speed of the motor is maintained constant at 2,520 r.p.m. by a centrifugal governor of the type described on page 376. Different values of the governing resistance are used for the two lower and two higher voltage range motors, the arrangement of the circuit being as shown in Fig. 11.69.

The various shafts of the teleprinter and their speeds are indicated in Fig. 11.70. It will be noted that the transmitting cam shaft rotates at 392 r.p.m., i.e. 153 milliseconds per revolution, and the receiving cam shaft at 420 r.p.m., i.e. 143 milliseconds per revolution.

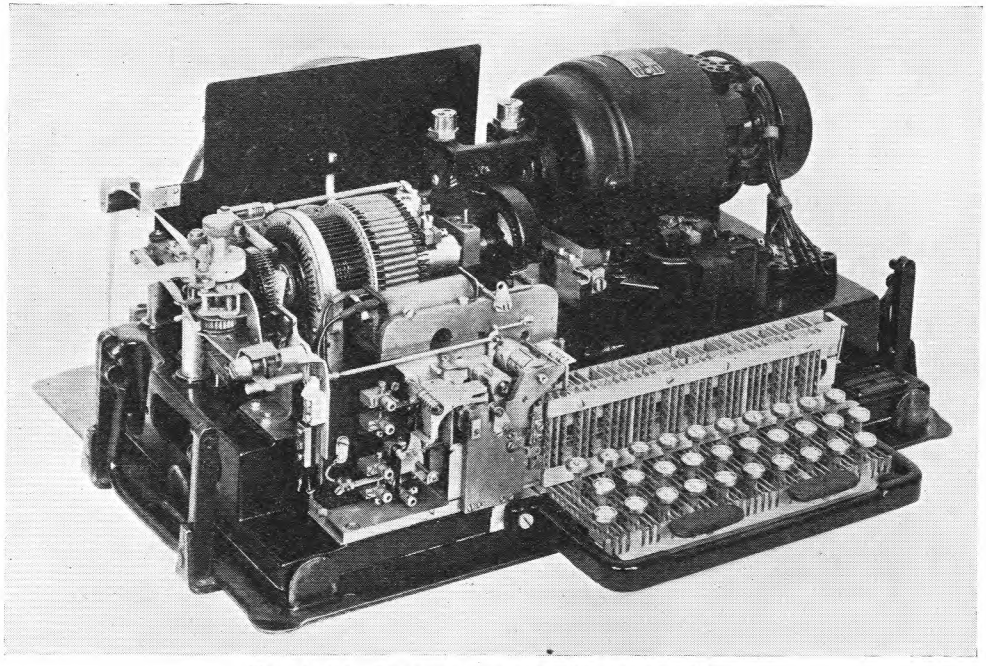


FIG. 11.68. TELEPRINTER NO. 3X: COVER OFF

(By courtesy of H.M. Postmaster-General)

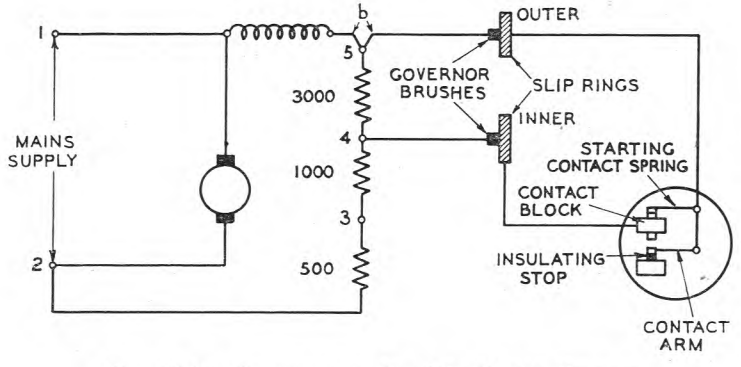


FIG. 11.69. TELEPRINTER NO. 3X: MOTOR CIRCUIT

All the bearings, except those on the motor, are of the journal type and consequently fairly frequent lubrication is necessary.

The various signalling connexions are brought out to a 17-way plug the circuit arrangement being as shown in Fig. 11.71; the power connexions for the motor are connected via a three-way plug and

cord, the third connexion being used to earth the frame (base) of the teleprinter.

Transmitting Mechanism. This, as in the case of the Teleprinter No. 7, consists of the keyboard, transmitting and answer-back units. The latter is similar to that of the corresponding units on the Teleprinter No. 7. A schematic representation of these units is given in Fig. 11.72.

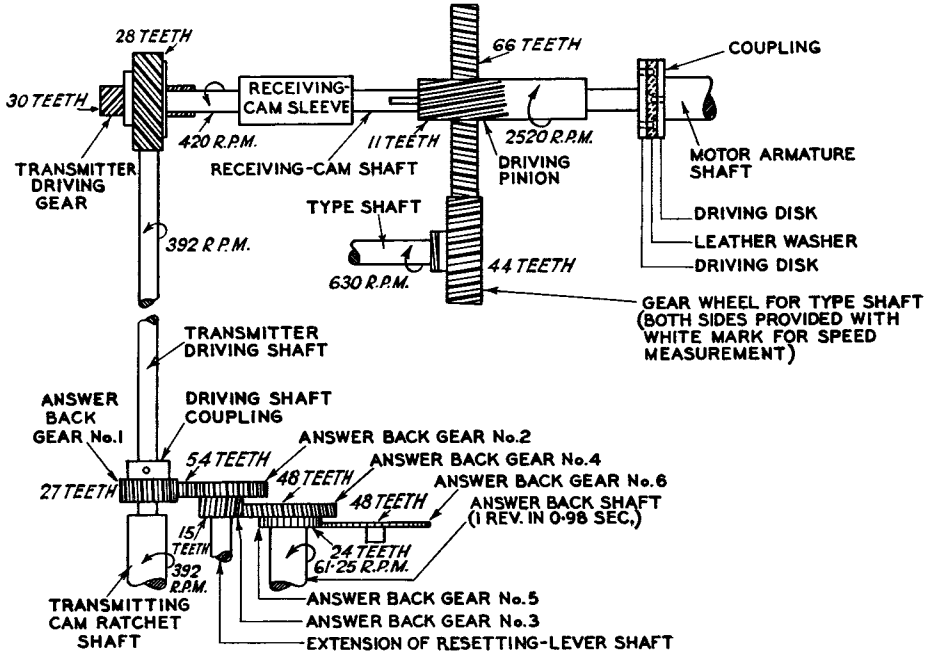


FIG. 11.70. TELEPRINTER NO. 3X: SHAFT AND GEAR DETAILS

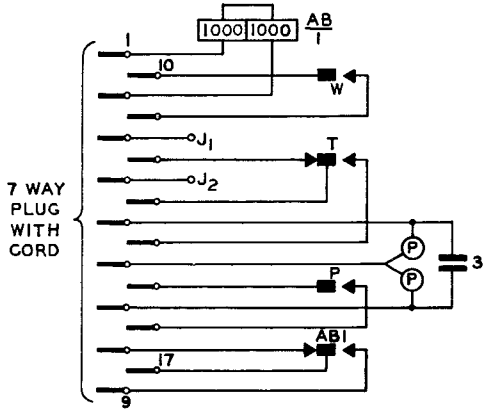


FIG. 11.71. TELEPRINTER NO. 3X: SIGNALLING CIRCUIT CONNEXIONS

will be described later as its operation is controlled from the combination head.

It will be seen from Fig. 11.67 that the general appearance of the keyboard and transmitting units

In addition to a few minor differences in the design of individual parts, the keyboard differs in three major respects from that of the Teleprinter No. 7, viz.—

(1) The layout of the keyboard is different due to

(*a*) Differences in the allocation of the secondary characters.

(*b*) The association of the letter- and figure-shifts with the space function.

(*c*) The absence of the carriage return and line feed keys which of course are not required for inter-operation of tape printing machines. These differences have been explained on page 371.

(2) Since the keyboard layout is different, the combination bars are cut differently.

(3) The keyboard is provided with an advanced unlocking feature. On the Teleprinter No. 7 and the early model of Teleprinter No. 3, the unlocking of the keyboard, which is controlled by the resetting lever, occurs just before the completion of the revolution of the transmitting cam sleeve, i.e. towards the end of transmission of the stop signal of a character. With this arrangement an operator capable of typing at the maximum speed of the machine (Teleprinter No. 7—66·6 w.p.m. and

Teleprinter No. 3—65·3 w.p.m.), may occasionally attempt to depress a keybar whilst the keyboard is still locked. This was considered to be undesirable and consequently it was decided to advance the instant of unlocking so that it occurs towards the end of the transmission of the fifth code element. This has been achieved by arranging that the resetting lever is operated after the cam has rotated approximately 285° which is equivalent to 121 milliseconds from the commencement of the start signal. Under this condition, if the fifth code element is marking, the fifth selecting lever will be in the path of the vertical extension at the left-hand end of the fifth combination bar when the latter is reset. Therefore, the vertical extension of this combination bar is made flexible by hinging it, see Fig. 11.73, so that it can be turned in a clockwise direction by the resetting lever as it is operated. When the fifth selecting lever eventually rides out of its recess in the cam, the extension of the combination bar is returned to the vertical position by its spring. Thus the advanced unlocking feature results in a freer touch, since a second key can be depressed slightly before the transmission of the character corresponding to the previous key depressed is completed.

The transmitting unit, which can be seen on the left of Fig. 11.68, is essentially a link operated transmitter but, as can be seen from a comparison of Figs. 11.72 and 11.23, the components, especially the contact operating lever and the transmitting tongue, are arranged somewhat differently from the corresponding parts of the link transmitter used on the earlier Teleprinters No. 7.

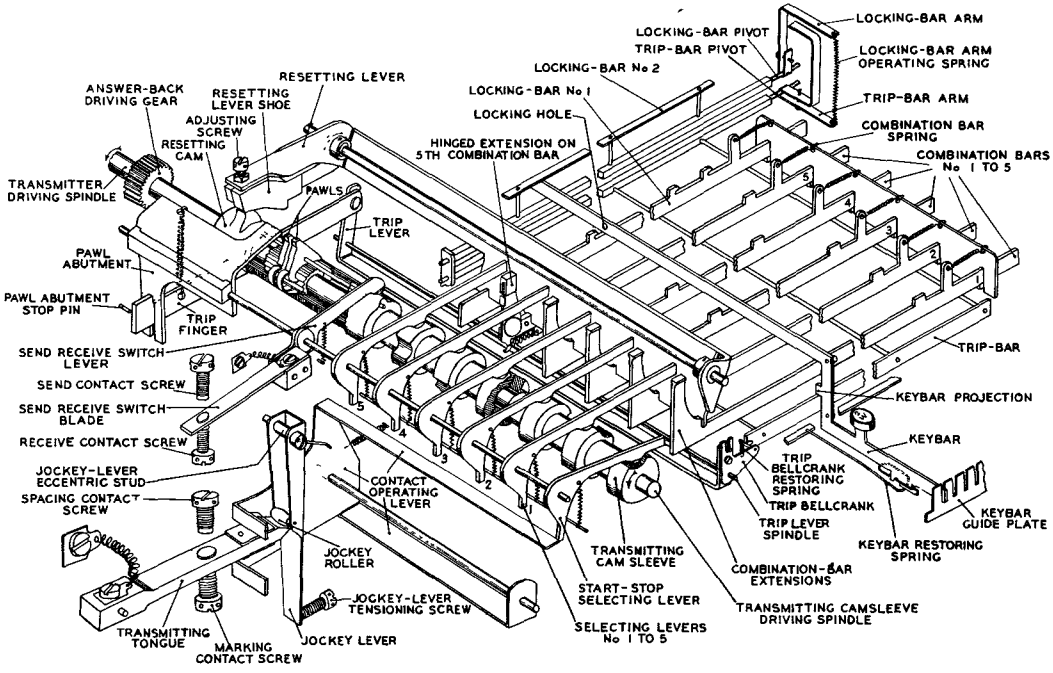


FIG. 11.72. TELEPRINTER NO. 3X: SCHEMATIC OF KEYBOARD AND TRANSMITTER

The principles of operation of the keyboard and transmitting units are fundamentally the same as those of the Teleprinter No. 7 units which have already been described on pages 380 to 386 and no difficulty will be met by the reader in applying the description to Fig. 11.72.

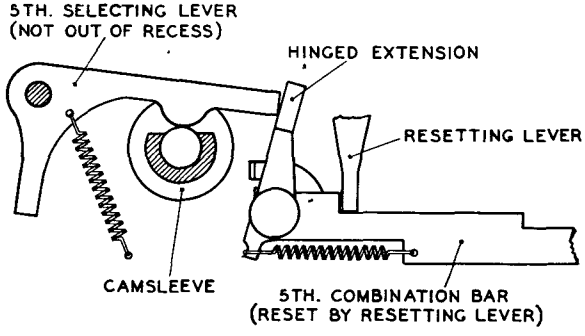


FIG. 11.73. TELEPRINTER NO. 3X: PERMISSIVE 5TH COMB BAR

The Receiving and Selecting Mechanisms. As in the case of the transmitting mechanism, the principles of the receiving and selecting mechanisms are similar to those already described for the Teleprinter No. 7 and apart from minor differences in the designs of parts and the disposition of the electromagnet to the receiving cam unit, the only major differences arise from the changes in the link-up with the paper movement due to the machine being designed for tape printing.

A schematic representation of the mechanisms is given in Fig. 11.74.

The electromagnet, Fig. 11.75 is similar in principle and design to that of the Teleprinter No. 7, the differences being—

(*a*) owing to the altered position of the electromagnet with relationship to the selecting mechanism the mark and space positions of the armature are the reverse of those on the Teleprinter No. 7.

(*b*) the arrangements for adjustment for bias and

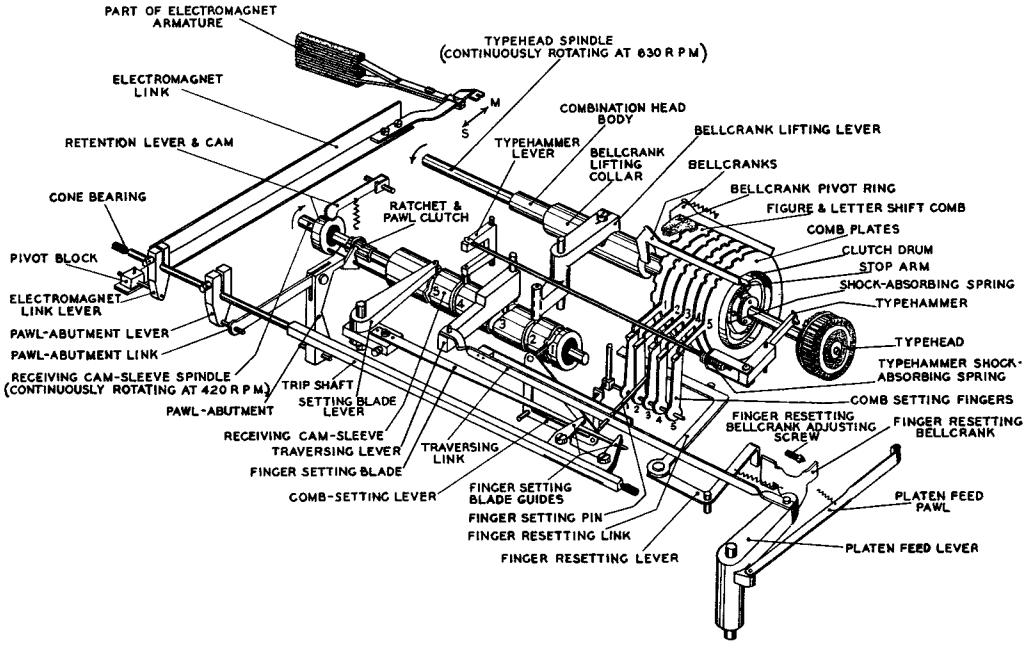


FIG. 11.74. TELEPRINTER NO. 3X: SCHEMATIC OF RECEIVING AND SELECTING MECHANISM

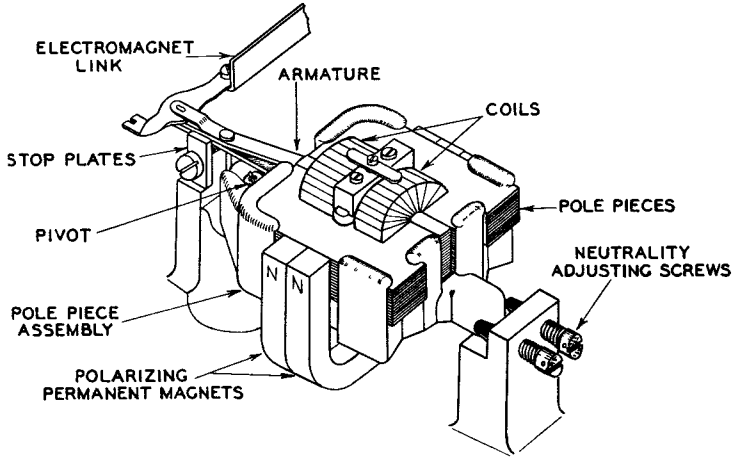


FIG. 11.75. TELEPRINTER NO. 3X: RECEIVING ELECTROMAGNET

(*c*) the armature stop plates are secured to the moulding whereas on the Teleprinter No. 7 a separate bracket is employed. Details of (*b*) and (*c*) will be seen by reference to Fig. 11.75.

By a comparison of Figs. 11.74 and 11.35, the similarity of the selecting mechanisms of the Teleprinters No. 3 and 7 will be observed although the design of individual parts differs. Therefore a detailed description of the Teleprinter No. 3 mechanism is unnecessary and the detailed operations of the Teleprinter No. 7 mechanism given on pages 390 to 396 apply equally to Fig. 11.74.

The receiving combs on the Teleprinter No. 3 combination head are cut to conform with its special alphabet. Moreover, since the carriage return and line feed signals are not used, the number of control levers operated from the combination head bell-cranks is reduced to one only, viz. the WRU (A secondary). It will be noted that there is no feed throw-out arrangement and therefore, if for any reason such as a line fault or interference an all spacing signal is received, the paper tape will be fed out continuously from the machine. The arrangement for operating the figure-shift and letter-shift combs is similar to that used on the Teleprinter No. 7.

Fig. 11.76 shows the relative positions of the bell-cranks on the combination head and the types on the type-head.

The Printing Mechanism. As in the case of the Teleprinter No. 7, the type-head is driven from the type-head spindle, see Fig. 11.74, via a clutch but the design and functioning of the clutch mechanism are different. The component parts of the type-head and clutch are shown in Fig. 11.77.

As on the Teleprinter No. 7, the type-bars are carried in a type-rack and are held in position by a retaining plate which bears against shoulders on the front of the type-bars; three springs hold the retaining plate in position. Thus the type-bars are free to move in the rack when struck by the type-hammer and the retaining plate restores any type-bar which has been so displaced, after the printing operation is completed. The stop arm and shock absorbing spring are riveted to the main body of the typehead.

When assembled to the clutch, the type-head is coupled to the steel friction disc by means of the driving pin which fits into the loop of the shock absorbing spring. The parts are assembled in the order shown in Fig. 11.77 and are secured on to the type-head spindle by the fixing screw and washer. When assembled the clutch spring is slightly compressed and thus the surfaces of the clutch drum, the felt clutch-washer and the steel friction disc are held in close contact with each other, forming a friction clutch. Whilst the motor is running, the type-head spindle, which carries the clutch drum, rotates continuously. When the machine is not receiving signals, the stop-arm, which is secured to

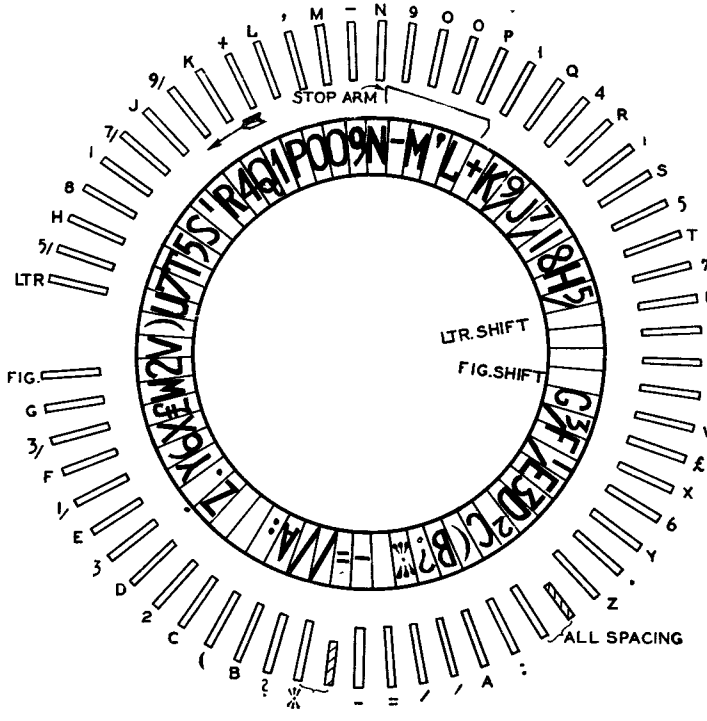


FIG. 11.76. TELEPRINTER NO. 3X: COMBINATION HEAD

the type-head, is held by an operated bell-crank (due to the previous character selection); consequently the type-head is held stationary and the clutch slips. After the type-hammer has been operated to print the previously selected character, the bell-cranks are lifted momentarily and consequently the stop arm is released and the turning movement of the clutch drum is communicated to the type-head via the felt washer and friction disc; the type-head is again arrested when the stop arm encounters the bell-crank selected for the character now being received.

It will be apparent, therefore, that the clutch drives the type-head only during the short period when the stop arm is travelling to an operated bell-crank, and that for the remainder of the time

the clutch slips. This results in considerable wear of the clutch parts and in this respect the clutch is inferior to the Teleprinter No. 7 type which is latched and disengaged during idle periods.

The type-hammer, see Fig. 11.74, is similar to that used on the Teleprinter No. 7 and is operated

The paper tape, upon which the characters are printed, is fed forward by a ratchet and pawl mechanism which is shown schematically in Fig. 11.78. The feed pawl is coupled at one end to the feed lever on the end of the traversing link and the other end, which is hooked to serve as a pawl, is

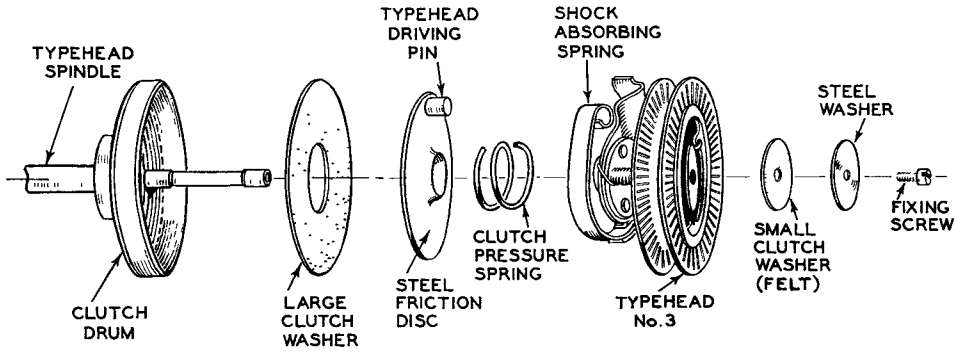


FIG. 11.77. TELEPRINTER NO. 3X: TYPEHEAD CLUTCH

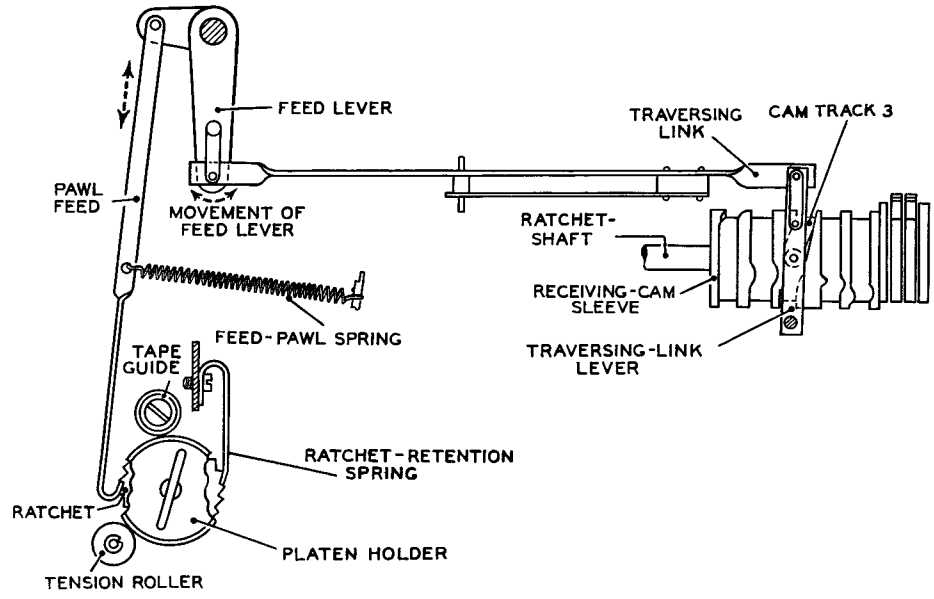


FIG. 11.78. TELEPRINTER NO. 3X: TAPE FEED MECHANISM

from one of the tracks on the receiving cam sleeve.

The platen and platen bracket can be seen on the left of Fig. 11.68. The platen is a rubber-covered metal roller about $1\frac{1}{4}$ in. in diameter, mounted on a spindle, which is carried vertically on the platen bracket. The upper end of the platen roller is provided with a knurled knob for feeding the tape forward manually when required; at the lower end of the spindle is fixed the platen ratchet.

held engaged in one of the teeth of the ratchet by means of a spring. Normally the feed pawl rests halfway along a tooth on the ratchet and, during the reception of the start element of a signal combination, the traversing link moves to the right of the diagram, Fig. 11.78, and this causes the feed lever to turn anti-clockwise on its pivot; thus the feed pawl is moved until it engages with the next tooth of the ratchet. The pawl then rotates the

platen, carrying the paper tape forward by the space of one letter, while the signal combination is being received, i.e. whilst the traversing link is travelling from right to left. During the period of the stop element the traversing link moves to the right to its rest position and the pawl also moves to its normal position half-way along the next tooth on the ratchet.

A ratchet retention spring engages with the teeth of the ratchet on the opposite side to the feed pawl and prevents reverse motion of the ratchet wheel and platen.

The paper tape is $\frac{3}{8}$ in. wide and may be gummed on one side if required, e.g. for sticking on a telegram form; it is made up into rolls of 8 in. diameter. A roll of paper tape is carried in the tape roll holder, see Fig. 11.79, which is mounted vertically at the rear of the machine, as seen in Fig. 11.68. The roll is supported between two metal discs which are allowed to rotate under the control of a brake. The braking system is so arranged that while paper tape is being fed from the roll, the brake is inoperative but is immediately applied when paper feeding ceases. This prevents overrunning of the roll and the consequent forming of undesirable loops of paper.

The paper tape is passed from the roll holder, via the braking system and guide roller, through the

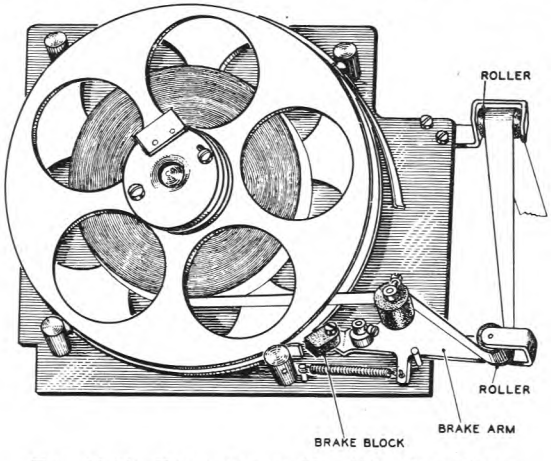


FIG. 11.79. TELEPRINTER NO. 3X: TAPE ROLL HOLDER

paper grips of the paper failure alarm unit and then round the platen, passing in front of the type-bars, between the platen and the tension roller and then out between the paper knife and the tape guide as can be seen in Fig. 11.68. The tape is thus gripped between the platen and the tension roller and, when the platen is rotated by the ratchet, the paper tape is moved forward.

Inking of the types is effected by two felt rollers which are impregnated with ink. They are carried on spring supports so arranged that the rollers press lightly on the type faces and roll over them as the typehead rotates. The platen and associated ratchet are mounted on a bracket which can be

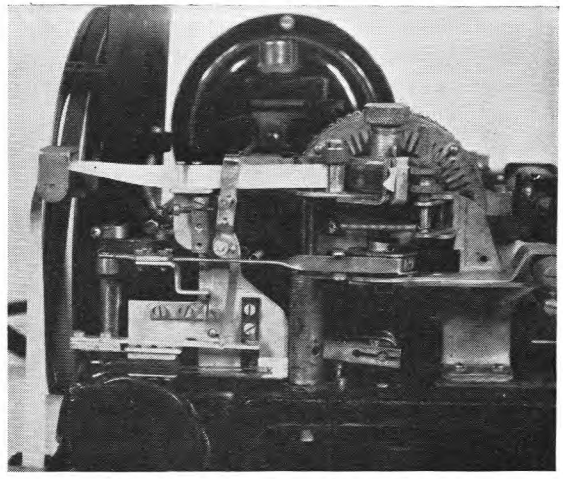


FIG. 11.80. TELEPRINTER NO. 3X: PAPER FAILURE ALARM UNIT
(By courtesy of H.M. Postmaster-General)

swung away from the typehead to facilitate cleaning of the types and changing of the ink rollers.

Paper Failure Alarm. When tape teleprinters are used on either manual or automatic switching systems it is usual to transmit messages to machines which are not continuously staffed and, to avoid lost messages, it is essential that if the end of a roll of paper tape is reached or the tape breaks or fails to feed for any reason, a warning alarm should be given. Therefore, it has become standard practice in the B.P.O. to fit some form of paper alarm device to tape teleprinters.

Fig. 11.80 illustrates the type of paper alarm unit fitted to Teleprinters No. 3 and Fig. 11.81 is a schematic of the mechanism. It comprises a vertical member known as the oscillating lever and a horizontal member called the contact operating arm which operates a contact spring set. In addition, a trip arm is mounted on the paper feed pawl of the teleprinter in such a position that, when the pawl is moved forward, the trip arm engages with the oscillating lever.

The upper part of the oscillating lever is designed to grip the paper tape as it is fed forward and the lower end is shaped as a pivot for a small toggle finger the free end of which is a knife edge and rests in a V-shaped notch in the contact operating

arm. The latter is a spring mounted cantilever which is forced upwards against the toggle finger by the action of the spring and which, at its free end, bears an insulated plunger for operating the contact spring set mounted underneath.

The mounting bracket for the unit is bent at the top to form a horizontal platform supporting two vertical bollard pins which act as a paper guide to ensure that the paper is vertical as it passes through the paper grip on the oscillation lever. The bracket

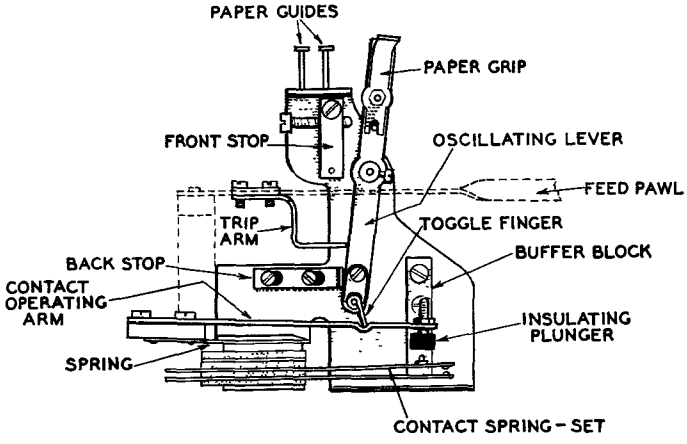


FIG. 11.81. TELEPRINTER NO. 3X: SCHEMATIC OF PAPER FAILURE ALARM UNIT

also carries adjustable front and back stops which are used to limit the movement of the oscillating lever. When the lever is against the front stop the contact operating arm is depressed and the contacts operated; when it is against the back stop the contact operating arm is up and the contacts are open.

During the reception of a character, the paper feed pawl moves forward, i.e. to the right on Fig. 11.81, and the trip arm on the pawl engages with the lower part of the oscillating lever causing it to rotate anti-clockwise and come to rest against the forward stop and thus operate the contacts. At the same time the paper grip slides backwards along the paper tape which is held between the platen and the pressure roller. The subsequent action of the feed pawl moves the paper tape forward and the paper grip of the oscillating lever grips the tape and causes the lever to move clockwise thus opening the contacts.

Hence during each tape feeding cycle the contacts are closed for a period which is normally between 35 and 50 milliseconds but which is increased when any of the following fault conditions exist—

(*a*) The tape breaks or the end of the paper roll is reached and the contacts remain closed after the tape has passed beyond the paper grips.

(*b*) There is an intermittent failure to feed and the contacts are thus made for at least one paper feed cycle, i.e. 153 milliseconds.

(*c*) The amount of paper tape fed forward is less than normal.

The alarm contacts are connected to an external circuit and operate a relay which has a minimum operate lag of 100 milliseconds. Thus an alarm will always be given under conditions (*a*) and (*b*) above whilst the standard adjustment of the paper alarm unit is such that an alarm will be given if the amount of paper fed forward under condition (*c*) is reduced to such an extent that legibility is lost due to overprinting.

The Answer-back Unit. The answer-back unit is set into operation upon the receipt of the character combination of the secondary of letter A and causes the automatic transmission of a group of five characters twice in succession; the characters are normally arranged to represent the code of the office concerned and thereby serve as a recognition signal. The answer-back code is transmitted twice so that the first printed code may be fed out from the printing head on the receiving machine to a point where it is readily visible to the operator.

On receipt of the character combination for the secondary of letter A, the corresponding bell-crank in the combination head is selected and, as described later, causes the WRU contacts to be closed and complete a circuit (see Fig. 11.82) for the answer-back operating electromagnet. When the contacts close the 2 μF capacitor is charged and the surge of current causes the answer-back operating electromagnet to be energized. When the capacitor is fully charged the current ceases and the electromagnet is de-energized. When the WRU bell-crank is restored, by the receipt of another character combination, the WRU contacts are opened and the capacitor discharges through the 30,000 Ω resistance. This circuit arrangement ensures that the answer-back mechanism is tripped once only for each A secondary combination received although, as described later, a mechanical feature which causes double transmission is included on the answer-back unit.

An auxiliary change-over contact spring set is operated while the answer-back code is being transmitted and can be used to complete an alarm circuit which will give an indication that a message is about to be received on the teleprinter.

Fig. 11.83 illustrates the method by which the WRU contacts are operated by the WRU (A secondary) bell-crank. The operating shaft carries at one end an arm which bears on the bell-crank whilst, at the other end, is the plunger operating arm against which the contact operating plunger rests. When the bell-crank is operated on receipt of the A secondary combination, the contacts are closed by the plunger which is depressed by the operating arm under the action of the operating spring.

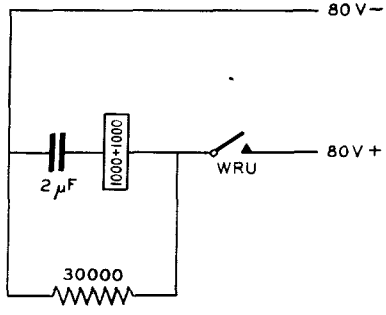
The answer-back mechanism is a part of the transmitter assembly, see Fig. 11.84. Fig. 11.85 shows a schematic representation of the component parts which consists essentially of—

(*a*) A ward barrel containing five wards cut to represent the required code and capable of being rotated by the teleprinter motor via a train of gears and a friction clutch.

(*b*) A release magnet, cam and detent arranged to allow the ward barrel to rotate through two complete revolutions when the release magnet is energized.

(*c*) Five selecting fingers operated by each ward in the ward barrel successively as it rotates and which interact with the keyboard combination bars to set up the required combinations.

(*d*) A trip lever, operated by the wards, which



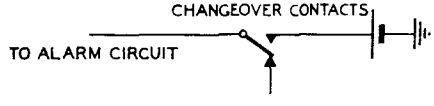


Fig. 11.82. Teleprinter No. 3X: WRU Circuit Connexions

lifts the transmitter pawl abutment and causes transmission of each signal combination.

The ward barrel is carried on the answer-back spindle which is driven from the transmitter driving shaft via gears numbers one, two, three and four. The speed reduction thus obtained is from 392 r.p.m. to 61·25 r.p.m. Gear No. 4, also carried on this spindle, transmits its drive through a friction clutch assembly consisting of two fabric washers,

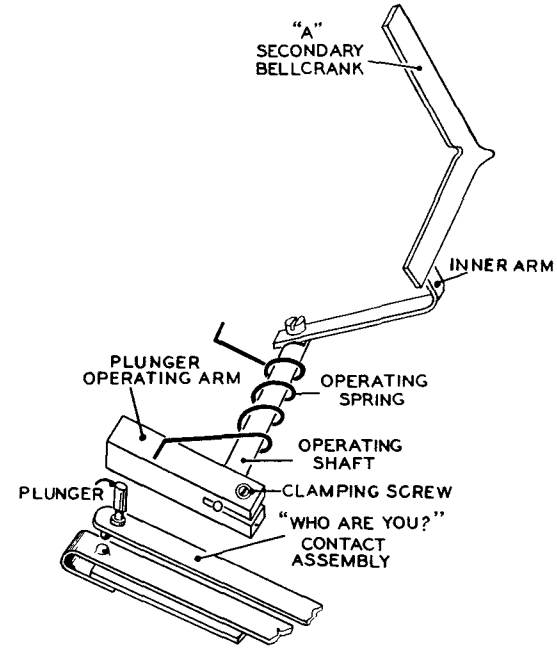


Fig. 11.83. Teleprinter No 3X: WRU Bellcrank and Contacts

each backed by a steel washer and clamped one to each side of the gear by means of a spring washer and nut. While the answer-back mechanism is not in operation a detent engages with a step on the cam on the spindle and prevents the ward barrel from rotating; gear No. 4 slipping against the clutch.

The ward barrel has five wards located in longitudinal slots; each ward is cut to represent a signal combination, a cut-away portion representing a marking element and an uncut portion a spacing element.

The release magnet consists of a standard B.P.O. 3,000-type relay coil, with two 1,000 Ω windings connected in series, used with a modified 3,000-type yoke and a hinged armature. The armature is provided with two extensions called the armature extension and armature lever, which function respectively with the detent and a projection at the circumference of gear No. 6. The detent, which is forked, operates in connexion with the cam on the answer-back spindle. Gear No. 6 meshes with gear No. 5 which is also situated on the spindle, adjacent to the cam. While the answer-back mechanism is not in operation, the armature

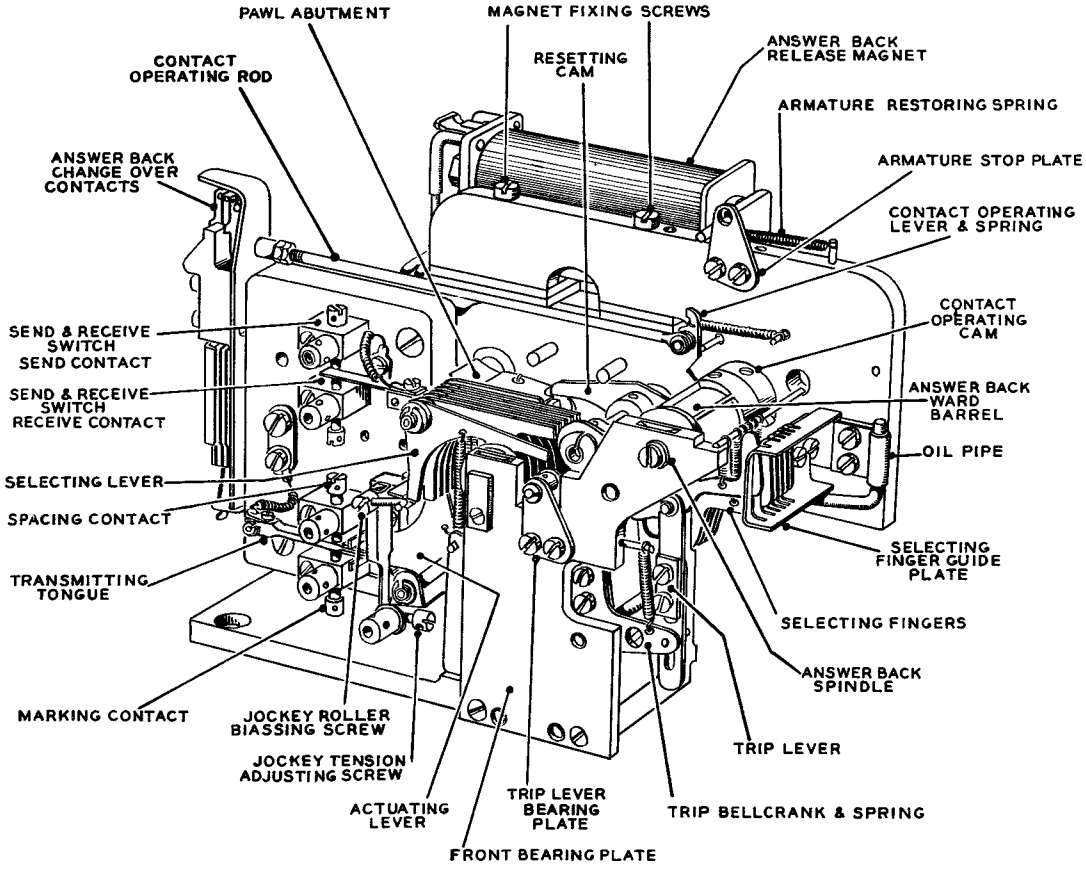


FIG. 11.84. TELEPRINTER NO. 3X; ANSWER-BACK UNIT

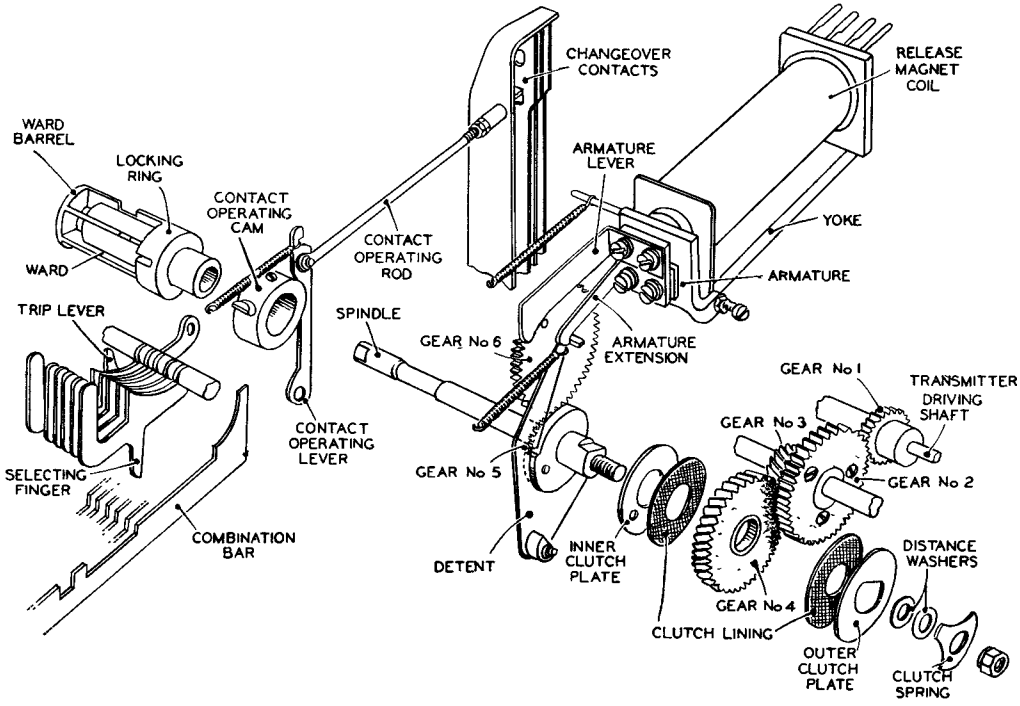


FIG. 11.85. TELEPRINTER NO. 3X: SCHEMATIC OF ANSWER-BACK UNIT

extension holds one arm of the detent in engagement with a step on the cam and prevents the ward barrel from rotating. When the release magnet is operated the armature extension is lifted away from the detent, which disengages itself from the cam under the action of its spring and the ward barrel, cam and gear No. 5 are allowed to rotate. The detent is pulled by its spring so that the other arm now rides on the rotating cam and towards the end of the first revolution the detent is lifted by the cam so that it is latched under the armature extension. At the same time the projection on gear No. 6, which is being rotated by gear No. 5, engages with the armature lever and lifts it so that the armature is mechanically operated and the armature extension withdrawn from the detent. Thus the detent is prevented from arresting the rotation of the cam which continues to rotate with the detent riding against it. Towards the end of the second revolution, the cam again lifts the detent and latches it under the armature extension and this time the projection in gear No. 6, which makes only half a revolution for one complete revolution of gear No. 5, is diametrically opposite the armature

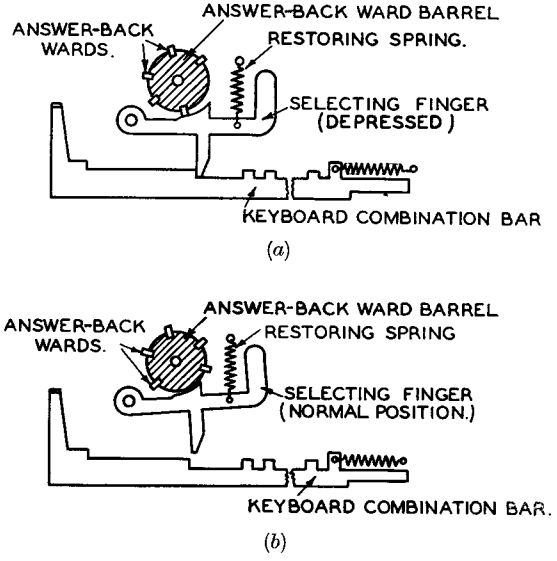


FIG. 11.86. TELEPRINTER NO. 3X: ANSWER-BACK UNIT SELECTING FINGER

lever and does not lift it. The detent therefore remains latched under the armature extension and at the end of the revolution engages with the step on the cam and the answer-back ward barrel is brought to rest, having made two revolutions in all.

The five selecting fingers (Fig. 11.86) are pivoted on a common spindle beneath the ward barrel and explore each ward in turn when the barrel rotates. The selecting fingers are situated immediately above the combination bars, one finger to each bar and an uncut portion of a ward depresses the associated finger, placing its tip in the path of the combination bar concerned. A finger encountering a cut portion of a ward is not depressed and is not

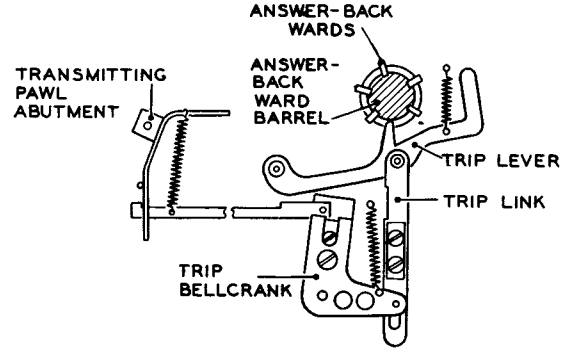


FIG. 11.87. TELEPRINTER NO. 3X: ANSWER-BACK UNIT TRIP LEVER

therefore placed in the path of a combination bar. At the same time as the selecting fingers are set the ward operates the trip lever (Fig. 11.87) which is coupled to the transmitter trip bell-crank by means of an adjustable trip link. This lifts the transmitter pawl abutment and allows the transmitter cam to rotate and the combination bar resetting lever to release the combination bars. Where a selecting lever has been depressed the bar is prevented from moving and where a selecting lever has not been depressed the combination bar moves to the right. Thus a combination is set-up representing the required signal combination and this is translated and transmitted as already described. The selecting fingers remain set sufficiently long for the signals to be transmitted and are then released and subsequently reset to the next code combination on the next ward. In this way five signal combinations are transmitted from the answer-back mechanism for every rotation of the ward barrel.

The change-over contacts, Fig. 11.88, are standard B.P.O. 3,000-type used with a buffer block and are attached to the side of the transmitter contact block. They are operated from the contact operating cam by means of the contact operating lever and connecting rod. The cam is located on the ward barrel and rotates during transmission of the answer-back code. The profile of the cam is such that while the answer-back mechanism is at rest the contacts are operated. During one revolution of the cam the contacts are

released for 440 milliseconds, operated for 50 milliseconds, released for 440 milliseconds and finally operated again.

The Teleprinter No. 11

The Teleprinter No. 11, manufactured by Creed & Co., Ltd., is an improved design of tape printing teleprinter introduced during 1947 and its facilities are such that it is particularly suitable for use on teleprinter switching systems. It has a working speed of 50 bauds and is designed to transmit and receive signals in accordance with the International Telegraph Alphabet No. 2.

(*e*) Radio interference suppression has been incorporated in the design.

(*f*) The receiving cam unit is provided with an orientation facility.

(*g*) An improved design is used in the typehead clutch.

(*h*) Ribbon inking of the types with automatic reversal of the ribbon feed is used.

(*i*) A paper failure alarm is provided as an integral part of the paper movement.

The Teleprinter No. 11B is illustrated in Figs. 11.89, 11.90 and 11.91. It is designed on the unit construction principle and the various units are

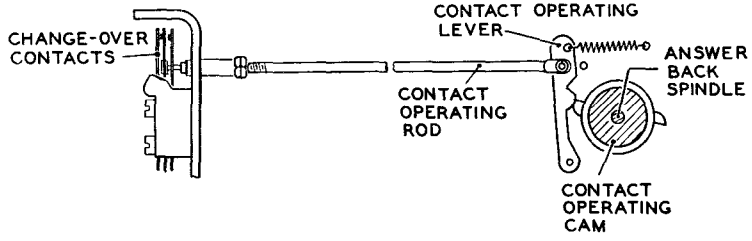


FIG. 11.88. TELEPRINTER NO. 3X: ANSWER-BACK UNIT CHANGE-OVER CONTACTS

The transmitter is arranged to produce 7½ unit signals, i.e. a start signal of one unit, five code elements each equal to one unit, and a stop signal of one and a half units. The receiving mechanism is designed to accept 7 unit signals, i.e. it will receive satisfactorily signals with a minimum stop element of one unit duration.

Thus it will be seen that the Teleprinter No. 11 conforms with C.C.I.T. agreements on all points applicable to tape teleprinters.

Apart from the use of the internationally agreed speed and alphabet, the Teleprinter No. 11 incorporates the following improvements over the Teleprinter No. 3—

(*a*) The transmitting unit is of the striker type.

(*b*) Oil impregnated porous bronze bearings have been used wherever possible so as to reduce the need for lubrication at frequent intervals.

(*c*) The keyboard is designed on the saw-tooth principle in which the combination bars have projections like saw-teeth and are moved directly by depression of the keybars in contrast to the keyboards of Teleprinters Nos. 3 and 7 in which the movement of the combination bars is effected by the motor power. This produces a keyboard with a freer touch since the locking bar mechanism associated with the motor driven type of keyboard is eliminated.

(*d*) The answer-back unit accommodates 20 characters.

disposed on the main base, which is of lattice construction to avoid any sounding board effect, so that the printing and tape tear-off positions are on the left-hand side which is most convenient for the operator. Further, the paper movement and ink ribbon mechanisms are arranged so that the roll of paper tape and the ink ribbon can be changed without the necessity for removing the dust cover.

The dust cover can be seen in Fig. 11.89. It has four pins, one at each corner, which rest in four cups on the main base. These pins are on shock absorbing mountings which tend to reduce vibration and thus keep noise at a low level. A message tray fits on the top of the cover.

The dimensions of the machine are—

Width	19 in.
Depth	17 in.
Height	(without message tray) 9½ in.
Height	(with message tray) 12 in.

The weight of the complete assembly is approximately 67 lb.

All external or non-machined surfaces are finished with black rivolin enamel, with the exception of the pencil rack and routing card frame on the cover which are lacquered copper bronze.

The motive power for the teleprinter is supplied by a series wound d.c. motor with a rated output of 0·04 h.p. (30 W) which is suitable for either

160 V or 220 V supplies with a tolerance of 15 per cent. The methods of making connexion to the motor and of mounting the governor slip ring brushes have been improved over those used on signalling connexions and a five amp plug and cord for the power connexions similar to those used on the Teleprinter No. 3. On the Teleprinter No. 11B the cords are dissociated from the machine and

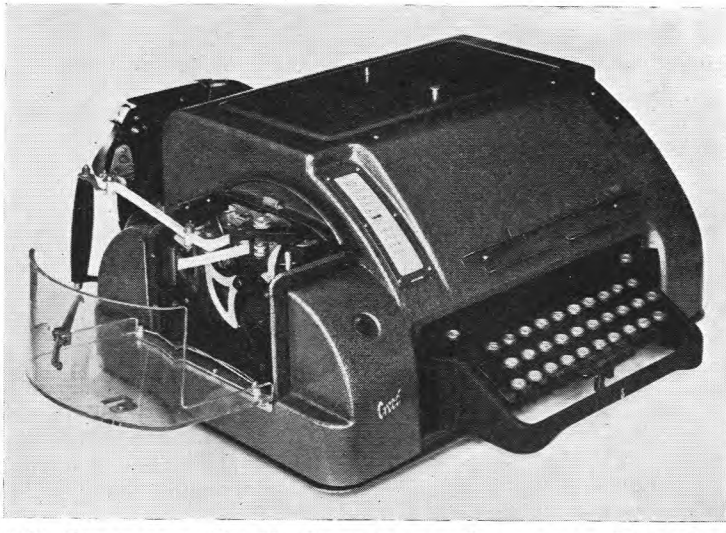


FIG. 11.89. TELEPRINTER NO. 11: COVER ON BUT TRANSPARENT PRINTING COVER LOWERED
(By courtesy of H.M. Postmaster-General)

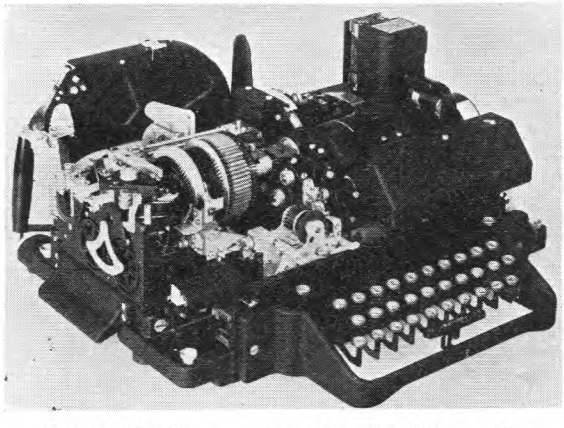


FIG. 11.90. TELEPRINTER NO. 11: COVER OFF
(By courtesy of H.M. Postmaster-General)

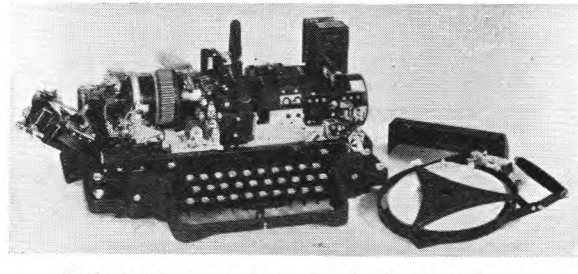


FIG. 11.91. TELEPRINTER NO. 11: COVER OFF AND ROLL HOLDER REMOVED
(By courtesy of H.M. Postmaster-General)

Teleprinters Nos. 3 and 7. The speed of the motor is 3,000 r.p.m. and is maintained constant by a centrifugal governor of the type described on page 376. The various shafts of the teleprinter and their speeds are indicated in Fig. 11.92.

The schematic signalling and motor connexions are shown in Fig. 11.93 (*a*) and (*b*). The Teleprinter 11A is fitted with a 17-way plug and cord for the become part of the position equipment. The internal wiring of the teleprinter is terminated on connectors of the shrouded pin type, one for the signalling circuit and one for the motor power circuit into which plugs connected to cords on the position are fitted.

The Transmitting Unit. The transmitting mechanism is of an entirely different design from

that of the Teleprinters Nos. 3 and 7. It comprises three units, viz.—

(*a*) the keyboard unit
(*b*) the transmitting unit and
(*c*) the answer-back unit.

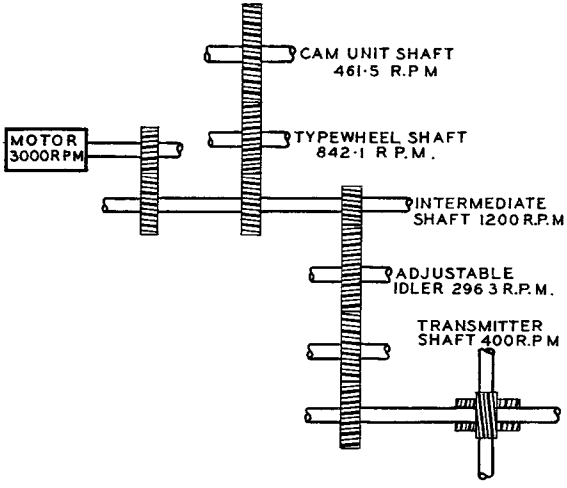


FIG. 11.92. TELEPRINTER NO. 11: SHAFT AND GEAR DETAILS

The transmitting and answer-back units are accommodated at the rear of the keyboard; the complete assembly is illustrated in Figs. 11.94 and 11.95.

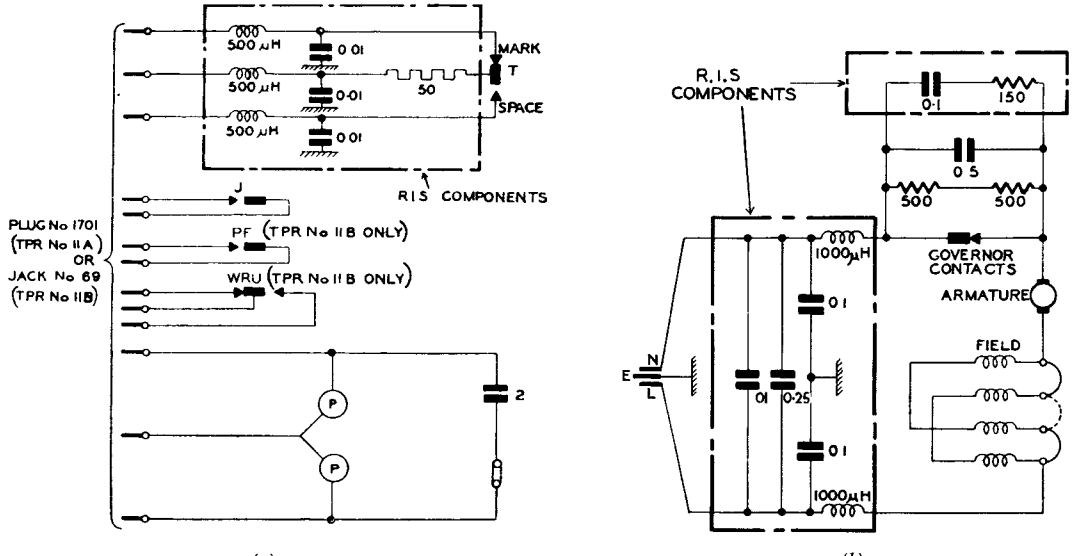
The keyboard and transmitting unit will now be described, the answer-back unit is described on page 452.

The keyboard has three rows of keys and utilizes combination bars of the saw-tooth type operated directly by the depression of the keybars. When a keybar is depressed, the combination bars are moved to represent the corresponding code and are held in position until the transmission of the combination concerned is completed; this lock is imposed indirectly by a locking frame which acts on the selecting levers in the transmitting unit, see page 436. With saw-tooth type combination bars it is unnecessary to provide special arrangements to prevent the operation of a second key during the transmission of a character combination because, whilst the combination bars are set and held in the position for one character, the projections on them prevent the full operation of keys other than that for the character concerned.

The layout of the keyboard and the functions of the keys have been described on page 371.

The keybars are shaped as shown in Fig. 11.96. They are supported by a common pivot bar at the rear of the unit, see Fig. 11.95, and are held in their normal position, against the tops of slots in the front guide plate, by helical springs. Each keybar has a knife edge formed on its underside so that when the keybars are operated the knife edges engage the saw-teeth of the combination and functional bars.

The five combination bars are provided with saw-tooth projections, according to the requirements of



(*a*) (*b*)

FIG. 11.93. TELEPRINTER NO. 11: SIGNALLING AND MOTOR CONNEXIONS

the teleprinter code. Thus, when a keybar is depressed, the knife edge on its under side exerts a downward pressure on the sloping side of a tooth on

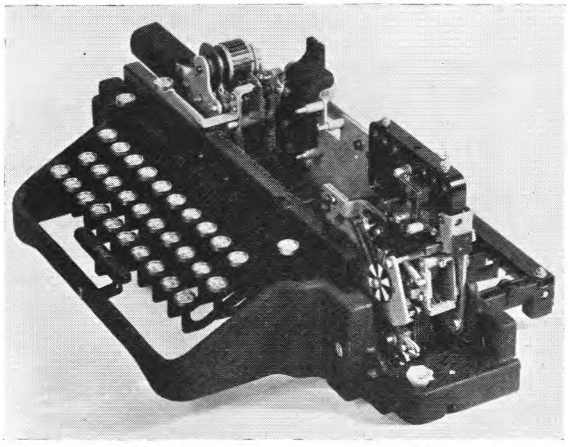


FIG. 11.94. TELEPRINTER NO. 11: KEYBOARD UNIT
(By courtesy of H.M. Postmaster-General)

certain bars, depending upon the combination for the character concerned and shifts the bars as fits into slots in the undersides of the bars, see Fig. 11.97. The bars are not restored between characters and thus, after a keybar has been depressed, some bars will be in the extreme right-hand position representing marking elements of the signal combination and others will be in the left-hand position representing spacing elements.

The saw-tooth projections on the combination bars each have one vertical and one sloping face. The sloping face may be either on the left or right of the vertical face according to the movement required.

Fig. 11.98 is a schematic representation of a section of the combination bars from which the principle will be understood. Thus depression of the U keybar would cause bars 4 and 5 to move to the left to give the combination MMMSS. Subsequent depression of the letters keybar, all marking combination, would move bars 4 and 5 again into their right-hand positions. The right-hand end of each combination bar is coupled to a connecting lever as shown in the figure.

The shift lock bar is mounted in front of the five combination bars and has two saw-tooth and two rectangular projections. The figures and letters shift keys each act on the sloping face of one of the

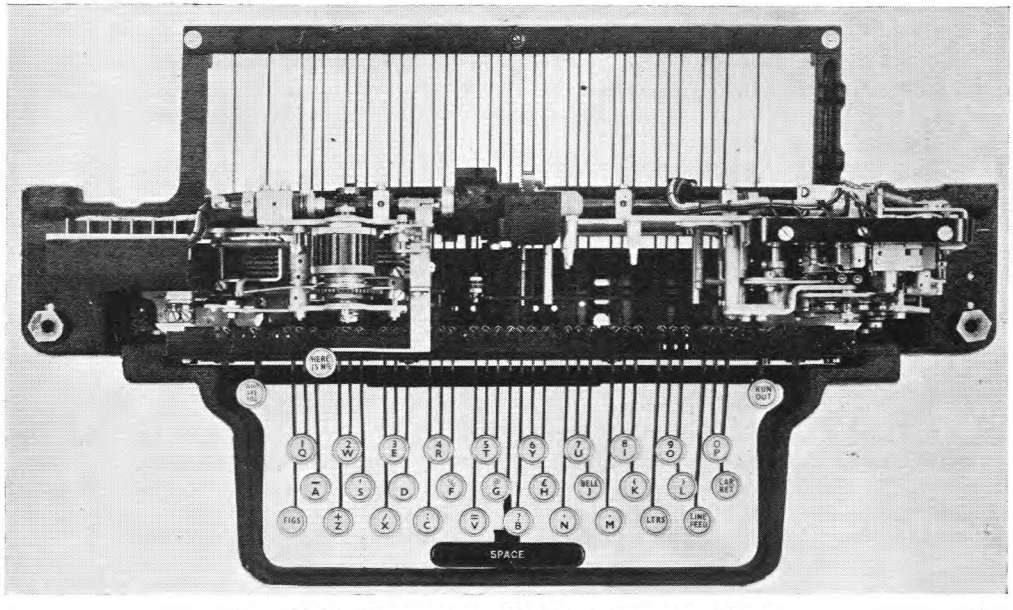


FIG. 11.95. TELEPRINTER NO. 11: KEYBOARD UNIT
(By courtesy of H.M. Postmaster-General)

required. The combination bars are supported in guide blocks and are free to move a small distance from left to right or vice versa, the amount of movement being limited by a stop plate which saw-tooth projections so that depression of the figures key causes the bar to take up its left-hand position and the letters key moves it to its right-hand position. One of the rectangular projections

obstructs the D key, and thus prevents its operation, whilst the shift lock bar is in the left-hand (figures) position and the other obstructs the WRU keybar whilst the shift lock bar is in the right-hand (letters) position.

The transmitting unit is of the striker type and fundamentally its principles of design and operation are the same as those of the transmitting unit used on the Teleprinter No. 7 viz.—

(*a*) A single revolution clutch which allows a cam to make one complete revolution per character, i.e. for each key depressed.

(*b*) Five selecting levers which are positioned by the keyboard combination bars and which, in con-

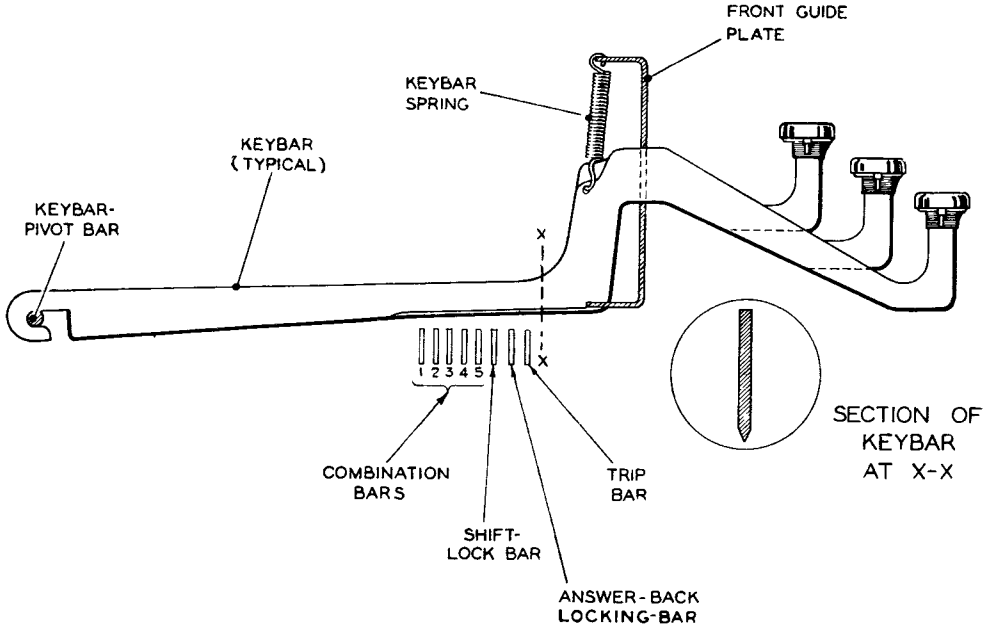


FIG. 11.96. TELEPRINTER NO. 11: KEYBARS

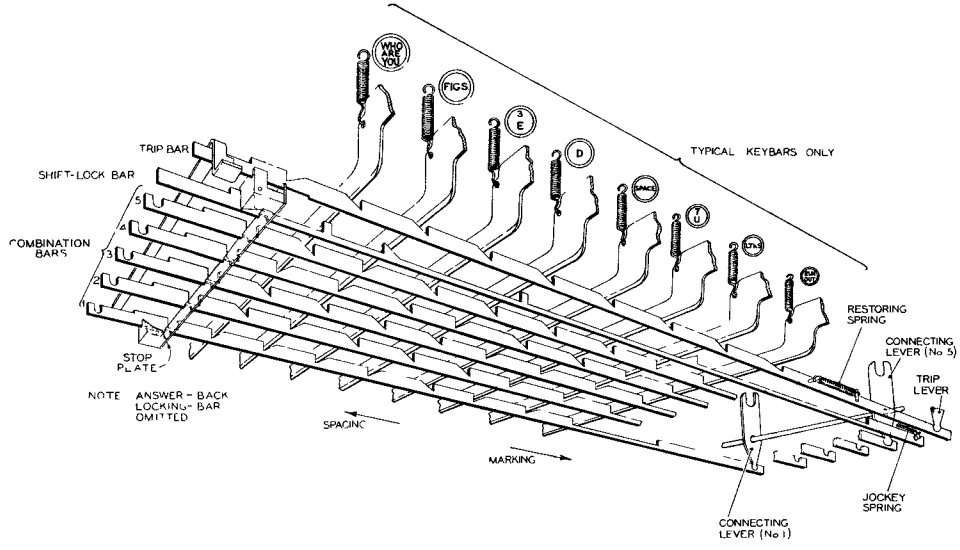


FIG. 11.97. TELEPRINTER NO. 11: KEYBOARD COMBINATION BARS

junction with the cam and five operating levers, control the positioning of the striker which moves the transmitting tongue between the Mark and Space contacts.

(*c*) An accurately divided timing cam which controls the timing of the operations of the striker and consequently determines the lengths of the signal elements.

However, as can be seen from Fig. 11.94, in this case the transmitting unit is mounted on the right-hand side of the keyboard and this necessitates a different layout and design of parts as compared with the Teleprinter No. 7 transmitting unit.

The mechanism for effecting a single revolution of the transmitting cam, each time a key is depressed, is shown in Fig. 11.99.

Each time a keybar is depressed, the trip bar, which is normally held to the right against a stop by a spring, is moved to the left and causes the trip lever to be rotated about its pivot in a clockwise direction. A pin, fixed in the top arm of the trip lever, engages with a forked extension of the detent operating lever which is free to rotate about the detent control shaft and therefore is turned in an anti-clock wise direction.

A latch carrier is pinned to the detent control shaft and carries on its right-hand extremity the pivoted detent release latch. A step on the under side of this latch lies in the path of the upper arm of the detent operating lever. Therefore, the anti-clock wise movement of the detent operating lever is communicated to the detent control shaft via the latch and latch carrier.

The detent is rigidly fixed to its control shaft and is normally urged in a clockwise direction by a spring, so that the cylindrical projection on its end engages with a radial cam surface on the clutch ratchet, holding the latter out of engagement with the driving ratchet. The driving ratchet is positively fixed to the driving gear which is free to rotate on the transmitting cam shaft and is driven continuously in a clock wise direction. When the detent is raised, the clutch ratchet is forced by a spring, into engagement with the driving ratchet, causing the cam shaft to rotate in a clock wise direction.

Immediately after the transmitting cam shaft has commenced to rotate, the retention lever, see Fig. 11.100, rides out of the notch in its cam. When the shaft has rotated through part of a revolution, the right-hand end of the latch is moved to the left by its cam and the step on the underside of the top arm of the latch is disengaged from the detent operating lever. The latch carrier is then free to move independently of the detent operating lever and is rotated clock wise by the detent spring; thus the cylindrical projection on the end of the detent is lowered into the path of the radial cam surface on the clutch ratchet in readiness to disengage the ratchet at the end of the revolution of the transmitting cam shaft, even if the keybar is held down indefinitely and the trip lever is held operated.

After the clutch ratchet is cammed out of engagement with the driving ratchet, the transmitting cam shaft continues to rotate for a small fraction of a revolution until it is arrested by the retention lever dropping into the notch in its cam.

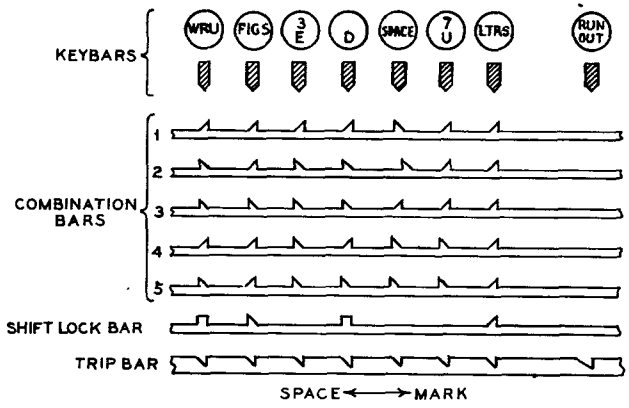


FIG. 11.98. TELEPRINTER NO. 11: SCHEMATIC OF KEYBOARD COMBINATION BARS

Upon the release of the key, the trip bar is restored to its normal (right-hand) position by its tension spring and the trip lever rotates in an anti-clock wise direction. The detent operating lever is thereby rotated clock wise until the vertical arm of the lever is again caught by the latch.

To provide the facility of transmitting one character combination continuously, the "run-out" key is depressed and engages with an extra long tooth on the trip bar, see Fig. 11.97, thus imparting more movement to the trip bar than is given by the character keys. This has the effect of rotating the latch carrier, and therefore the detent, through an angle greater than normal and, when the latch is disengaged from the detent operating lever by its cam, the latch carrier is prevented from returning to its normal position by a pin on the latch carrier engaging with the edge of the detent operating lever. Consequently, the detent is held away from the ratchet so long as the "run-out" key is held depressed, the combination transmitted being that corresponding to the last character key depressed since the combination bars will still be in the positions to which they were moved by the operation of that keybar.

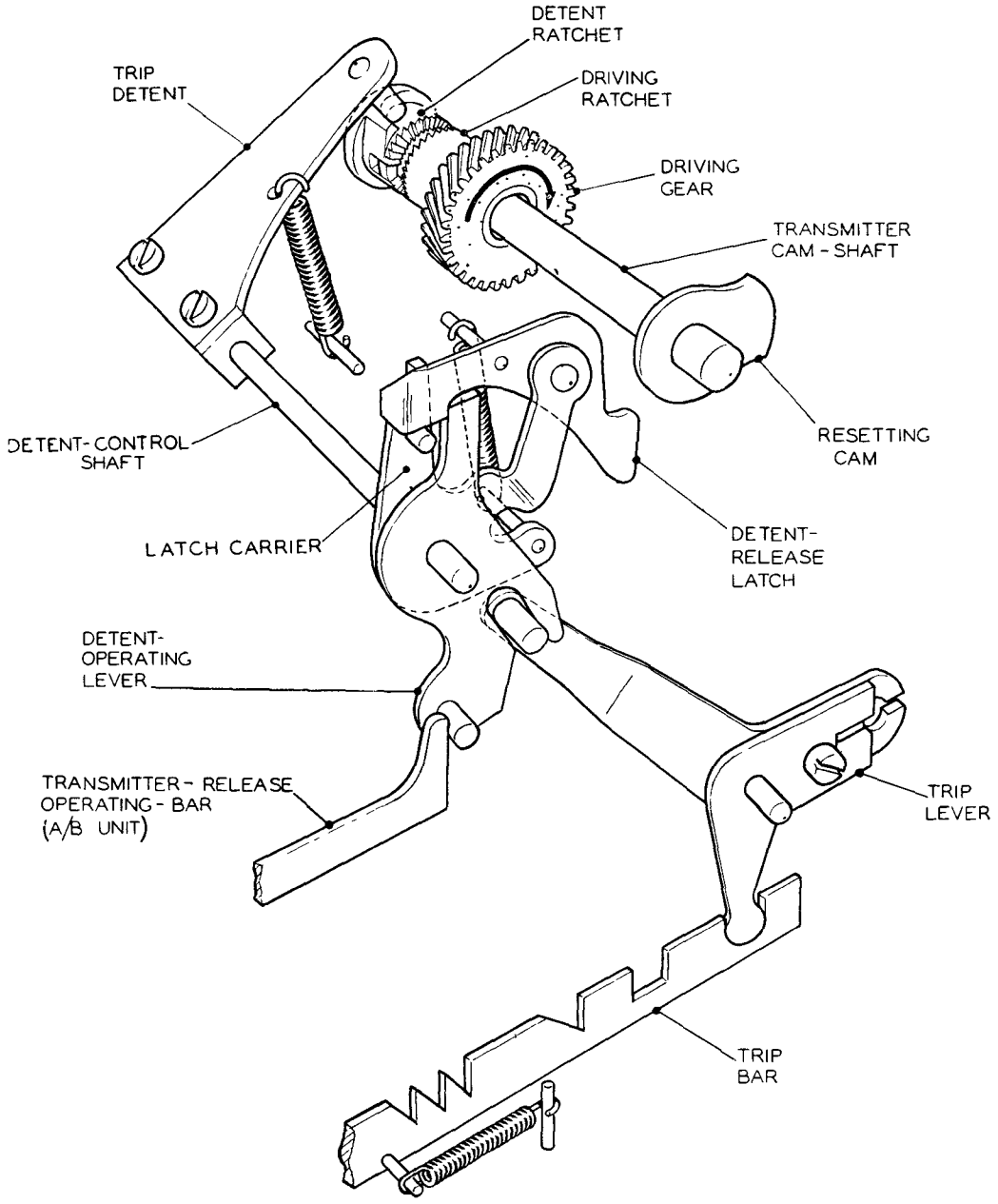


FIG. 11.99. TELEPRINTER NO. 11: TRANSMITTER TRIP MECHANISM

It has been explained that the depression of a key sets up a code combination on five combination bars and also causes the transmitting cam shaft to make one complete revolution. The mechanism for converting the code, set up on the keyboard combination bars, into a sequence of accurately timed electrical impulses is shown in Figs. 11.101 and 11.102.

Five selecting levers, each of which has three projections, are pivoted on a common spindle. The lower projections are engaged by the five connecting levers which, as already described, are operated from the keyboard combination bars. The left-hand horizontal projections are used to control the movements of five striker operating levers and the right-hand horizontal projections are used for locking the keyboard.

There are six striker operating levers, one for each element of the character combination and one common to the start and stop signals. They are mounted side by side on a common spindle and each has three operational arms. The horizontal arms, extending to the right, ride on the periphery of the transmitting cam against which they are held by spring tension. The lower vertical arms of the five code levers act in conjunction with the five

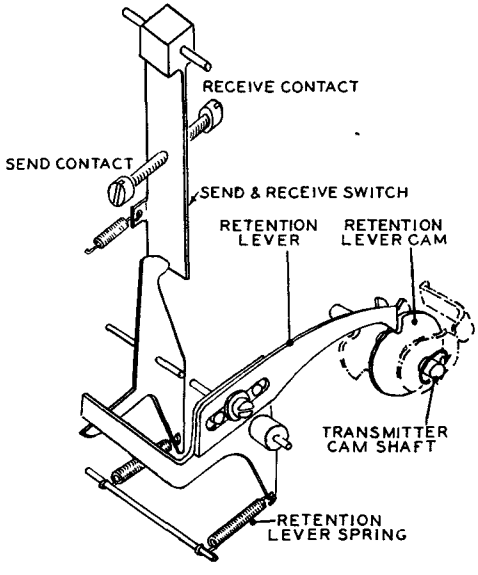


FIG. 11.100. TELEPRINTER NO. 11: TRANSMITTER RETENTION LEVER

selecting levers, and the upper arms of all six levers have operating faces which act on the common striker positioning lever.

The transmitting cam, see Fig. 11.102, has six flats cut into it. The flats are arranged sequentially and positioned so that the horizontal extensions of the operating levers ride on to them, one after the other, providing the positions of the corresponding

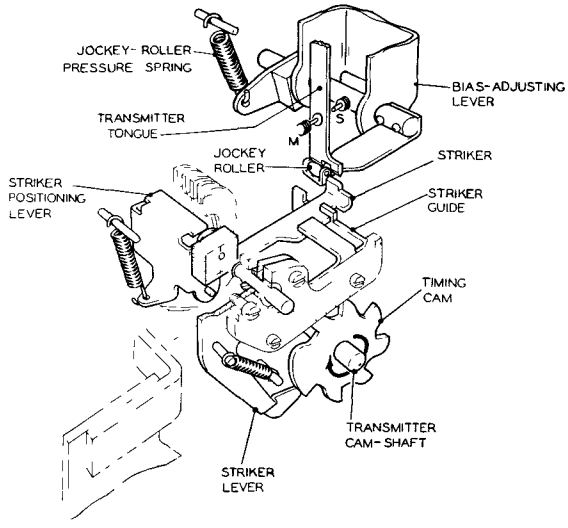


FIG. 11.101. TELEPRINTER NO. 11: TRANSMITTING MECHANISM

selecting levers allow them to do so. As an operating lever rides on to its flat, its upper vertical projection is moved to the left against the striker positioning lever. Fig. 11.103 shows schematically the relative timing of the cam operations.

In the rest position of the transmitting cam, the start-stop operating lever has commenced to ride on to its flat and the face on its upper arm is touching, but not operating, the striker positioning lever. The upper arms of all the code operating levers are held to the right by the cam.

The striker positioning lever is pivoted and is urged in a clock-wise direction by its spring. The striker is pivoted on the striker positioning lever and has a slot which is engaged by the striker guide and thus limits the movement of the striker positioning lever so that it cannot touch the faces of the operating levers when these levers are in the non-operated, or right-hand, position.

The striker guide is mounted on an insulating plate which has a lower extension, the striker lever, which is held, by spring action, in engagement with the periphery of the timing cam. As the cam rotates, the striker is raised and then lowered, seven times; the cycle of movements being timed to correspond accurately with the change-over instants required by the elements of the code combination.

The transmitter tongue is a small lever, fitted with platinum contacts, mounted vertically and

pivoted at its upper end on the contact block assembly. The tip of the tongue is bevelled to form a knife-edge which is divided into two sections by a slot. One section is operated upon by the striker and the other by the jockey roller.

The tongue plays between two contact screws the jockey roller is held against the knife-edge of the transmitter tongue. The complete assembly is mounted so that it can be moved laterally thus providing an adjustment for bias. The jockey roller is provided to give adequate contact pressure, small transit time and freedom from bounce.

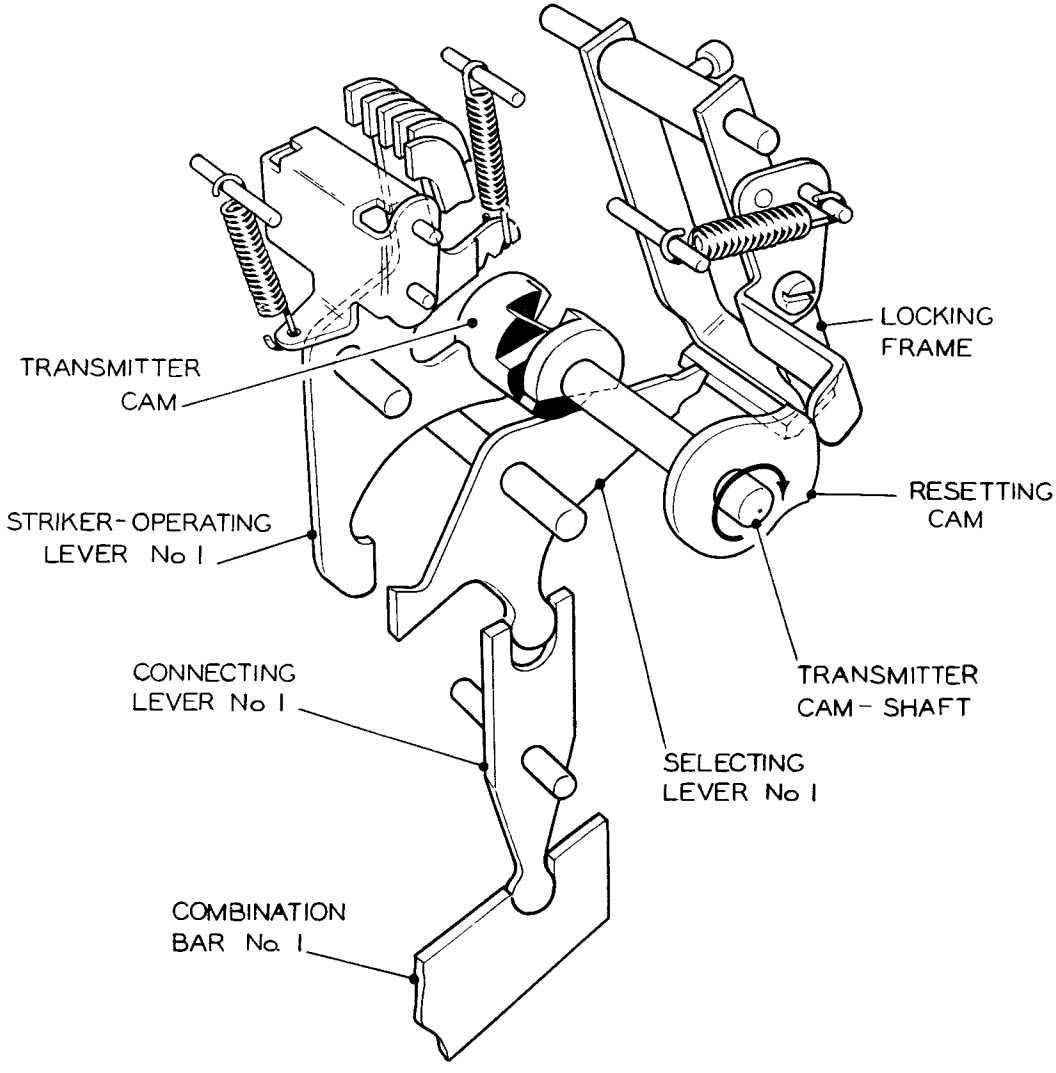


FIG. 11.102. TELEPRINTER NO. 11: TRANSMITTING MECHANISM

which are adjustable in their mounting blocks. The marking, or left-hand, contact screw is connected to the negative battery supply and the spacing, or right-hand, screw to the positive battery supply.

The jockey roller is pivoted at the end of an arm attached to a spindle at the other end of which is another arm which is acted upon by a spring so that

The locking frame is actuated by a cam on the transmitting shaft immediately the shaft begins to rotate. The knife edges on the right-hand projections of selecting levers set to the marking position will lie below, and those of levers set to the spacing position will lie above, the knife-edge of the locking frame which is moved between them and locks them

in position until transmission of the character is completed. Just before the transmitting cam shaft again comes to rest the locking frame is again withdrawn from the selecting levers. The locking of the extension of the retention lever, see Fig. 11.100.

When the transmitter is in the rest position, the following conditions apply—

(*a*) Since it is not operated upon by any operating

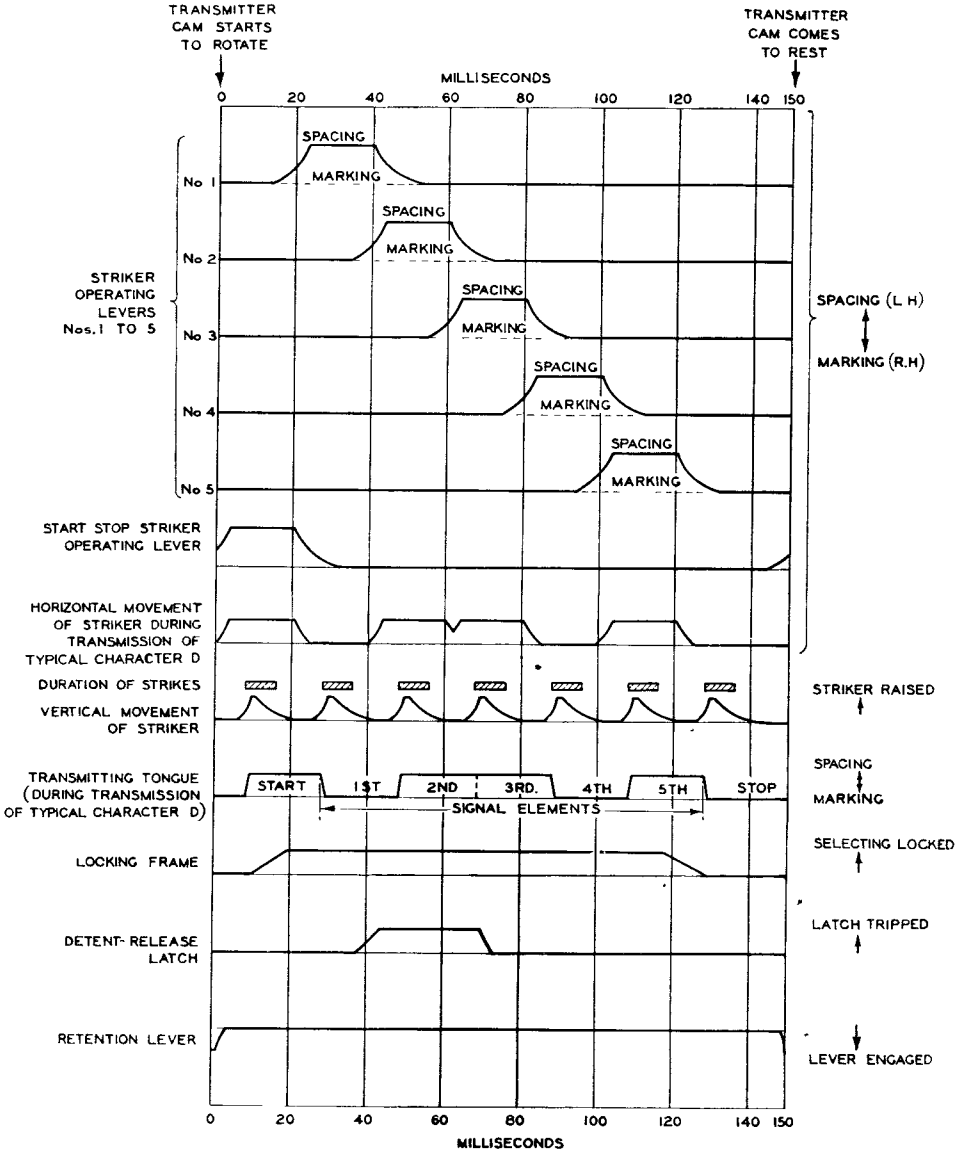


FIG. 11.103. TELEPRINTER NO. 11: TRANSMITTER TIMING DIAGRAM

selecting levers ensures the correct transmission of the character combination and also, via the connecting levers, locks the keyboard combination bars in position thereby preventing the operation of a second key whilst transmission is in progress.

The send and receive switch is operated by an lever, the striker positioning lever is held in its normal position by its spring and the striker is in its extreme right-hand (marking) position.

(*b*) The striker lever rests on a projection on the timing cam and hence the tip of the striker is clear of the knife edge on the contact tongue.

(*c*) The jockey roller is holding the contact tongue against the left-hand (marking) contact to which it was moved for the stop signal of the last character transmitted.

(*d*) The send and receive switch tongue is resting against the receive contact.

Depression of a key bar results in—

(1) the release of the transmitting cam shaft which makes one revolution as already described,

(2) the code set up on the keyboard combination bars being transferred into a positional setting of the selecting levers by the connecting levers. Thus those selecting levers which represent marking elements will be moved so that their left-hand projections are in the paths of the corresponding striker operating levers whilst the projections on selecting levers representing spacing elements will be below the operating levers.

Immediately the cam shaft commences to rotate the following operations take place—

(1) The retention lever rides out of the notch in its cam and the send and receive switch is operated, the tongue moving to the send contact.

(2) the locking frame is permitted, by its cam, to rotate about its pivot in a clock wise direction, under the action of its spring, until the knife-edge has locked the selecting levers in the positions to which they have been moved.

The start-stop operating lever is not associated with a selecting lever and therefore is free to move each time the cam shaft rotates. In the rest position, the lever has just commenced to ride on to its flat on the cam and, as the cam rotates, it rides fully on to the flat with the result that its upper projection moves to the left and engages the striker positioning lever which moves anti-clock wise on its pivot and causes the striker to be moved into its left-hand (spacing) position. The striker lever then rides into the first indentation in the timing cam and the striker is moved upwards. The knife-edge of the striker engages the left-hand side of the knife-edge of the transmitter tongue which is moved to the right-hand (spacing) contact.

As the cam-shaft continues to rotate, the flats on the cam are presented to each of the code operating levers in sequence and, if the selecting levers permit, the operating levers will move in an anti-clock wise direction as already explained. The left-hand projections of those selecting levers set in the marking position, are in the paths of the corresponding operating levers which therefore are prevented from operating. The selecting levers for spacing elements lie below the operating levers which are permitted to move.

Anti-clock wise movement of an operating lever causes the striker positioning lever to be moved to, or held in, its operated position and the striker to be moved, or held, to the left. When an operating lever is not permitted to move, the striker lever will either remain in its normal position or, if the previous element was spacing, return to its normal position under the tension of its spring, as soon as the operating lever for the previous element has been restored by the cam. Thus for marking elements the striker is set in its right-hand position and for spacing elements in its left-hand position.

Following the transmission of the start signal, the continued rotation of the cam-shaft causes the striker lever to ride on to the next projection on the timing cam and the striker is lowered clear of the transmitter tongue. After the first code operating lever has taken up its selected position and the striker has been positioned accordingly, the striker lever rides into the succeeding indentation in the timing cam and the striker is again moved upwards. This sequence of operations is repeated, the timing cam being so designed that the instants at which the striker is raised, and the transmitter tongue moved, if necessary, are such that the duration of each of the start and code elements is an accurate 20 milliseconds and the stop signal, from its commencement to the end of the rotation of the cam shaft, is 30 milliseconds.

The upwards movement of the striker causes it to engage the knife-edge of the transmitter tongue. The faces of the knife-edges on the striker and transmitter tongue which engage are determined by the position into which the striker has been set and the position of the contact tongue for the last element. The various conditions which can arise and the resulting effect on the contact tongue are indicated in Table 11.1.

TABLE 11.1

Position of		Knife Edge Faces Engaged		Resulting Movement of Transmitter Tongue
Striker	Tongue	Striker	Tongue	
RH (marking)	LH (marking)	LH	RH	Nil
RH (marking)	RH (spacing)	LH	RH	S to M
LH (spacing)	LH (marking)	RH	LH	M to S
LH (spacing)	RH (spacing)	RH	LH	Nil

In between movements, the transmitter tongue is held firmly in position by the action of the jockey roller.

After the sequence of operations for the fifth code element, the cam will have rotated to a point at which no flat is presented to any of the selecting levers and consequently the operating levers

and the striker positioning lever take up their normal positions. Thus the striker is in the right-hand (marking) position and, when it is moved upwards, a marking current is transmitted for the stop signal.

The cam is brought to rest at the end of its revolution, just as the start-stop operating lever commences to ride on to its flat on the cam. The retention lever drops into the notch in its cam and the send and receive switch tongue is restored to the "receive" contact; the locking frame is withdrawn from the selecting levers and the keyboard is freed for the depression of another key.

The Receiving and Selecting Units. The receiving and selecting mechanisms are similar in principle to those used on the Teleprinter No. 7 but incorporate a number of improvements as follows—

(*a*) The electromagnet has an improved permanent magnet made of Alnico.

(*b*) The receiving cam unit is designed to include an orientation facility and has an improved design of traversing link.

(*c*) An improved design is used for the type-head clutch and the type-hammer is provided with an overthrow stop.

The electromagnet is shown in Fig. 11.104, in which the Alnico permanent magnet can be seen fixed to the rear ends of the pole pieces to which it is held by a clip. On later models the Alnico magnet is arranged so that it can be tilted by means of a screw, thereby providing a means of adjusting the flux in the pole pieces. The method of providing for adjustment of bias is similar to that used on previous models of teleprinters. Another improvement is the more rigid construction of the armature stop plate which renders it less liable to move during the normal operation of the armature. The position of the electromagnet relative to the receiving cam unit can be seen in Fig. 11.90.

The receiving cam unit includes an orientation facility whereby the instants at which the selections for the five code elements take place can be varied with relation to the commencement of the start signal. The orientation facility enables the margin of the receiving mechanism to be adjusted for the best reception of the signals, a facility which is particularly useful for single-current working where bias distortion commonly occurs; alternatively it allows the margin of the receiving mechanism to be adjusted so as to give an equal response for marking and spacing elements of signal. The latter facility is very useful as a maintenance check of the performance of the receiver and in B.P.O. practice the orientation device is employed to adjust for equal amounts of "early" and "late" margin, since the effects of distortion in double-current signalling systems are just as liable to cause signal transitions to be early as late. Furthermore, in switching systems where one teleprinter may be connected to any combination of circuits it is quite useless to adjust the margin to suit one particular circuit condition; standardized adjustments must be employed throughout.

When no orientation facility is fitted, e.g. on the Teleprinter No. 7, the design of the selecting mechanism is inherently such that, when undistorted signals are received, the instants of selection occur at the middle of each of the code elements (refer to Figs. 11.63, 11.65 and 11.66). Thus the margins of the teleprinter for receiving signals, which are early or late with respect to the commencement of the start signal are approximately the same, some small difference in the margins arising because of normal manufacturing tolerances of the mechanism parts; no ready means is provided for field adjustment of the receiving mechanism to give the optimum position for receiving early and late signals equally well.

When an orientation facility is fitted, the reception of a start signal releases a pilot cam which in turn controls the delayed release of the receiving cam sleeve. The extent of the delay thus introduced may be varied, by adjustment, from 11·7 to 31·7 milliseconds. The receiving cam sleeve is identical with that employed on a Teleprinter No. 7B, except that the cam is advanced by 60° (equivalent to 21·7 milliseconds) in its rest position. Thus the timing operation performed by the cam, after the commencement of the start signal, may be varied from $-21{\cdot}7 + 11{\cdot}7 = -10$ milliseconds, i.e. 10 milliseconds early, to $-21{\cdot}7 + 31{\cdot}7 = +10$ milliseconds, i.e. 10 milliseconds late, in relationship to the corresponding timing operations of a receiving cam without orientation facilities.

Thus it will be seen that, by adjustment of the relationship between the pilot cam and levers which control the release of the receiving cam sleeve as explained later, the instants of selection of the code elements may be varied by $\pm$ 10 milliseconds, i.e. 50 per cent of a code element, in relation to the commencement of the start signal. This allows the selecting mechanism to be correctly phased so that selection is effected during a short period in the middle of each code element when undistorted signals are being received; this ensures that the margins for receiving early and late signals are symmetrical.

In addition to its use for setting the receiving mechanism in its optimum position, the orientation facility can be used to check that the receiving

mechanism is in good order. The overall margin can be measured by feeding the electromagnet with undistorted signals and progressively moving the

Because the rest position of the receiving cam sleeve has been advanced by 60°, several changes to the receiving mechanism have been necessary. The

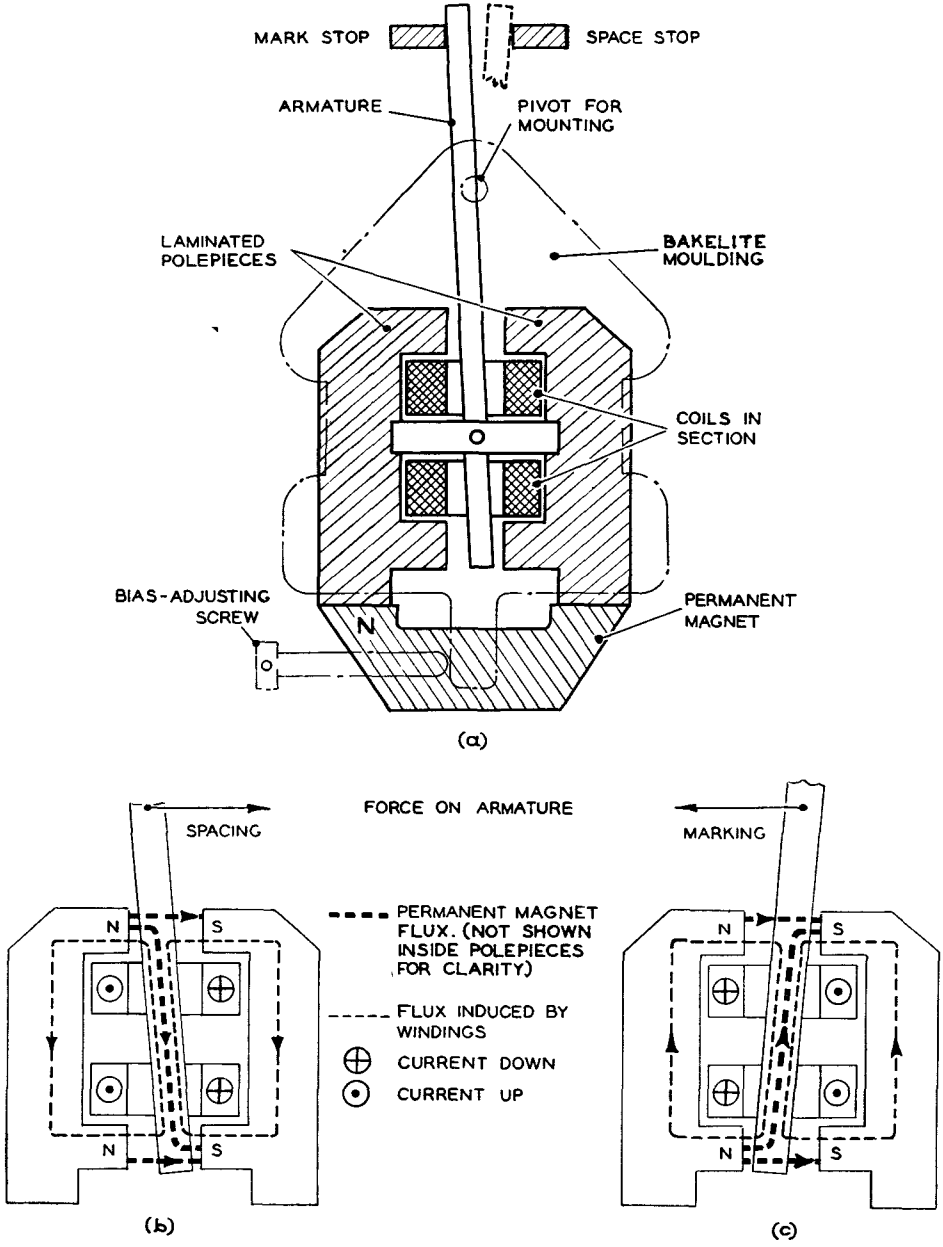


FIG. 11.104. TELEPRINTER NO. 11: RECEIVING ELECTROMAGNET

setting of the orientation adjustment, first in one direction and then in the other, until the reception fails; the overall margin is found by subtracting the two readings, one from the other.

slope of the track of the traversing lever cam has been altered slightly in order to provide a flat for the traversing lever cam roller in the rest position of the cam. In other respects the angular divide of

the cam, see Fig. 11.105, is identical with that of the cam used on the Teleprinter No. 7B but, owing to its advancement by 60°, the rest position corresponds with the point when the finger setting pin is opposite the first selecting finger instead of, as in the Teleprinter No. 7B, opposite the third selecting finger. Thus the operations which in the Teleprinter No. 7B occur during the start signal, viz. the resetting and lowering of the fingers, now take place during the period between the selection of the fifth element and the end of the rotation of the cam.

Several other small alterations to the design and position of the parts of the selecting mechanism, shown in Figs. 11.106 and 11.107 have been necessary but they do not affect the principles of operation of the unit. Moreover, the traversing link used on the Teleprinter No. 11 is die-cast in a zinc base alloy and is designed to give better bearing surfaces at its bearing ends.

The additional mechanism for providing the orientation adjustment facility can be seen in Fig. 11.108, and consists of the following—

(*a*) A pilot cam driven from the receiving cam shaft by means of a friction clutch, shown in Fig. 11.109.

(*b*) A pilot cam detent, Figs. 11.108 and 11.110, which is coupled to the trip shaft and which controls the starting and stopping of the pilot cam.

(*c*) An adjusting control block, Fig. 11.108, by means of which the instant of engagement between the pilot cam and the orientation link may be varied. The block is adjustable on a guide plate and may be locked in position by a knurled screw compressing a locking spring. A scale, calibrated from 0 to 100, is provided adjacent to the path of the block which has a pointer fixed to its upper surface.

Pivoted at the lower end of the block is the orientation link, which is deflected in an anti-clock wise direction by the cam through a shock absorbing spring.

(*d*) A release lever assembly, Figs. 11.108 and 11.110, comprising the cam release lever and release adjustment lever, both of which are fixed to the same spindle. When the cam deflects the orientation link, the cam release assembly is operated, and, as will be seen from reference to Fig. 11.108, the receiving cam pawl abutment is operated. The instant of operation is dependent upon the setting of the orientation adjustment block.

The sequence of operations of the receiving cam unit with an orientation facility is as follows (refer to Fig. 11.108)—

With the receiving mechanism in the rest position,

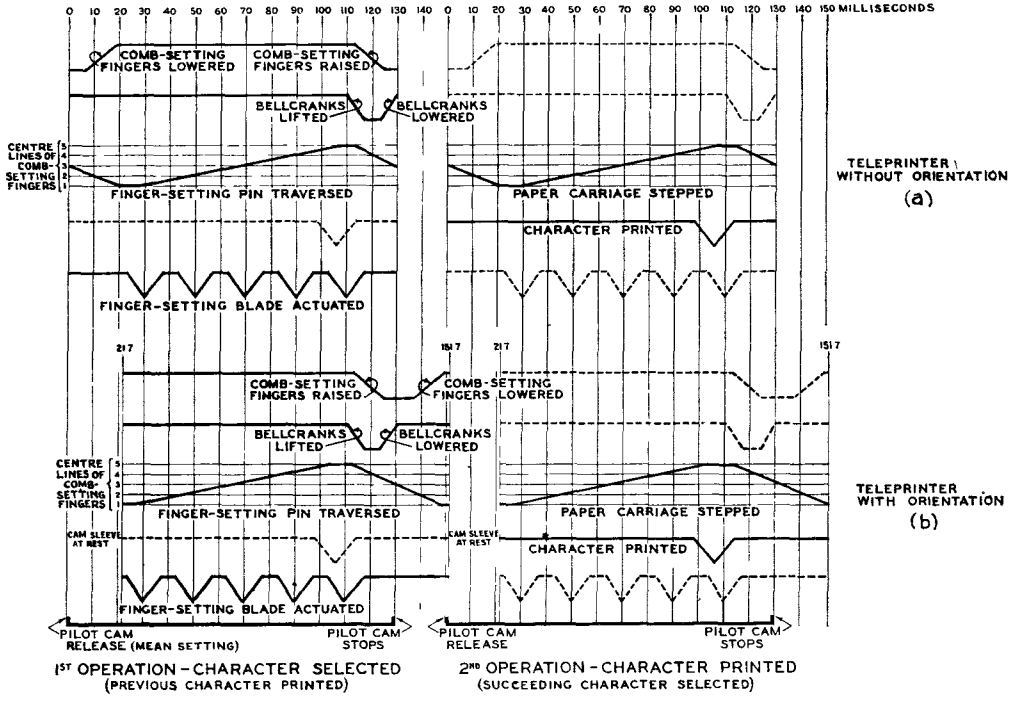


FIG. 11.105. TELEPRINTER NO. 11: TIMING DIAGRAM OF RECEIVING CAM WITH AND WITHOUT ORIENTATION DEVICE

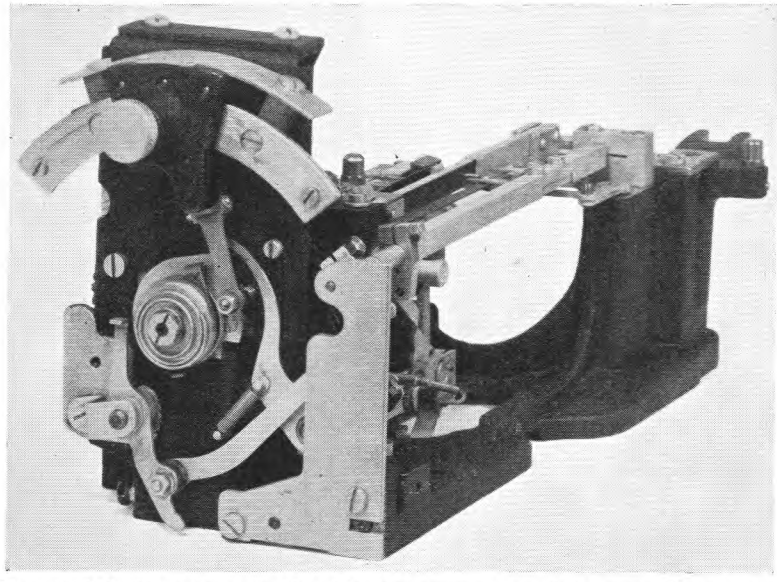


FIG. 11.106. TELEPRINTER NO. 11: RECEIVING AND SELECTING MECHANISM

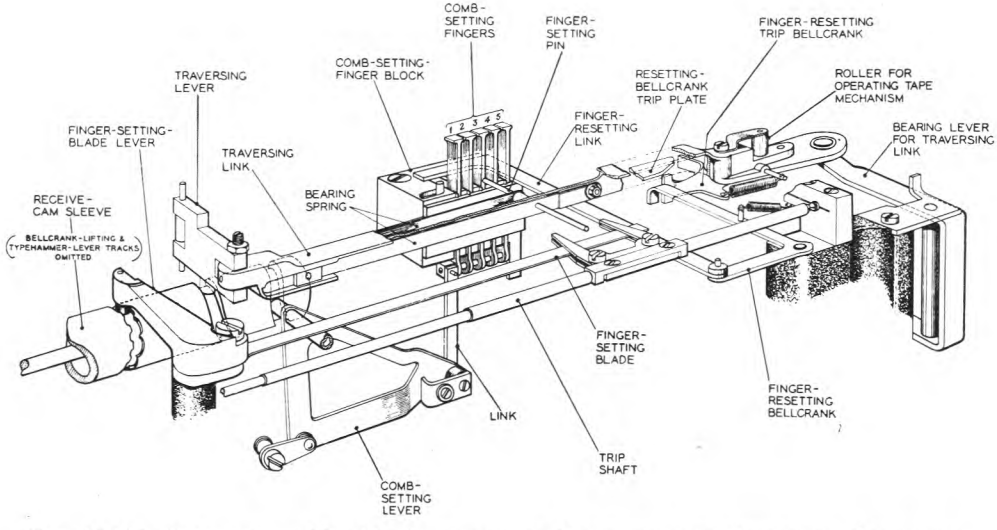


FIG. 11.107. TELEPRINTER NO. 11: SCHEMATIC OF RECEIVING AND SELECTING MECHANISM

i.e. the electromagnet armature at marking, the pilot cam detent is held in engagement with the abutment on the pilot cam and prevents the cam the pilot cam detent is withdrawn from engagement with the pilot cam which then rotates under the action of the friction clutch.

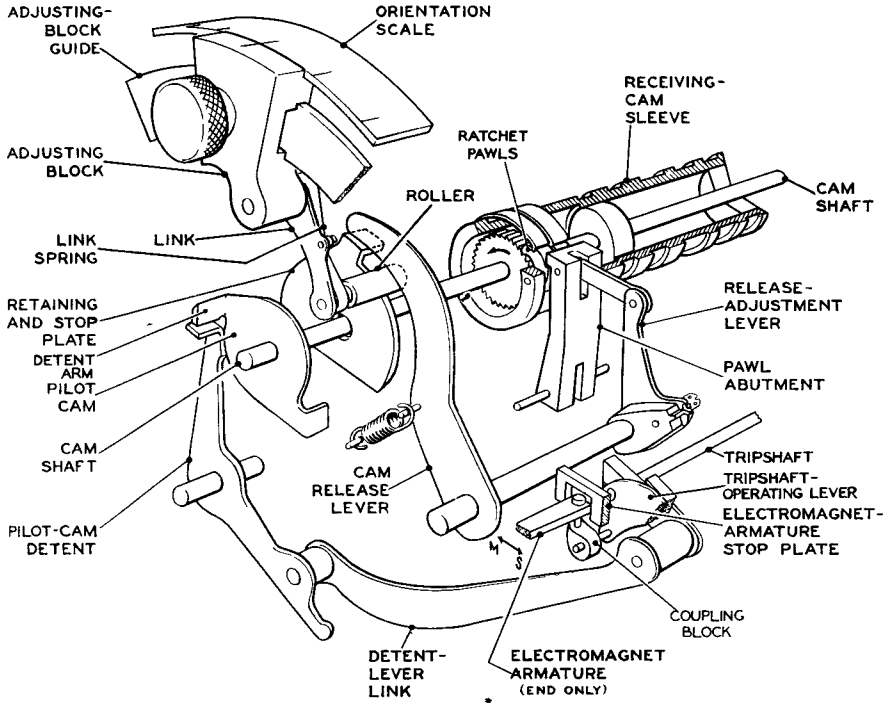


FIG. 11.108. TELEPRINTER NO. 11: ORIENTATION DEVICE

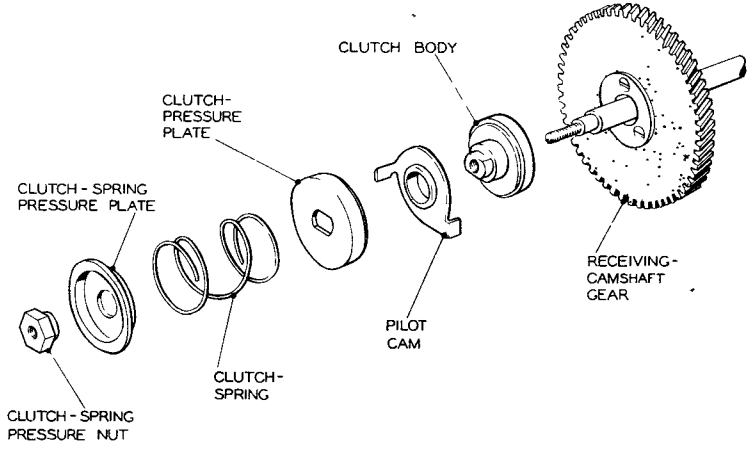


FIG. 11.109. TELEPRINTER NO. 11: FRICTION CLUTCH OF ORIENTATION DEVICE

from rotating under the action of its friction clutch.

On receipt of the start signal, the electromagnet armature moves to the spacing stop and causes the trip shaft to be tilted anti-clock wise. Consequently the pilot cam makes one revolution in 130 milliseconds before it is again arrested by the detent when it is restored due to the electromagnet armature being moved to the marking stop on

receipt of the stop signal. During its rotation the cam engages with the orientation link spring and deflects the orientation link against the receiving cam release lever which causes the release of the receiving cam sleeve. This occurs at a time predetermined by the setting of the orientation adjusting block.

Subsequent to the release of the receiving cam sleeve, the mechanical movements required for the selection of the character are the same as those described on pages 391–396 for the Teleprinter No. 7B receiving cam unit but the timing in relation to the rest position of the cam sleeve is different. Fig. 11.105 is a timing diagram showing the instants at which the various operations controlled by the tracks of the receiving cam sleeve occur (*a*) on a cam unit without an orientation facility and (*b*) on a cam unit with an orientation facility. Two successive revolutions of the receiving cam sleeve are shown to indicate how a particular character is selected during one revolution of the cam sleeve and printed during the revolution for the reception of the succeeding character.

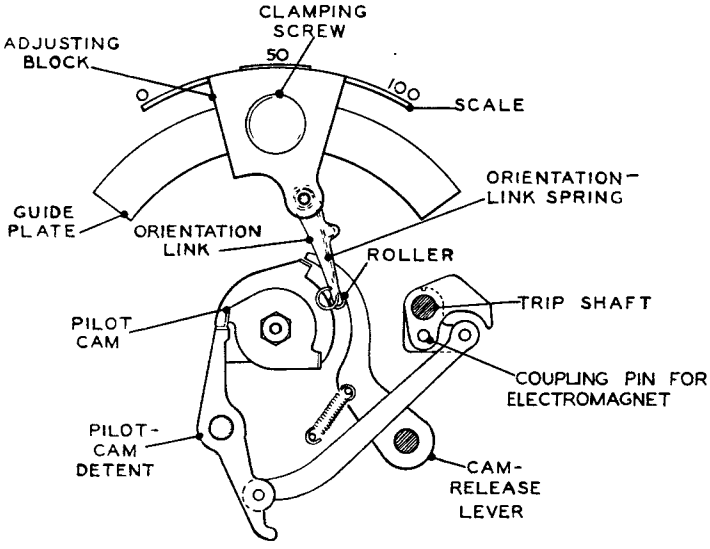


Fig. 11.110. Teleprinter No. 11: Orientation Device Trip Mechanism

The timing given in Fig. 11.105 (*b*) is based on the assumption that the orientation adjusting block is set centrally within the margin range thus giving a delay of 21·7 milliseconds in the release of the receiving cam sleeve after the release of the pilot cam; this is the condition of maximum equal margins.

It will be appreciated that, since the time for one revolution of both the pilot cam and the receiving cam sleeve is 130 milliseconds, the receiving cam sleeve will still be rotating for 21·7 milliseconds after the pilot cam has been arrested by the detent. Under automatic transmission conditions, where the stop signal of one character combination is followed immediately by the start signal of the next, this gives an overlap of 1·7 milliseconds between the end of rotation of the receiving cam sleeve and the commencement of rotation of the pilot cam for the reception of the succeeding character.

The Combination and Type-head Units. The combination and type-head units of the Teleprinter No. 11 function similarly to those of the Teleprinters Nos. 3 and 7 but have differences in detailed construction. In addition the type-head clutch is of a special shock absorbing type designed to increase the working life of the parts and reduce maintenance. The speed of the type-head shaft, see Fig. 11.92, has been increased to allow time for the shock absorbing mechanism of the clutch to function.

The principle of operation of the combination head, which can be seen in Fig. 11.90, is the same as that of the Teleprinter No. 7 and therefore it is unnecessary to describe its operation. The receiving combs are cut to conform with the International Telegraph Alphabet No. 2. Further, for certain signal combinations, viz. "Letter Shift," "Figure Shift" and "All Space," special control levers are associated with the respective bell-cranks and these, in conjunction with the feed throw-out lever, prevent any feeding of the paper tape when these combinations are received. The operation of the feed throw-out mechanism will be described later when explaining the action of the paper feed mechanisms.

The construction of the type-head is similar to that used on earlier models of teleprinters and can be seen from Figs. 11.111 and 11.113. The type fount used has been specially designed from the point of view of distinguishing badly printed (e.g. blurred) characters of similar shape.

As in other teleprinters, when the bell-crank lifting collar is operated and the bell-cranks are lifted, the type-head is allowed to rotate, driven by the combination head spindle via a friction clutch. When another bell-crank is selected the type-head is brought to rest, gradually because of the shock absorbing mechanism, in the correct position for printing the selected character.

Fig. 11.111 represents the type-head and type-head clutch with the parts shown in the order in

which they are assembled on the type-head spindle; the boss on the type-head is pinned to the spindle and holds the assembly together. Located next to the type-head are the thrust washer and thrust collar, the latter being keyed by the diametrically opposite lugs to the boss on the latch arm. The stop arm is assembled between the latch arm and the driving plate.

Between the latch arm and the stop arm is a damping (friction) washer, and a second damping washer is placed between the stop arm and the driving plate. The friction damping spring, assembled between the thrust collar and the latch arm, thrusts the latch arm, the stop arm and two damping washers towards the driving plate, so that any movements of the latch arm and the stop arm are heavily damped.

The driving plate has a projection, i.e. a centralizing pin, and the shock-absorbing springs of the latch arm and stop arm apply a clock wise torque to the stop arm and an anti-clock wise torque to the latch arm, so that the two edges A1 and A2 are normally thrust against the centralizing pin (see Fig. 11.112 which depicts the assembled parts).

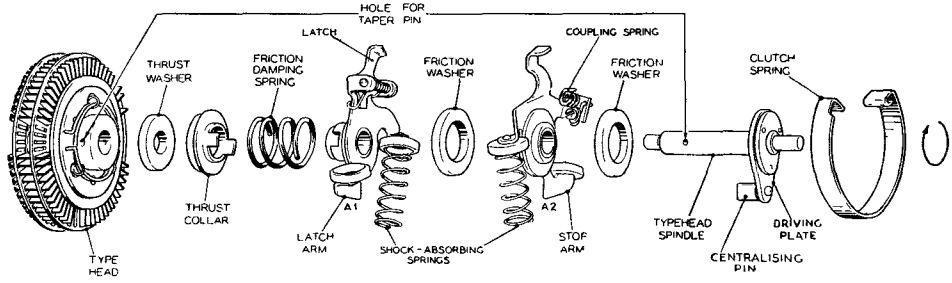


FIG. 11.111. TELEPRINTER NO. 11: TYPEHEAD AND CLUTCH

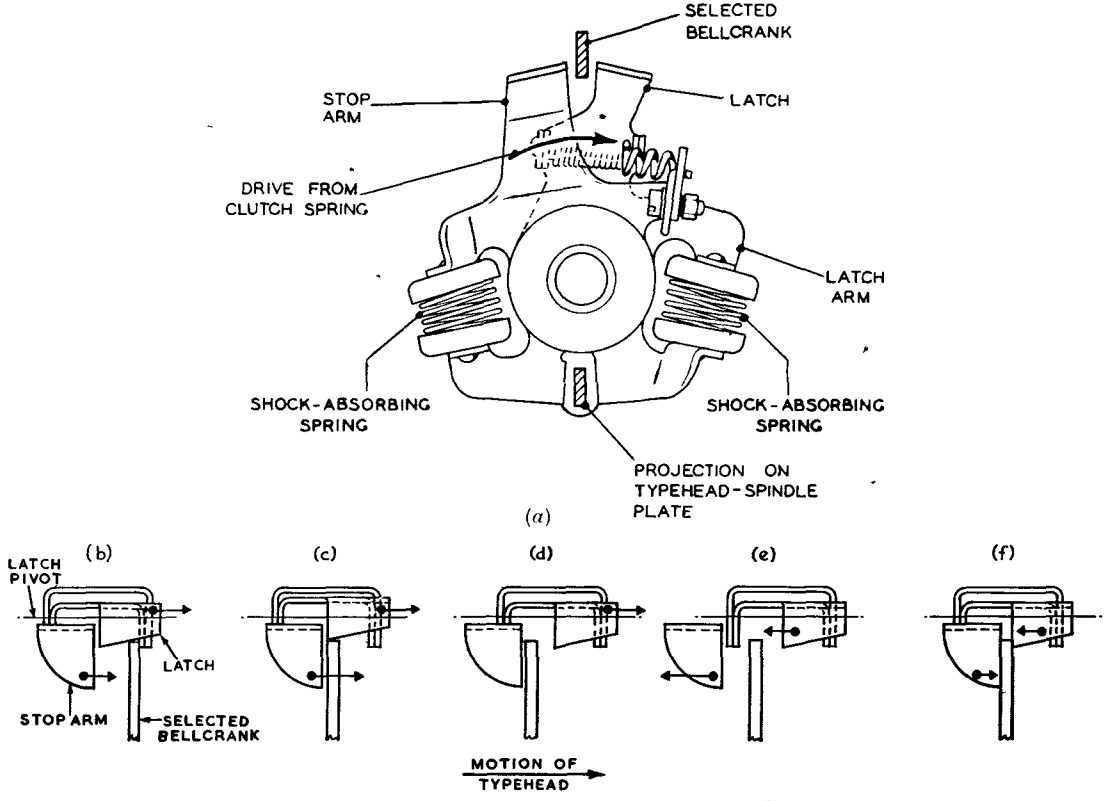


FIG. 11.112. TELEPRINTER NO. 11: TYPEHEAD CLUTCH

The action of stopping the type-head and positioning it for printing may be understood from Figs. 11.111 and 11.112. The rotation of the mechanism, shown in Fig. 11.112, before the type-head is

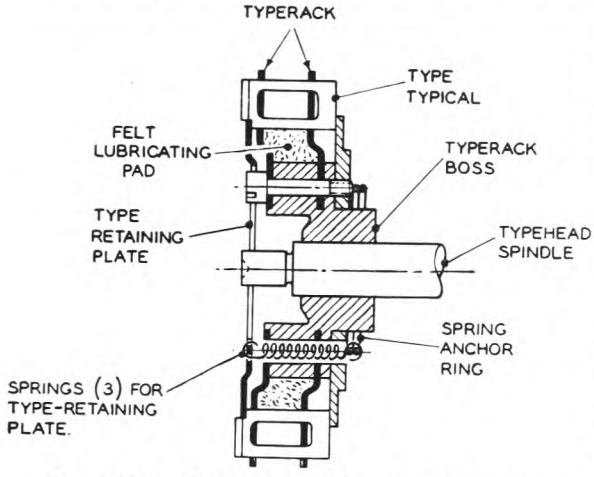


FIG. 11.113. TELEPRINTER NO. 11: TYPERACK

stopped by an operated bell-crank, is in a clock wise direction and it is driven by the type-head clutch drum and the clutch spring, expanded and in contact with the drum, which engages with the type-head coupling spring, see Fig. 11.111.

After a bell-crank is selected and drops, the type-head continues to rotate until the stop arm approaches the fallen bell-crank. The latch on the latch arm first engages the bell-crank and is pressed back against the tension of its spring, Fig. 11.112 (*a*) and (*b*). When the stop arm meets the bell-crank, Fig. 11.112 (*c*), the latch arm passes beyond it and, jumping forward again under the action of its spring, latches on the other side of the bell-crank.

The inertia of the type-head now causes it to go on rotating. Thus, the centralizing pin, which is solidly connected to the type-head, continues to move in a clock wise direction, thrusting against the bottom of the latch arm and compressing both shock-absorbing springs. During this motion some of the energy of the type-head is dissipated in the two damping washers, the rest being stored in the shock-absorbing springs which then expand, the centralizing pin moving in an anti-clockwise direction until it makes contact with the bottom of the stop arm. The stop arm is moved and again causes the shock-absorbing springs to be compressed, although not to so great an extent as they were before by the latch arm, because more of the energy of the type-head has been dissipated in the damping washer.

Thus, as shown in Fig. 11.112 (*d*), (*e*) and (*f*), the type-head executes a rapidly damped oscillatory movement, coming to rest opposite the appropriate type, its final position being determined by the facts that the stop arm and the latch arm are at rest against each side of the bell-crank and the centralizing pin, firmly held between the two arms, is solidly connected to the type-head. As previously mentioned, the speed of rotation of the type-head shaft has been increased so as to allow time for the damping movements.

The type-hammer is similar to those used on the Teleprinters Nos. 3 and 7, but it is provided with an overthrow (back) stop so that it cannot be moved too far forward and cause damage to the type-head. Also it is designed so that the hammer cannot be permanently deflected in either direction. The type-hammer is operated from one of the tracks on the receiving cam sleeve.

Tape and Ink Ribbon unit. The tape and ink ribbon unit, which can be seen on the left of Fig. 11.90, accommodates the platen and the ink ribbon spools and also the mechanisms for—

(*a*) Moving the paper tape forward each time a character selection is set up on the receiving mechanism preparatory to printing.

(*b*) Rendering the paper feed non-operative on certain non-printing combinations.

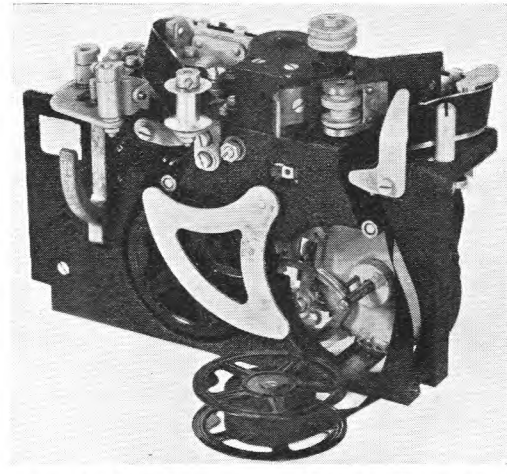


FIG. 11.114. TELEPRINTER NO. 11: TAPE AND INK RIBBON UNIT (FRONT)
(*By courtesy of H.M. Postmaster-General*)

(*c*) Causing alarm contacts to close in the event of the paper feed being defective.

(*d*) Providing the ink ribbon feed and automatic reversal of the direction of feeding when either spool is exhausted.

Figs. 11.114 and 11.115 show front and rear views

of the unit and indicate the main components. The unit is hinged, at the bottom, to the main base casting and is normally held in a vertical position by a latch which can be released by a lever. When unlatched, the unit can be swung outwards to uncover the printing faces of the types for cleaning and to allow ready access to the mechanisms for maintenance purposes. A spring-cushioned stop holds the unit at an angle of 30° to the horizontal when unlatched.

The platen consists of an aluminium cylindrical core, free to rotate about a fixed central spindle. The platen surface is provided by a layer of hard rubber round the aluminium core. The platen rotates as the paper tape moves forward, thus presenting a new surface to the type-head for each impression and also reducing the frictional drag on the tape.

The paper tape is taken from the exit of the tape roll holder, at the rear of the teleprinter, via the jaws of the paper failure alarm mechanism, to the guide pulley shown in Fig. 11.116 and thence round the platen and between the tape feed and pressure rollers. The feed roller is fluted and the pressure roller has a plain surface; both are cut away so that they grip the tape at its edges only, i.e. away from the printed characters. The pressure roller is self-aligning and is spring loaded so that it presses the paper against the feed roller. Thus, when the feed roller is rotated, the paper tape moves with it.

A hardened steel roller, mounted on the end of the traversing link, see Fig. 11.116, engages with the head of an abutment screw in the tape feed operating lever, which is pivoted and, at its other end, carries the feed throw-out pawl. This pawl is acted upon by a spring so that, in its normal position, one of its operational arms engages with a pin on the tape feed lever which is free to move about the same pivot as, but independently of, the tape feed operating lever; a second arm, as explained later, is used to provide the non-feed facility. Thus, as the traversing link is moved forward during the selection of a character combination, the tape feed operating lever is moved anti-clock wise and, provided the tape feed throw-out pawl is in its normal position, the tape feed lever is moved with it.

The tape feed lever carries at its end a square trunnion block, pivoted on a vertical pin, which engages in a slot in the tape feed plate. The tape feed plate pivots about the spindle of the tape feed roller and carries the tape feed pawl which is held, by a spring, in engagement with the tape feed ratchet. Thus each anti-clock wise movement of the tape feed lever produces a rotation of the tape feed roller and the tape is fed forward.

When the traversing link is subsequently moved backwards to its normal position, the tape feed operating lever is moved clock wise under the influence of its restoring spring and the tape feed pawl is moved back one tooth on the ratchet in readiness for the next feed cycle. A retention pawl is provided to hold the feed ratchet and roller in position during this operation.

A knob, for manual feeding of the paper tape, is secured to the top end of the tape feed roller spindle.

For certain signal combinations, viz. "Letter Shift," "Figure Shift" and "All Space," feeding of the paper tape is not required and therefore a feed throw-out mechanism is provided. Associated with the combination head bell-crank for each of these combinations is a control lever, one end of which is held against the bell-crank by a spring; the other end normally rests against an extension of a common feed throw-out lever. A typical control lever is shown in Fig. 11.116. The other end of the feed throw-out lever carries the feed pawl throw-out rod, the upper end of which is normally flush with its guide.

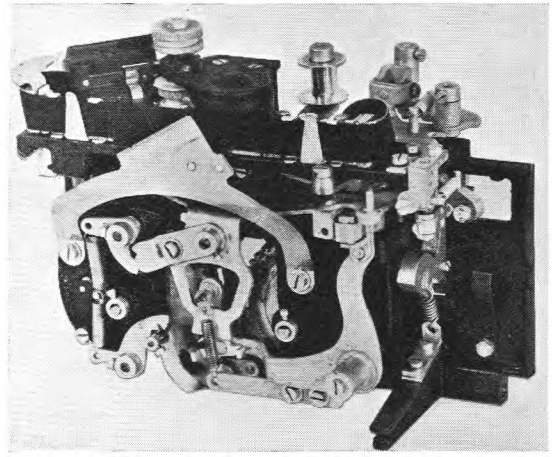


FIG. 11.115. TELEPRINTER NO. 11: TAPE AND INK RIBBON UNIT (REAR)
(By courtesy of H.M. Postmaster-General)

When one of these bell-cranks is selected and falls into the prepared channel in the receiving combs, the associated control lever and the feed throw-out lever move on their pivots and the feed pawl throw-out rod is lifted.

The feeding of the paper tape occurs during the forward movement of the traversing link and will have been completed before the feed pawl throw-out rod is raised. Thus, although the combination being received is one for which feeding of the paper tape is not required, a feed will take place during the cycle of operations for the reception of the character unless the previous selection also was

for a non-feed character; as explained below, the paper feed on the succeeding character is suppressed.

As already described, during the subsequent return of the traversing link to its rest position, the tape feed operating lever is restored and, if the feed pawl throw-out rod is raised, the projection on the feed throw-out pawl will engage with the rod and the pawl will be rotated on its pivot so that its other operational arm is moved out of engagement with the driving pin on the tape feed lever. Thus, when the traversing link is actuated during the selection of the succeeding character, although the tape feed operating lever is rotated, the tape feed lever is not moved and no feed occurs. If other non-feed character combinations are received the tape feed throw-out pawl will be held retracted; subsequent reception of the combination for a feed character will cause the feed pawl throw-out rod to be lowered and the feed throw-out pawl to be restored ready for the tape to be fed on the cycle for the subsequent character.

Thus the tape is fed forward during the reception of the first non-feed combination; but not for subsequent non-feed combinations or for the first subsequent feed combination.

A paper failure alarm mechanism is provided and is designed to operate a pair of contacts, which may be connected to an external alarm circuit, should the paper tape break, become jammed or slip to such an extent that the feed is so much less than normal that overprinting of characters occurs. The correct value of the tape feed for each printed character is 0·125 in. and, in effect, the alarm mechanism measures the actual feed, as it occurs, and operates the alarm contacts when the movement of the tape falls below 0·06 in. approximately.

The mechanisms concerned with the alarm feature are shown in Figs. 11.117 and 11.118. The seeker operating lever is free to rotate, in a horizontal plane, about its pivot and carries a self-aligning tape gripper. The tape roller lever is pivoted on the seeker operating lever and carries the tape roller which is held against the tape gripper, by the action of a spring on the lever, thus forming a pair of jaws through which the paper tape is passed on its way from the tape roll holder to the platen; the combination of roller and self-aligning flat surface ensures that the tape is gripped uniformly over its whole width.

Consequently, when the tape is moved forward by the action of the feed and pressure rollers, the seeker operating lever is rotated anti-clock wise (as seen from above) on its pivot, the angle of rotation being determined by the amount the tape moves.

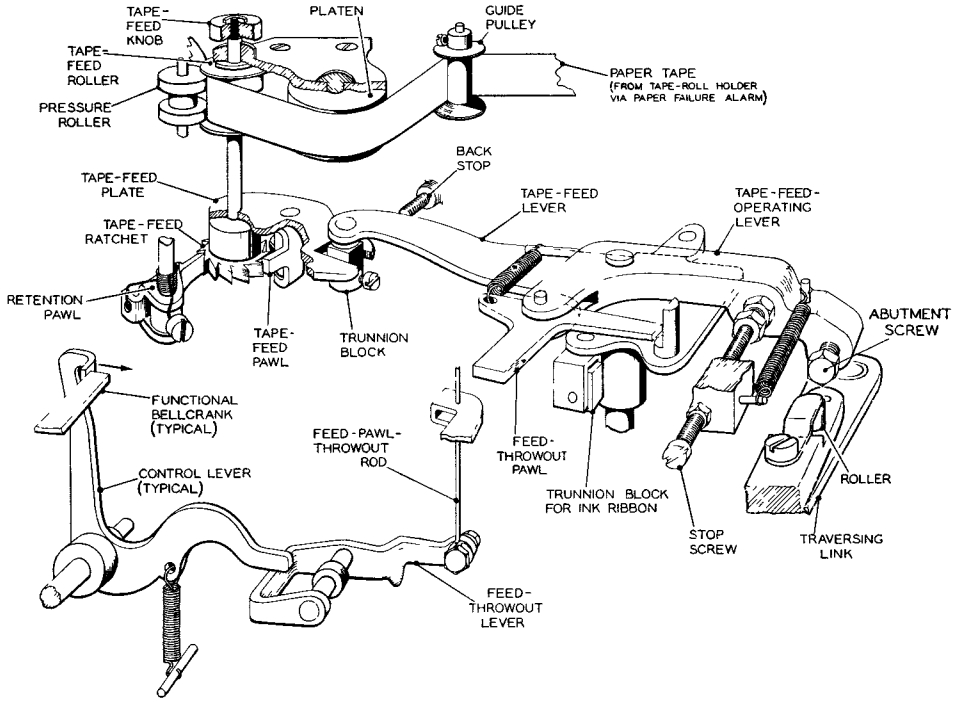


FIG. 11.116. TELEPRINTER NO. 11: TAPE FEED MECHANISM

As the seeker operating lever rotates, a vertical extension, at its rear, comes into contact with the paper alarm seeker and moves it outwards. The seeker is mounted on a spindle on the tape feed lever and is spring loaded so that it is normally against the shoulder on the paper alarm trip arm which is held against the casting by a light spring.

Simultaneously with the rotation of the seeker operating lever, due to the paper movement, the seeker is withdrawn towards the front of the machine by the rotation of the feed lever. If the paper movement is satisfactory, i.e. above the specified minimum of 0·06 in., the seeker is moved clear of the paper alarm trip arm and, when the tape feed lever is subsequently restored, it will come to rest in its normal position against the shoulder on the paper alarm trip arm. If, however, the paper fed forward is below the minimum, the step at the end of the seeker is allowed to fall behind the shoulder on the trip arm and when, on the restoration of the tape feed lever, the seeker moves to the rear again, the trip arm moves with it and operates the paper alarm contact operating mechanism. The seeker operating lever and the tape roller lever are reset at the end of each paper feed cycle by an extension of the tape feed operating lever pivot, see Fig. 11.117. During this restoration, the tape gripper jaws slide backwards on the tape which is held by the feed and pressure rollers.

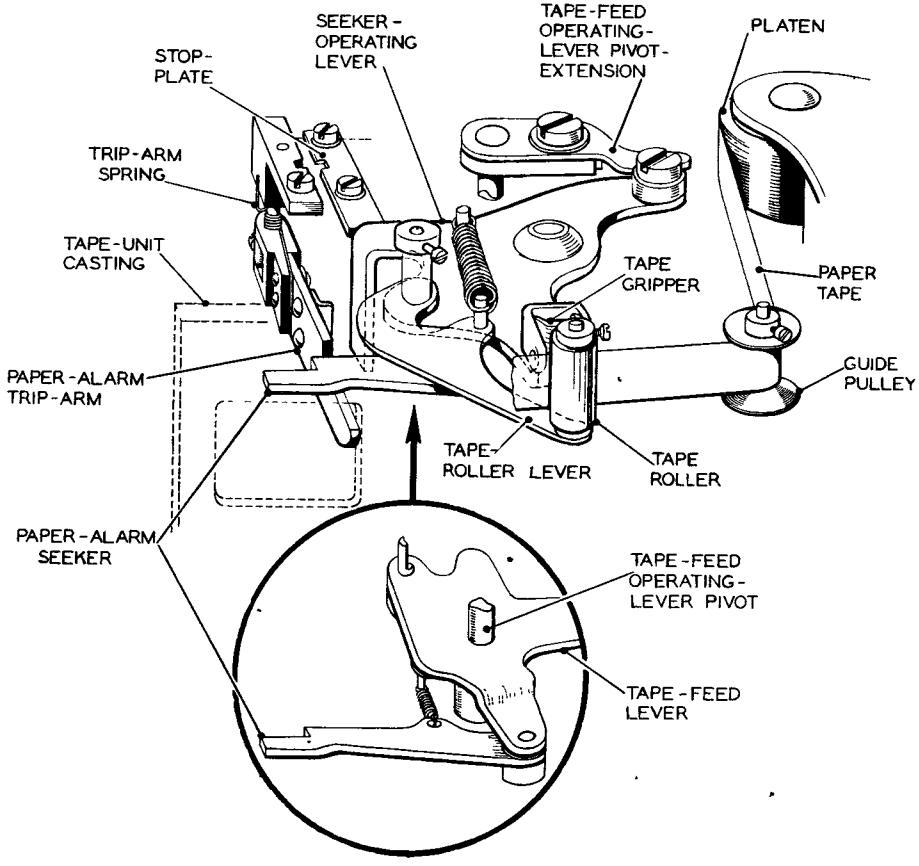


FIG. 11.117. TELEPRINTER NO. 11: PAPER FAILURE ALARM

It will be seen that, under feed throw-out conditions, the seeker operating lever is not displaced from its normal position so that the alarm condition is not set up.

The paper alarm contact operating mechanism is shown in Fig. 11.118. The paper alarm operating lever is mounted on a common spindle with a resetting lever, the lower end of which has an adjustable screw which abuts against an extension at the lower end of the traversing link bearing lever. The operating lever is normally held in the unoperated position by a detent on the paper alarm trip arm.

When the trip arm is displaced, as described

above, due to an unsatisfactory feed, the lower end of the operating lever moves inwards, under the action of its spring, causing the alarm contacts to be closed. (The resetting extension on the traversing link bearing lever is withdrawn before the trip arm is tripped and does not interfere with the movement of the operating lever.) Whilst the operating lever is in its operated position, the end of the detent on the trip arm rests against it and thus the trip arm is held displaced.

As the traversing link is moved forward during the cycle for the next character, the extension on the bearing lever causes the resetting lever to be moved and the operating lever to take up its unoperated position. Thus the alarm contacts will be broken and will remain so if the paper feed for the cycle is satisfactory; if the feed is not satisfactory the alarm condition will again be produced. It is usually arranged that the external alarm circuit, when once operated, gives an audible or visual alarm until it is reset manually.

The feeding of the ink ribbon is effected at the same time as the feeding of the paper tape. As can be seen in Fig. 11.116, the tape feed lever carries a second trunnion block, pivoted horizontally, which abuts against a similar, but vertically pivoted, block on the ribbon feed lever, see Fig. 11.119. The oscillatory movement of the former lever is therefore transferred to the latter. (It will be observed that under feed throw-out conditions, the ribbon feed lever also is not moved.)

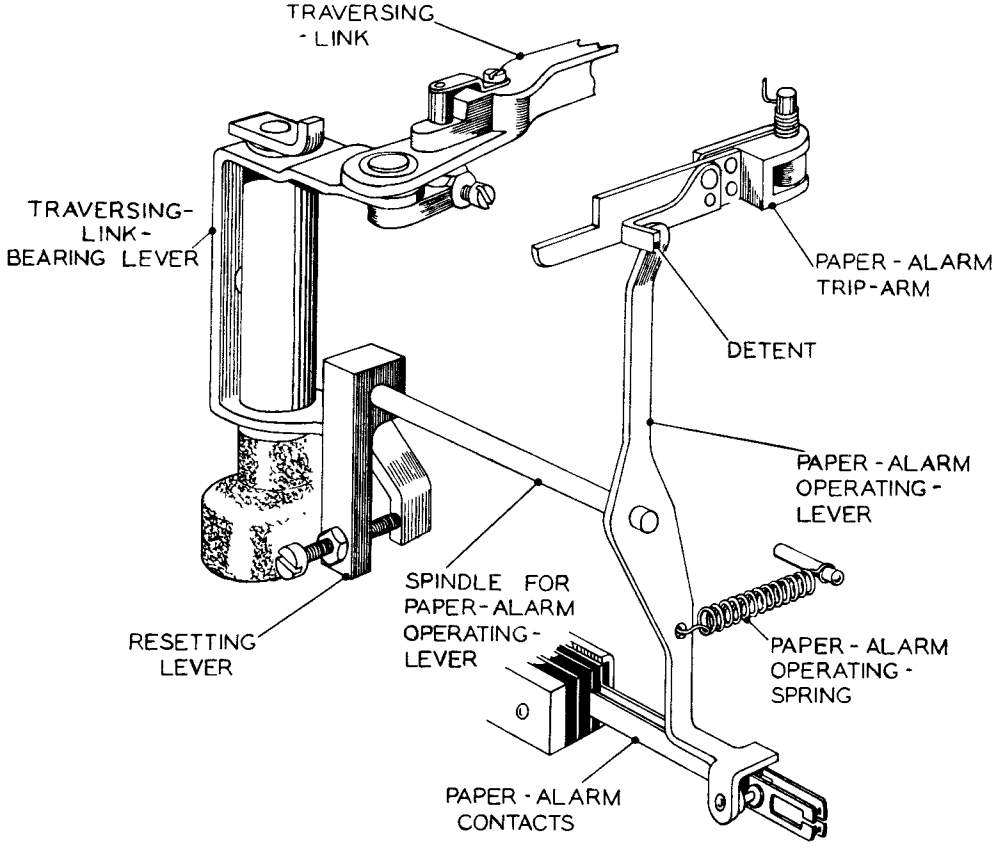


FIG. 11.118. TELEPRINTER NO. 11: PAPER FAILURE ALARM

As can be seen in Fig. 11.114, the ink ribbon spools are housed in the tape and ink ribbon unit casting. Each spool is supported on a spindle to which is attached a boss with a driving pin which projects into a hole in the ribbon spool. A triangular keep plate retains the spools in position on their spindles and is designed so that it can be swung about a pivot to enable either of the spools to be withdrawn. The ends of the spindles remote from the spools are fitted with ratchet feed wheels.

The ribbon is fed from the spools via the forked

ends of the ribbon feed change lever as shown in Fig. 11.119, and is then brought to the inner side of the unit in front of the typehead where it is held in place by guides, see Fig. 11.115.

Pivoted at the extremity of the lower arm of the ribbon feed lever is the ribbon feed pawl. The upper end of the pawl is fitted with a horizontal pin, one end of which can engage with either of the two ratchets as determined by the position of the change lever through which the ribbon is threaded. The ribbon feed change lever is therefore moved clock-wise into its reverse position where it is held by the action of the ribbon feed change jockey lever. In this position its foot is brought immediately over the front one of the two projections on the ribbon feed pawl and, therefore when the next upward movement of the feed pawl occurs, the front projection comes into contact with the foot and is

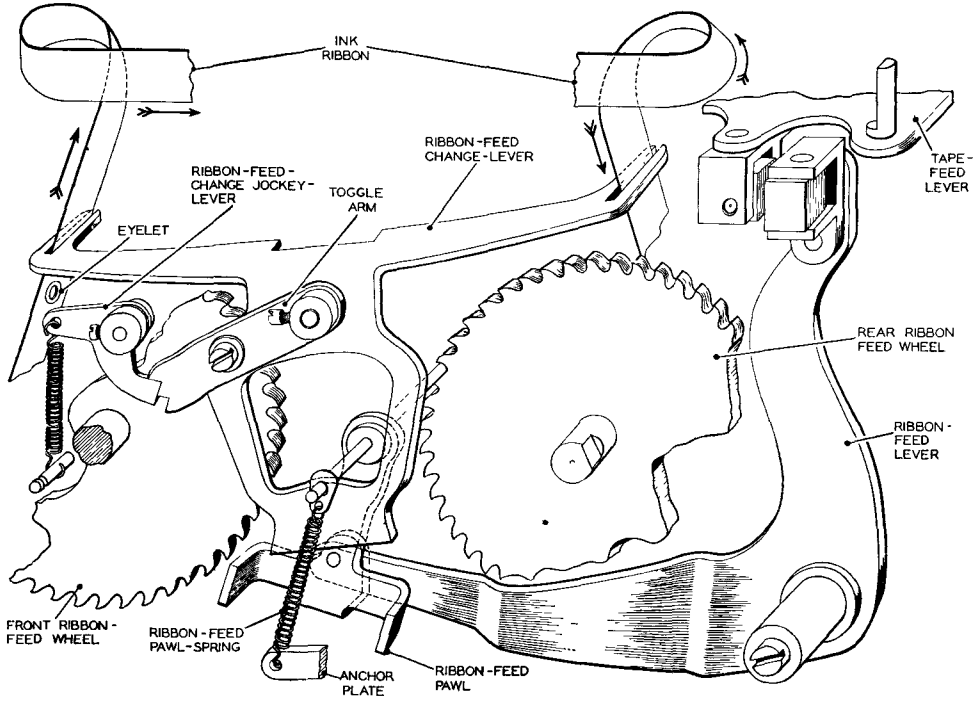


FIG. 11.119. TELEPRINTER NO. 11: SCHEMATIC OF RIBBON FEED MECHANISM

ribbon feed change lever; a toggle spring is attached to the other end of the pin. Thus, when the ribbon feed lever is actuated, the feed pawl causes one of the ratchets to be stepped forward one tooth and the associated spool is rotated.

A retaining pawl, which can be seen in Fig. 11.120, is provided to hold the ratchet during the return movement of the feed pawl. This pawl also can take up one of two positions as determined by the ribbon reverse mechanism; a jockey roller is provided to hold the pawl in the predetermined position.

Reversal of the direction of the ribbon feed is produced in the first case by eyelets inserted in the ink ribbon, six inches from either end. Considering the condition depicted in Fig. 11.119, the rear spool is being driven and, when the front spool is nearing exhaustion, the eyelet at that end will come into contact with the forked end of the ribbon feed prevented from rising. Consequently the feed pawl swings anti-clock-wise about its pivot and the pin on its end engages with the front ribbon feed ratchet thus reversing the direction of the ribbon feed. As can be seen in Fig. 11.120, the driving pin of the feed pawl projects through an opening in the frame of the retaining pawl and thus, as the feed pawl is changed over, the retaining pawl also is moved from engagement with the teeth of one ratchet to those of the other. A ribbon feed movement is lost whilst the change over is being effected but this is unimportant.

The Tape Roll Holder. The tape roll holder, see Fig. 11.121, is fitted with a handle to facilitate its removal and replacement on the teleprinter. It is supported on a bracket at the rear of the main base, outside the dust cover, and is automatically locked in position by a simple catch.

The roll of paper tape is accommodated on a boss, see Fig. 11.122, which is pivoted on a spindle fixed to the main body of the holder. A disc, which supports the paper roll, is fixed to the boss and a brake, which acts on the rim of the disc, is provided so that spinning of the roll of paper tape tending to produce loose turns, will not occur. A circular spring, incorporated in the boss, presses outwards against the inner surface of the cardboard ring, on which the paper tape is wound, and prevents its rotation relative to the boss when the brake is applied.

A tape guard, in the shape of a circular strip fixed on the main body so that it lies round the edge of the tape roll disc, prevents any loose turns of the tape from finding their way between the disc and the body of the holder.

The tape roll rotates clock wise, viewed from the rear, see Fig. 11.123, and tape from the top of the roll passes over a fixed guide roller, under the roller of the brake lever, over a second fixed guide roller and is then guided by a curved metal strip and an exit roller to the tape and ink ribbon unit.

When during a paper feed operation, the tape is tensioned by the tape unit, the brake lever is rotated clock wise away from its stop, moving an intermediate lever which causes the brake block to be lifted away from the rim of the tape roll disc. Immediately the pull on the paper tape ceases, the brake is re-applied and thus spinning of the roll is prevented.

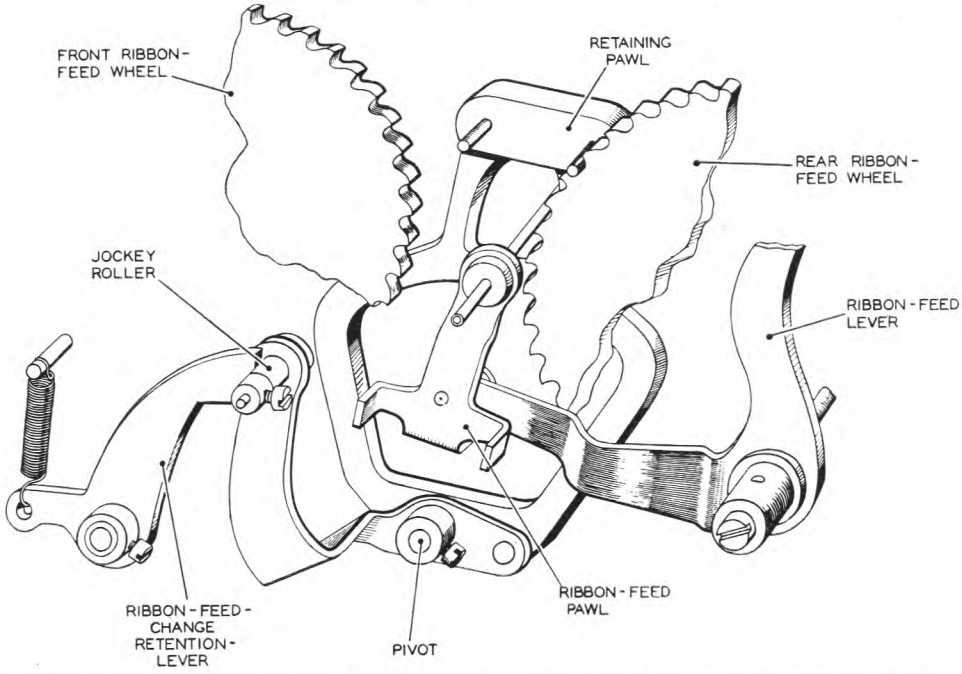


FIG. 11.120. TELEPRINTER NO.11: RIBBON FEED MECHANISM SHOWING RETAINING PAWL

The Answer-back Unit. The answer-back mechanism is arranged—

(*a*) to trip when a WRU signal selection (D

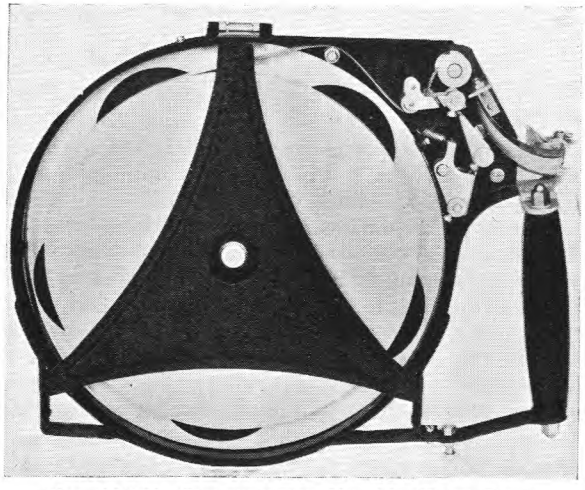


FIG. 11.121. TELEPRINTER NO. 11: TAPE ROLL HOLDER

(By courtesy of H.M. Postmaster-General)

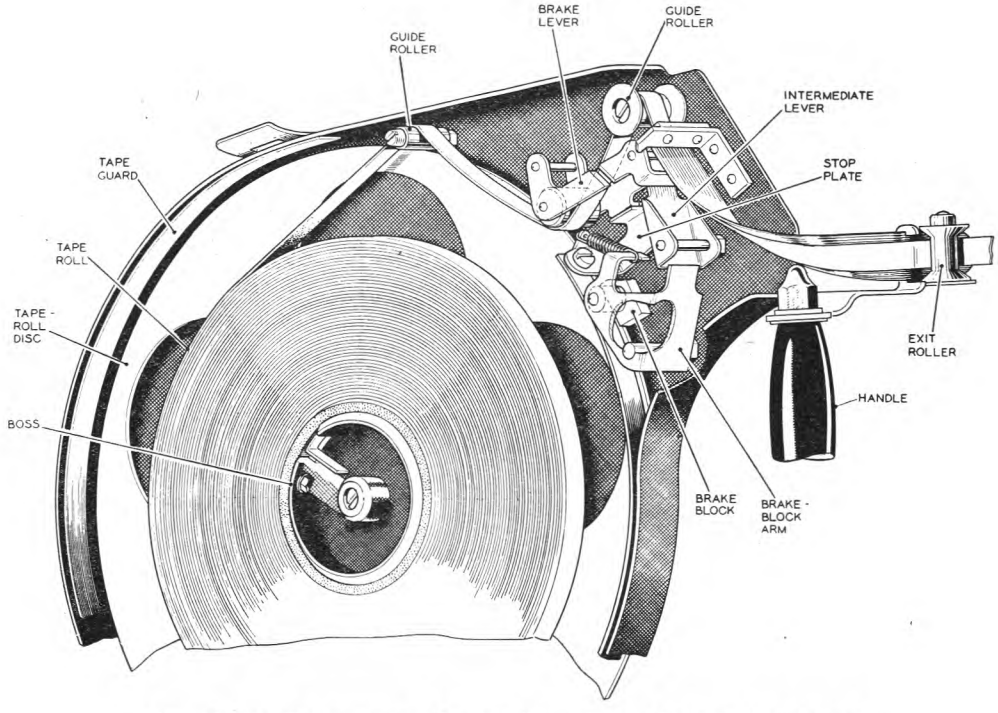


FIG. 11.122. TELEPRINTER NO. 11: TAPE ROLL HOLDER MECHANISM

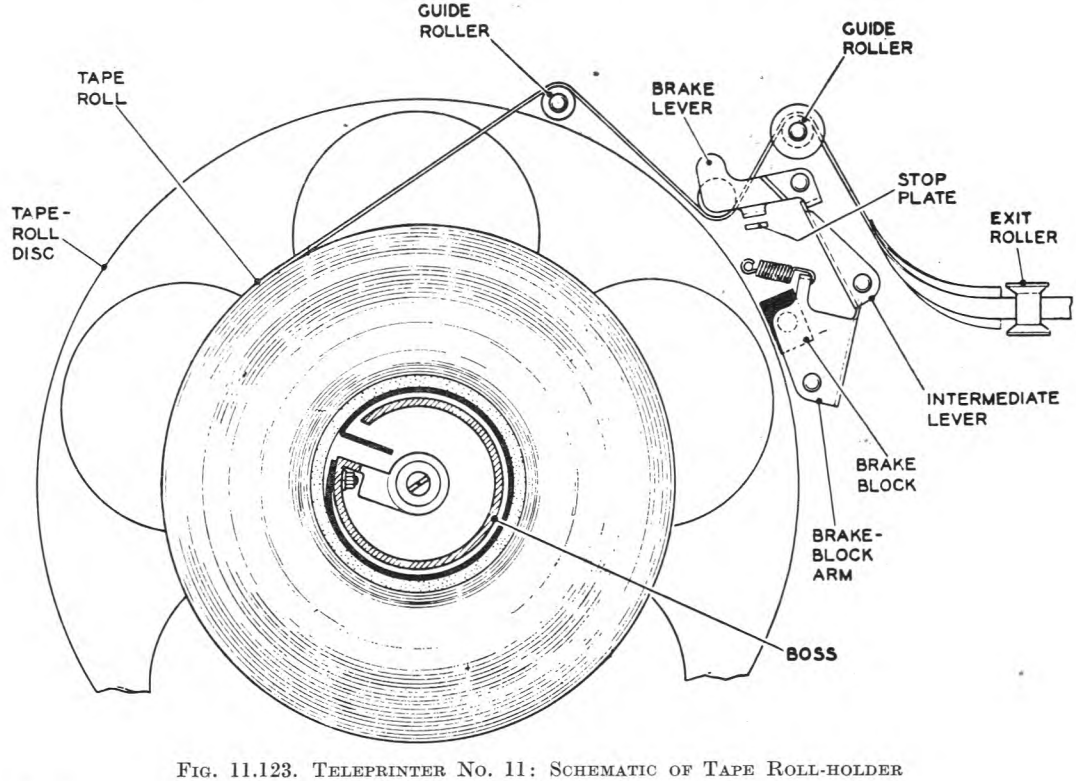


FIG. 11.123. TELEPRINTER NO. 11: SCHEMATIC OF TAPE ROLL-HOLDER

secondary) is set up on the combination head or when the "Here Is" key is depressed

(*b*) to remain inoperative to a WRU signal selection in the combination head when the WRU key on the keyboard is held depressed

(*c*) when tripped, to cause the transmitter to transmit 20 chosen teleprinter signal combinations after an initial delay of 160 milliseconds (approximately)

(*d*) at the end of transmission of the 20 characters, to restore to normal in readiness for its next operation.

The character combinations transmitted by the answer-back mechanism, in conjunction with the transmitting unit, are determined by 20 wards which are located in slots round the periphery of the answer-back drum, see Fig. 11.124. Each ward is cut to represent the code of a character, a cut-away portion of the ward corresponding to a spacing element and a projecting portion a marking element. Typical wards are shown in Fig. 11.124.

The standard arrangement of the wards is—

Ward No.	*Character Combination*
1	Letter shift
2	Carriage return
3	Line Feed
4	Space
5	Space
6	Letter shift
7–14	Answer-back code
15–19	Space
20	Letter shift

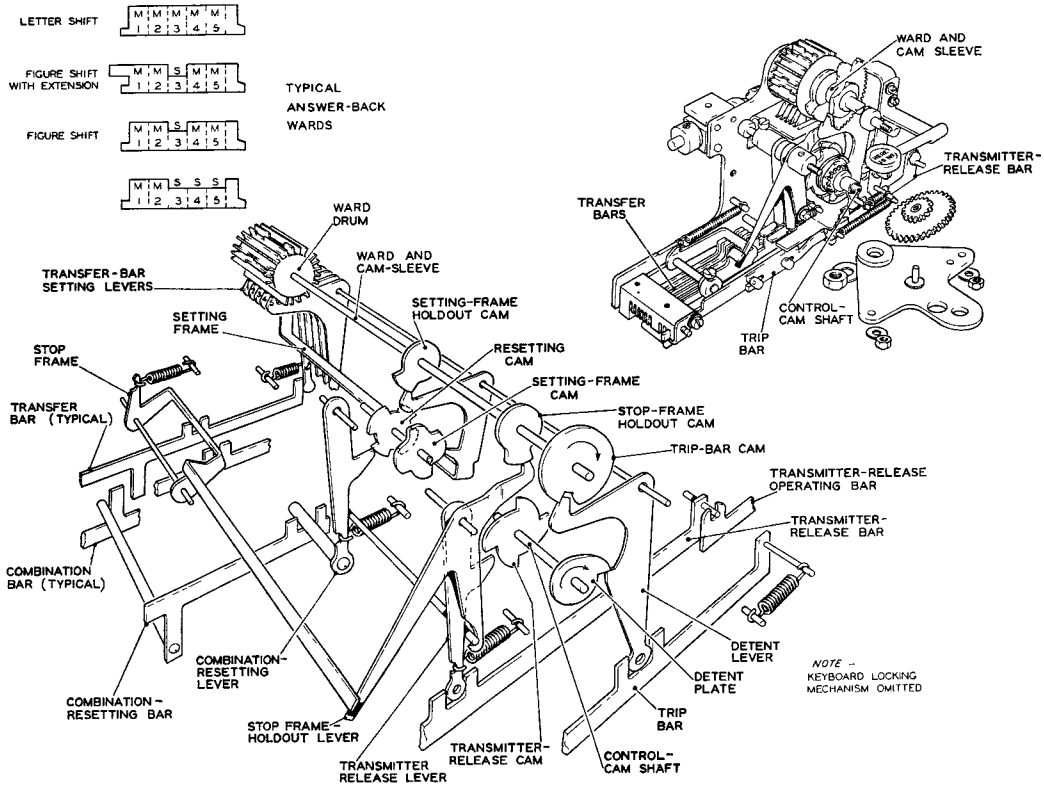


FIG. 11.124. TELEPRINTER NO. 11: ANSWER-BACK UNIT

Thus eight wards are available for the answer-back code (including shift combinations) but to obtain the single revolution feature which is described later, one of these wards must be a figure-shift ward with a special extension.

The reasons for the special wards in positions 1–3, 6 and 20 are the same as those already described on page 409 for the answer-back unit used on the Teleprinter No. 7. The additional spaces in positions 4 and 5 ensure a separation between the answer-back code and any service signals which may have preceded it. Wards 15–19 produce 5 spaces

which ensure that the answer-back code is brought into a position where it can readily be read on the tape by the operator. Where the full number of wards (8) available for the answer-back code are not required, the spare positions are fitted with uncut wards; this results in the transmission of a letter-shift signal combination.

The answer-back mechanism is located at the rear of the keyboard as can be seen in Figs. 11.94 and 11.95 and comprises the release mechanism, ward barrel shaft and control cam shaft assemblies and the transfer mechanism.

The release mechanism is illustrated in Fig. 11.125 and causes the answer-back unit to be tripped when the WRU (D secondary) selection is set up in the combination head. When the WRU bell-crank is selected, the spring loaded answer-back control lever follows it and moves the answer-back release lever clock wise. The displacement of the release lever is transmitted, by the release link, to the answer-back operating lever and a pin, projecting from this lever, engages with the latch support arm which is coupled to the trip-lever by a latch. Thus the trip-lever is moved anti-clock wise on its pivot and causes the trip-bar to be moved to the right. This operates the detent lever and the control shaft commences to rotate as described later.

When the teleprinter is connected to give a local record of the transmitted signals, depression of the WRU key will result in the selection of the WRU bell-crank in the combination head and, unless some means of preventing it is provided, the home answer-back mechanism will be tripped. To avoid this happening, since it would cause mutilation of the signals received from the operation of the answer-back unit of the distant teleprinter, the WRU keybar is fitted with an extension, shown in Fig. 11.125, so that, when the keybar is depressed, the extension abuts against a screwhead on the trip bar and prevents the latter from moving. In

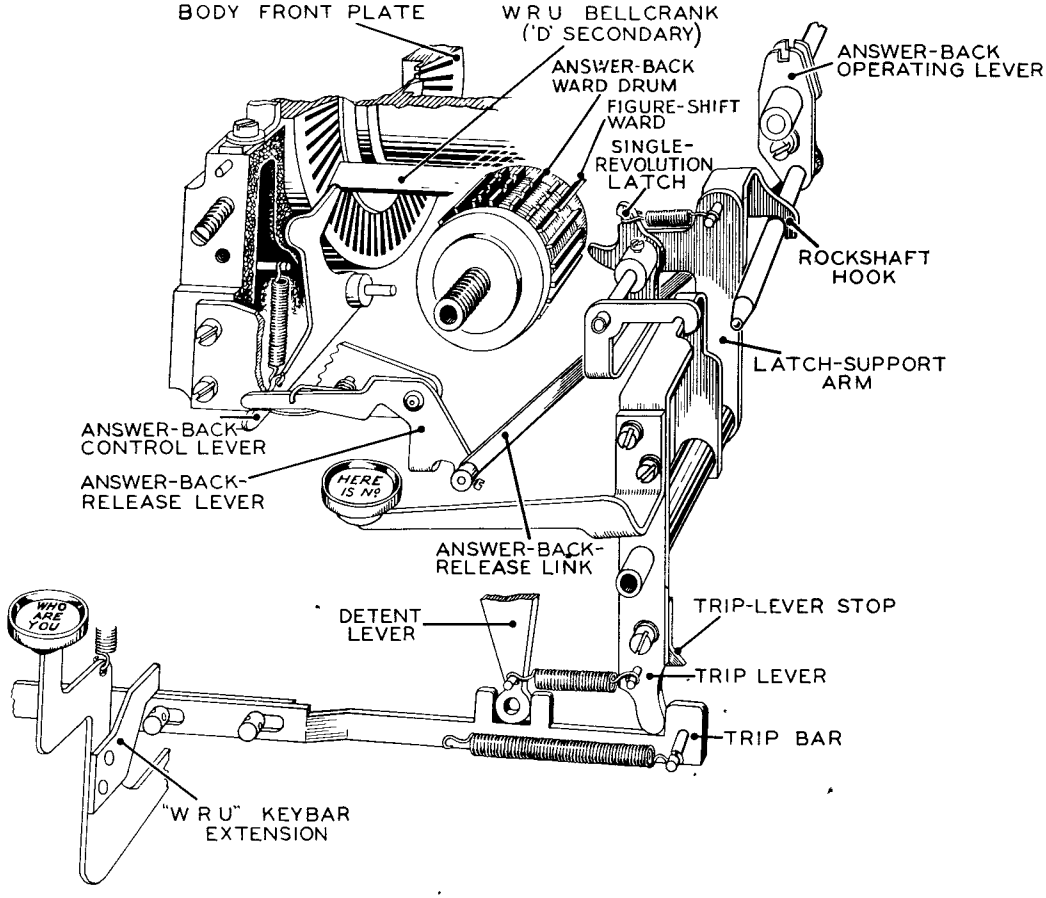


FIG. 11.125. TELEPRINTER NO. 11: ANSWER-BACK UNIT RELEASE MECHANISM

order that this may be effective, it is necessary for the WRU keybar to remain depressed until the next character combination has been set up in the combination head; friction between the screwhead abutment on the trip-bar and the WRU keybar extension normally keeps the WRU keybar in the operated position (depressed) whilst the WRU bell-crank is operated and the trip-bar is urged to the right.

The ward barrel shaft carries three cams in addition to the ward barrel, viz.—

the trip bar cam
the stop frame hold out cam
the setting frame hold out cam.

It is driven by gearing from the control cam shaft and makes one revolution for six revolutions of the latter, i.e. one revolution in 4·22 sec approx, during

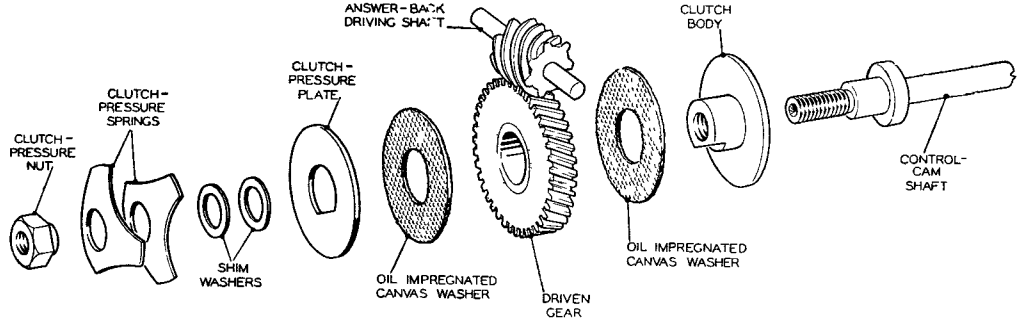


FIG. 11.126. TELEPRINTER NO. 11: ANSWER-BACK UNIT CLUTCH

The control cam shaft, Fig. 11.124, is driven by a friction clutch and carries four cams, viz.—

detent plate
transmitter release cam
setting frame cam
resetting cam.

When the clutch is released, the shaft rotates at a speed of 1 revolution in 702·8 msec, during which four complete character combinations of the answer-back code are transmitted. Each character combination takes 150 msec to transmit and there is a pause of about 25·7 msec between characters.

An exploded view of the clutch is shown in Fig. 11.126. It consists of a fibre gear wheel sandwiched between two oil impregnated canvas friction washers, the whole being clamped, under the pressure of two pressure springs, between a pressure plate and the clutch body. The latter is screwed on to the control cam shaft and has a flat on its hub to accommodate the pressure plate. The pressure nut also screws on to the control cam shaft and serves to lock the clutch body on to the shaft. The number of shim washers placed between the pressure springs and the shoulder of the control cam shaft can be varied thus enabling the clutch pressure to be altered.

The clutch gear is driven from a worm gear which is pinned to a short shaft, mounted on the back of the answer-back unit, in line with the main driving shaft of the keyboard unit and coupled to it by a flexible coupling.

which the complete answer-back code is transmitted.

The transfer mechanism, Fig. 11.124, comprises a system of levers and links which move the combination bars of the keyboard in accordance with the combinations represented by the wards, viz.—

the setting frame
five transfer bar setting levers
five transfer bars
stop frame
the comb bar resetting bar.

The lower ends of the five transfer bar setting levers abut against the corresponding transfer bars, the left-hand ends of which abut against projections riveted to the five combination bars of the keyboard unit (see Fig. 11.124). When the setting levers are allowed, by the setting frame, to move under the action of their springs, those setting levers whose upper ends are opposite cut-away portions (representing spacing elements) of a ward, displace their transfer bars and the corresponding combination bars are moved to the left. The amount of displacement of the transfer bars is limited by the stop-frame, which is lowered during transmission of the answer-back code, but is raised in the rest position to prevent any possible limiting of the combination bars during normal keyboard operation. Where the ward is not cut away (representing marking elements) it obstructs the upper end of the corresponding setting lever and therefore

the keyboard combination bar concerned is not moved.

At the end of the transmission for each character, the transfer bar setting levers are restored to normal by the action of the setting frame. The displaced keyboard combination bars are reset to the right-hand position (marking), by the pin at the end of the comb bar resetting bar, just prior to the setting operation for each character and the corresponding transfer bars are moved with them.

thus preventing its restoration until the 24th quarter revolution.

The rotation of the stop-frame hold out cam causes the stop-frame to be lowered and also puts the transmitter release lever under the control of its cam. The rotation of the setting frame hold out cam puts the setting-frame under the control of its cam.

The combination resetting bar is always under the control of the resetting cam and in the unoperated position is displaced to the left. Towards the end

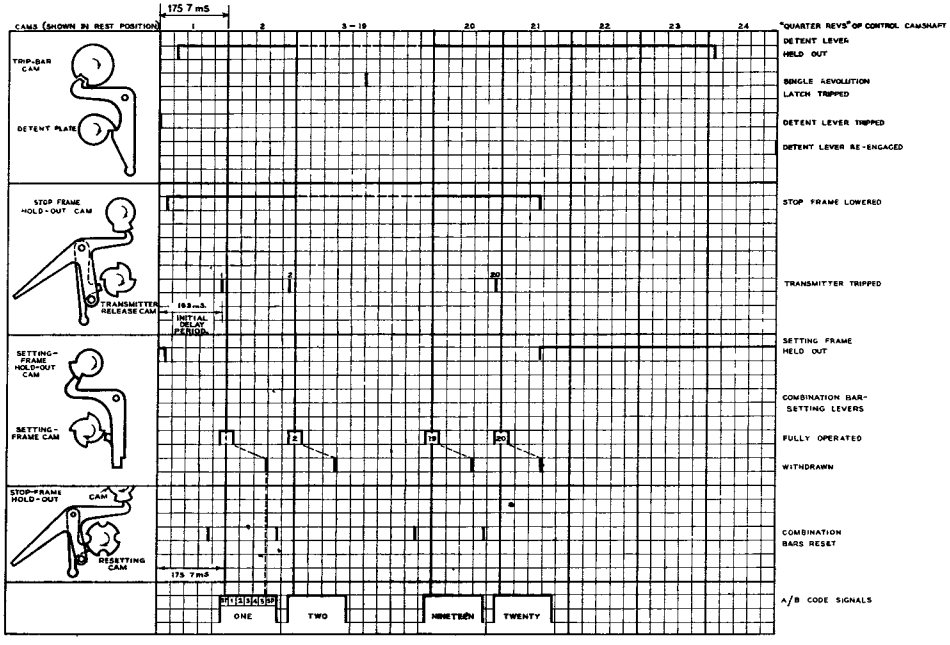


FIG. 11.127. TELEPRINTER NO. 11: TIMING DIAGRAM OF ANSWER-BACK UNIT

A detailed description of the operation of the answer-back mechanism during a complete cycle of operations will now be given, and reference should be made to Figs. 11.124 and 11.125.

As previously explained, during each revolution of the control cam shaft, four character combinations are transmitted and therefore it is convenient to refer to a quarter-revolution of this shaft as the basic interval of time. During the interval from the initial tripping of the answer-back mechanism to its final restoration, the control cam shaft makes six complete revolutions, i.e. 24 quarter revolutions, and Fig. 11.127 is a timing chart covering this complete cycle; it also shows the various cams and cam followers in simplified form.

When the detent lever is operated as already described and the control cam shaft commences to rotate, the cut-away portion of the trip bar cam is moved away from the upper end of the detent lever

of the first quarter revolution it operates for the first time, resetting the combination bars preparatory to transmitting the first answer-back code signal. (*Note.* It should be remembered that the keyboard utilizes saw-tooth combination bars which under normal keyboard transmission are not reset between characters. For transmission controlled by the answer-back wards resetting is necessary.)

Just before the end of the first quarter revolution, the setting frame is operated for the first time and allows the transfer setting levers to set the combination bars in accordance with the cutting of the first ward, which is by now in position opposite the upper ends of the setting levers. Simultaneously with the operation of the setting frame, the transmitter release lever is operated by its cam and displaces the transmitter release operating bar to the left, thus tripping the transmitter unit as described on page 433.

The combination bars having been set in accordance with the first answer-back code signal, this is now transmitted. The initial delay before the commencement of transmission of the first character is approximately 163 msec as shown in Fig. 11.127 and thus, the transmission of the start element of the first character is not quite complete at the end of the first quarter revolution.

During the transmission of the five code signal elements the setting frame is withdrawn and by the withdrawing of the transfer bar setting levers, the projection of the setting frame hold out cam prevents any further operation of the setting frame. The transfer bars therefore remain in their rest position and the combination bars are reset after the transmission of the twentieth character. Also during the 21st quarter revolution the stop frame is raised.

During the last three quarter revolutions no transmissions take place due to the action of the

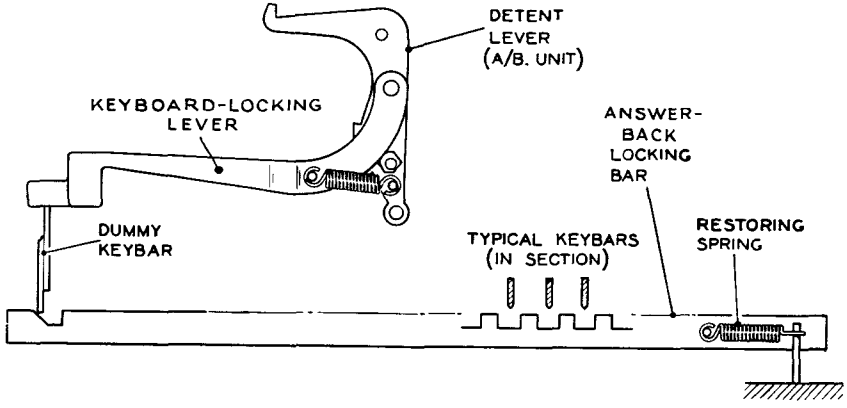


FIG. 11.128. TELEPRINTER NO. 11: KEYBOARD LOCKING MECHANISM

end of the transmission of the third code signal element the upper ends of the setting levers are moved clear of the wards so that they offer no obstruction to the oncoming second ward. After the fifth code signal element has been transmitted, the resetting lever is again operated and the combination and transfer bars are reset.

From this point the cycle of operations is repeated until 20 characters have been transmitted, i.e. until towards the end of the 21st quarter revolution.

As already stated, in order to obtain the single revolution feature, one of the wards Nos. 7 to 14 must be a figure shift ward with an extension. The extension on this ward engages with the single revolution latch rotating it anti-clock-wise, see Fig. 11.125, and the trip lever is allowed to restore independently of whether the WRU bell-crank remains operated. Thus the trip bar and the detent lever are free to restore and bring the unit to rest, as soon as the trip bar cam permits it, i.e. at the end of one complete cycle of transmission. It should be noted that if the unit is operated by the "Here Is" key and the key is held depressed, the detent lever cannot restore and the answer-back unit continues to rotate.

During the 21st quarter revolution, following the setting frame hold out cam. At the end of the 24th quarter revolution the detent lever nose falls into the recess in the trip bar cam and the unit is brought to rest.

An arrangement is provided whereby the keyboard is locked during the transmission of the answer-back code thus preventing mutilation of the transmission should the operator attempt to use the keyboard. This mechanism is shown in Fig. 11.128. When the detent lever is operated the locking bar is moved to the left and the projections on it obstruct the downward movement of all keybars. At the end of transmission of the answer-back code the detent lever is restored and the locking bar is moved to its normal position (right) under the influence of its spring.

End-of-Line Indicator. Should a Teleprinter No. 11 be used to transmit to a page printing teleprinter, e.g. Teleprinter No. 7B, it is necessary to provide a visual warning to the sending operator when the page printing attachment on the distant teleprinter is approaching the end of a line, so that he knows when to operate his Carriage Return key. For this purpose an End-of-line Indicator mechanism can be provided, if desired. It is essentially a counting device to record the number of key depressions after each operation of the Carriage Return key. When

55 depressions have been recorded, i.e. 14 characters before the end of a line of 69 characters, the device closes a pair of contacts and lights a lamp which is fitted on the Motor Radio Interference Suppression Unit on the right-hand side of the machine and which can be seen through an aperture in the cover. The operation of the Carriage Return key resets the mechanism.

The end-of-line indicator mechanism is shown schematically in Fig. 11.129. The drive for operating it is obtained from a cam on the transmitting cam shaft, a lever working off the cam engages a pin in the claw formed at the right-hand end of the trip release bar. Once during each revolution of the transmitting cam shaft, the trip release bar is moved to the right and a lug on it engages with a pin on the feed lever rotating it in an anti-clock-wise direction. The feed lever carries the feed pawl which causes the ratchet wheel to be fed one tooth. The ratchet wheel is held in the fed position by the retention pawl and its spring. Every time the trip release bar is moved to the right the foregoing sequence of operations is repeated.

As the ratchet wheel rotates about its spindle it stretches a spring *S*, shown in the upper part of Fig. 11.129, and partially winds this about the small drum *D*. After the ratchet has been stepped round 53 teeth, the stud *ST* on the ratchet wheel presses against the lower limb of the contact operating lever, Fig. 11.129, causing the contact roller to press the contact blade to the left. The action is completed and the contacts made after 55 teeth have been fed, a blank on the periphery of the ratchet wheel preventing further feeding.

Depression of the carriage return key rotates the cranked trip rod, which is connected by means of the resetting link to the resetting lever. The resetting lever, therefore, strikes inwards at the retention pawl disengaging it from the ratchet wheel. The lower extension of the retention pawl lifts the feed pawl clear of the ratchet. Also the bent lug on the locking lever holds the retention pawl in its disengaged position by locking over the tooth *T*. Thus, free from restraint, the ratchet wheel, under the tension of the spring *S*, restores in a clock wise direction and the pressure on the contact operating lever is relieved, the contacts break and the lamp is extinguished.

At the end of the restoration of the ratchet wheel, the stud *ST* strikes the lower extension of the locking lever which is rotated in an anti-clock wise direction; the release pawl is allowed to fall into the ratchet and in turn releases the feed pawl also. Thus the mechanism is in its normal position ready for the next counting operation.

Teleprinter Automatic Working

It is sometimes desirable to adopt automatic transmission or retransmission of messages on teleprinter circuits or networks; for this purpose, the following types of equipment are commonly used—

The Teleprinter Perforator has a keyboard similar to that of the teleprinter. This keyboard, instead of controlling a transmitter, controls a perforating mechanism which punches holes in a paper tape in

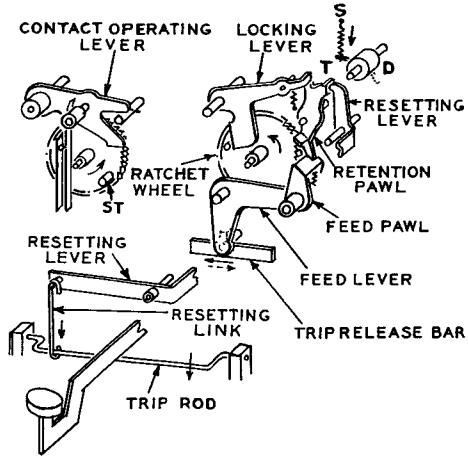


FIG. 11.129. TELEPRINTER NO. 11: END OF LINE INDICATOR

accordance with the five unit code combination corresponding to the key depressed.

The Teleprinter Reperforator is designed to receive signals in the teleprinter code and to translate them into the equivalent five unit code perforations in a paper tape.

The Teleprinter Automatic Transmitter is designed to transmit signals in the teleprinter code in accordance with the perforations in a paper tape which has been prepared on either a teleprinter perforator or reperforator and which is fed into the transmitting mechanism of the automatic transmitter. The transmitting mechanism is designed to automatically insert a start signal before, and a stop signal after, the code combination represented by the five unit code perforations in the paper tape. The automatic transmitter transmits the signals without any pauses between consecutive characters or words and thus enables maximum use to be made of the line-time by eliminating the pauses and hesitations which occur during manual transmission from a teleprinter keyboard. Repetition transmissions from one tape are also possible.

The Teleprinter Printing Reperforator is a machine very similar to a teleprinter but, on reception of

signals in the teleprinter code, it translates them into the equivalent five unit code perforations in a paper tape and, in addition, causes a printed record to be made on the same tape. If desired, a keyboard transmitter, similar to that of a teleprinter, can be fitted to the same machine thus enabling the instrument to be used for either transmitting or receiving.

The tape used in teleprinter perforators and reperforators is made of parchmentized paper,

Printing reperforators are designed to perforate a paper tape and also print the message on the same tape, the printed characters being superimposed upon the perforations for the fourth and fifth code elements. In order, therefore, that the printed characters are completely legible, the tape is perforated by the chadless method. A typical length of this type of perforated tape is illustrated in Fig. 11.131. The code and feed holes are perforated in the form of major arcs of a circle and the small

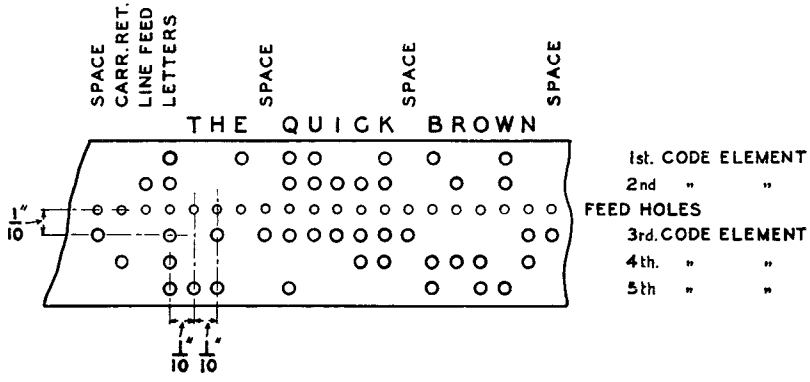


FIG. 11.130. 5-UNIT PERFORATED TAPE (ORDINARY)

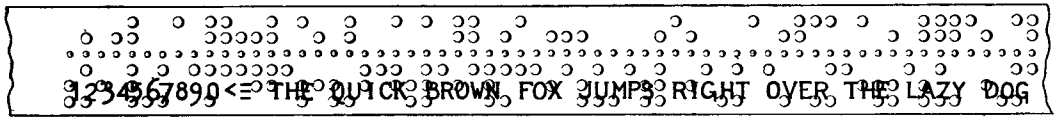


FIG. 11.131. 5-UNIT PERFORATED TAPE (CHADLESS TYPE)

$\frac{11}{16}$ in. wide, and is coiled in rolls of about 8 in. diameter. A typical length of perforated tape is shown in Fig. 11.130. A train of feed holes is punched longitudinally along the tape and the perforated holes corresponding to the five unit code elements of one combination are punched as required, in a line transversely across the tape, two on one side of the train of feed holes and three on the other side. In the British Post Office it is standard practice to have the perforating mechanisms arranged so that the centres of the code perforations are in line with the centre of the corresponding feed hole (centre line feed hole) but in some machines the front edges of the code and feed holes are in line (advanced feed hole). The distance between the centres of adjacent code or feed holes is $\frac{1}{10}$ in.

The five-unit perforations made in the tape are determined on the principle that a perforation is made for a marking element and no perforation is made for a spacing element.

hinged discs of paper, called "chads," remain attached to the body of the tape at the leading edges of the holes and the whole of the printed characters can be seen. When the tape is fed into an automatic transmitter the chads rise, like small hinged lids, in response to the sensing pins (peckers) of the transmitter.

The Teleprinter Perforator

The standard teleprinter perforating machine used by the British Post Office for many years was the Perforator No. 44. It has a keyboard layout similar to that used on a Teleprinter No. 7 and produces 5-unit code perforations in a tape in conformity with the International Telegraph Alphabet No. 2. In recent years a new perforator has been standardized by the B.P.O. to supersede the Perforator No. 44. It is designated the Perforator No. 45 and is manufactured by Creed and Co. Ltd. It conforms to the International Telegraph Alphabet No. 2 but has a motor-operated punching

mechanism and is faster and quieter in operation than the Perforator No. 44 which employs an electromagnet.

On a Perforator No. 44 any key depressed

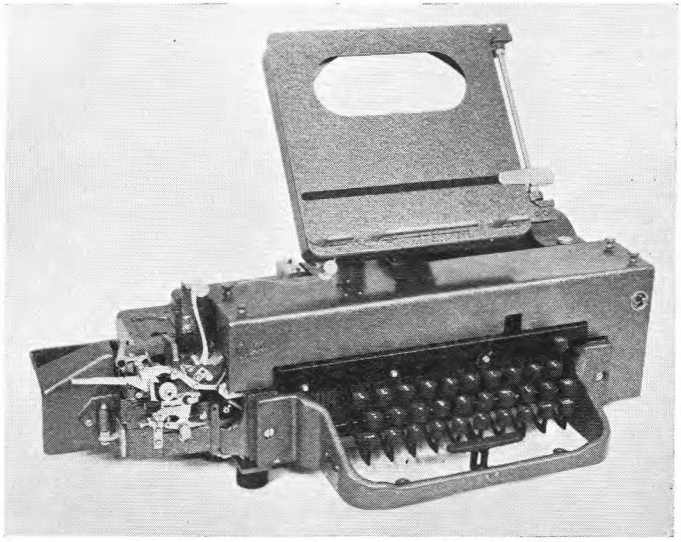


FIG. 11.132. PERFORATOR NO. 45
(*By courtesy of H.M. Postmaster-General*)

operates combination bars which determine the punching to be made in the tape. When the key is fully depressed, a circuit is completed for the electromagnet and the armature is attracted to the pole pieces; in moving it causes the operation of the punching hammer. When the key is released and restores, the circuit for the electromagnet is broken and the armature restores causing the tape to be fed forward ready for the next character combination to be punched. A letter counter is provided so that the machine can be used to punch tape for reception on a page printing teleprinter. The counter is operated each time a key is depressed and is restored to its zero position by depression of the Carriage Return key. There is no motor on the machine, and all the mechanical operating power is derived from the electromagnet except that the combination bars are moved directly by the depression of the keybars.

The Perforator No. 45 is illustrated in Fig. 11.132. It is driven by an a.c. induction motor, the motor speed being approximately 1,450 r.p.m. The motor is an ungoverned type as extreme accuracy of speed is not required.

The keyboard and character counting mechanisms are almost identical with those of the Teleprinter No. 11, see pages 430 and 458 and will not therefore be described in detail. The chief difference is that the cam-shaft controlled from the keyboard has two rest positions instead of one, and the keyboard can therefore be operated at almost twice the speed of that of the Teleprinter No. 11.

Perforator Mechanism (Figs. 11.133 and 11.134). The mechanism comprises the following sub-assemblies—

(*a*) The anvil-bracket assembly on which five selector bars, the tape-feed pawl and back-space key are assembled.

(*b*) The perforating unit, consisting of driving-cam assembly, a punch-block, and paper-moving mechanism.

Anvil Bracket (see Fig 11.133). This is secured to the keyboard casting beneath the perforating unit. The five selector bars are supported in slotted racks and one end of each bar is coupled, by means of a selector lever, to the appropriate keyboard combination-bar. The other end of each selector bar is located immediately below its corresponding message-hole punch. The bars move laterally under the control of the combination-bars and the amount of movement is just sufficient for them to be withdrawn from beneath the punches for spacing elements.

Perforating Driving-cam Assembly (see Fig. 11.134). This is secured to the keyboard casting and is driven from the motor, via an intermediate

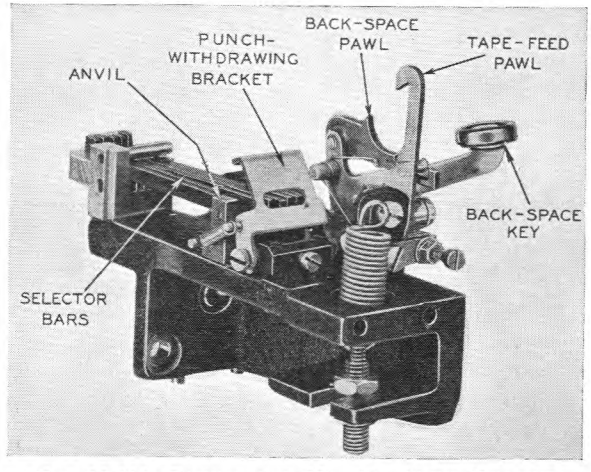


FIG. 11.133. PERFORATOR NO. 45: ANVIL BRACKET (REAR VIEW)
(*By courtesy of H.M. Postmaster-General*)

driving shaft. The assembly includes a clutch of the pawl-and-ratchet type, and two detents, spaced 180° apart, which limit the rotation of the cam-shaft to one half a revolution for each

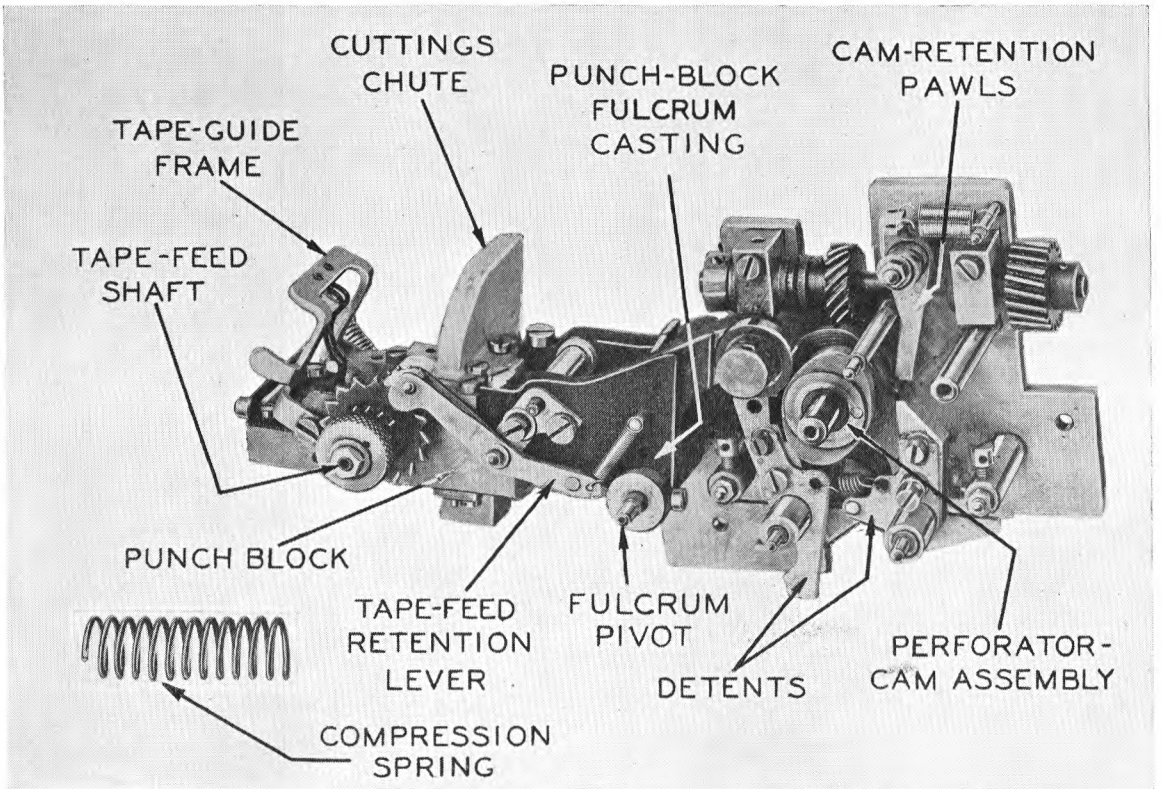


FIG. 11.134. PERFORATOR NO. 45: PERFORATOR DRIVING-CAM MECHANISM (FRONT VIEW)

(By courtesy of H.M. Postmaster-General)

operation. The detents are withdrawn to release the driving pawl by a perforator trip-bar, operated by the control unit. The cam-shaft carries a perforating cam, the two cam surfaces of which, in conjunction with two cam rollers on the punch-block-fulcrum casting, cause the punch-block to be moved first downwards, and then upwards, each time the perforator unit is tripped.

Punch-block (see Fig. 11.134). This includes six punches (five signal and one feed-hole) together with their associated die-plates and guide-plates. Normally, the punches are held below the level of the die-plates by the punch-withdrawing bracket, which engages in slots in the punches. The withdrawing bracket is pivoted on the anvil-bracket casting and is held in engagement with the punches by means of two springs. The punches are located directly above the left-hand end of the punch-selector bars which slide laterally (left for marking and right for spacing elements) between the punches and a small anvil-block.

During the downward movement of the punch-block, those signal punches associated with punch-selector bars which have not been withdrawn are forced through the paper. Those punches associated with selector bars that have been moved to the right by the action of the keyboard combination-bars will, however, enter the space which would have been occupied by the bars and will thus not perforate the paper. The feed-hole punch has no selector bar associated with it but, when the punch-block is lowered, the end of the punch is pushed against a raised portion of the anvil. The feed hole is, therefore, perforated automatically for each character.

Paper-moving Mechanism (not illustrated). This includes the following main parts—

(*a*) The tape-feed shaft, comprising a tape-feed wheel, feed ratchet, back-space ratchet and a retention wheel.

(*b*) An adjustable retention lever.

(*c*) A feed pawl and a back-space key.

The tape-feed shaft and retention lever are located on the punch-block assembly, while the feed pawl and back-space lever are pivoted on the anvil bracket. During operation, the feed ratchet is lowered past the tip of the feed pawl which enters the next tooth of the ratchet so that, during the succeeding upward movement of the punch-block, the tape-feed shaft is rotated and the paper moved forward $\frac{1}{10}$ in. in readiness for the next character. This movement is retained by means of the retention lever and ratchet.

Back-space Key. This is provided for the correction of punching errors. The key comprises a key lever and back-space pawl. On depression of the key, the pawl engages with a tooth on the back-space ratchet and moves the tape-feed shaft, and the paper, backwards through a distance equal to one tooth; at the same time, the shaped end of the pawl engages on a pin on the feed pawl and moves the latter out of engagement with the feed ratchet. For the correction of errors, the back-space key is depressed successively until the character combination containing the error is immediately above the punches. The letter-shift key is then depressed once for each character to be erased. Thus, any incorrect character (and all those subsequently perforated) can be changed to letter-shift combinations and errors will not appear on the printed copy when the tape is used for transmission.

Tape Roll Holder Unit (see Fig. 11.132). This is constructed in the form of a shallow box with a hinged lid. The lid serves as a message desk and the box contains the tape wheel and its associated brake arm. The lid, which is secured by a spring clip and hinged on the right-hand side, can be opened outwards to obtain access to the tape wheel.

The Teleprinter Automatic Transmitter

The standard machine used for many years by the British Post Office is designated the Automatic Transmitter No. 1B. It is manufactured by Creed & Co., Ltd. (Creed Model 6S) and is illustrated in Fig. 11.135. In 1954 an improved version of this transmitter was introduced, known as an Automatic Transmitter No. 2D, and this will be described later.

The Automatic Transmitter No. 1B consists of a main base on which are mounted—

(*a*) the driving motor and speed governor,

(*b*) the tape control unit which couples the driving motor to the transmitting head and provides a manual or automatic control of the transmission. The automatic control is provided so that if the feed of perforated tape into the transmitting head is held up for any reason, transmission is automatically stopped and the tape is not torn or mutilated.

(*c*) the transmitting head, which is provided with a sensing mechanism by means of which the perforations in the message tapes fed into the head are read and converted into teleprinter signals.

The complete machine weighs approximately 32 lb and has the following overall dimensions—

Height	8 in.
Length	15 in.
Width	8 in.

The telegraph signals transmitted to line by the automatic transmitter are $7\frac{1}{2}$ unit teleprinter signals,

the start signal of one unit length and the stop signal of one and a half unit length being automatically inserted by the transmitting mechanism. The speed of transmission can be varied, by adjustment of the speed of rotation of the motor, to either 49 or 50 bauds depending upon whether the transmission is to a Teleprinter No. 3 or 7.

The circuit connexions of the transmitter are shown in Fig. 11.136 which also indicates the arrangements made for radio interference suppression.

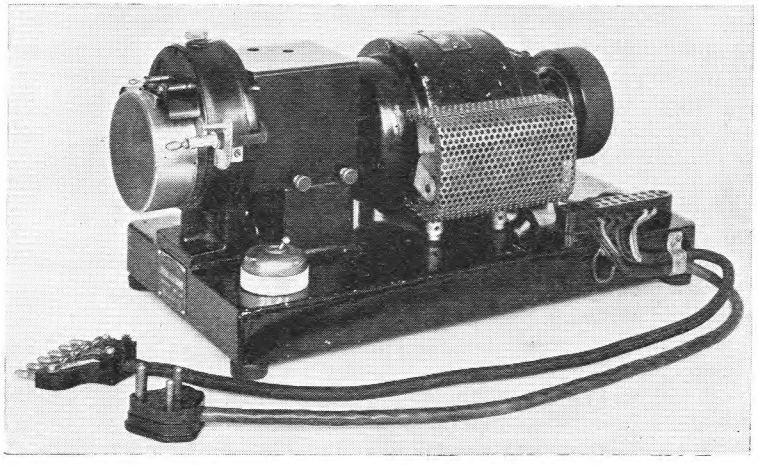


FIG. 11.135. AUTOMATIC TRANSMITTER NO. 1B
(By courtesy of H.M. Postmaster-General)

The driving motor, which is fitted with a centrifugal governor, is a d.c. shunt field motor similar to that used on the Teleprinter No. 3, and described on page 375, but as the load is less than that of a teleprinter it is wound to develop a lower torque. It has a rated output of $\frac{1}{28}$ h.p. (26·5 W) and is available in four voltage ranges, viz. 100–110 V, 150–170 V, 200–220 V, and 230–250 V.

The speed of the motor is maintained constant by a centrifugal governor of the type described on page 376, the speed being adjusted to 2,940 or 3,000 r.p.m. for 49 or 50 baud working respectively.

The Tape Control Mechanism. The tape control unit is mounted on the base between the motor and the transmitting head and comprises—

(*a*) the transmitting shaft clutch,

(*b*) the device for controlling the pawl abutment by the tension of the paper tape, and

(*c*) the send-receive switch.

The clutch mechanism is similar to the ratchet and pawl type of clutch used on the Teleprinters Nos. 3 and 7. A pinion on the motor shaft meshes with a fibre gear wheel on the ratchet shaft which revolves continuously whilst the motor is running. Surrounding the ratchet shaft is the clutch sleeve which carries the pawls. The pawls, under the pressure of their springs, tend to engage with the ratchet but, in the idle condition, the pawl abutment holds them out of engagement. A retention lever rests in a notch in the clutch sleeve when it is in its normal position.

The pawl abutment, when operated, is withdrawn from the pawls which are then allowed to engage with the teeth on the ratchet; thus the clutch sleeve and consequently the transmitting head is caused to rotate with the driving spindle. The pawl abutment is a lever which is pivoted at its centre and which has its movement limited by a pin which projects into a hole in the lever. At the end remote from the abutment face, the lever is provided with a knife edge having three inclined surfaces as shown in Fig. 11.137.

The movements of the pawl abutment are controlled by the tape control lever which consists of an inclined lever, pivoted at its left hand end, and a vertical lever which carries a jockey roller. One spring tends to pull the inclined lever down against a stop, whilst another spring acts on the vertical lever so that the jockey roller is held in engagement with the knife edge of the pawl abutment lever.

The transmitting head is declutched from the motor drive by lifting the inclined lever manually into its uppermost position. When this is done, the jockey roller rides on to the top inclined surface of the pawl abutment lever, the angle of which is such that it supports the lever against the tension of the springs. Thus the pawl abutment is turned clockwise and the pawls are withdrawn from engagement with the ratchet when they encounter the abutment face.

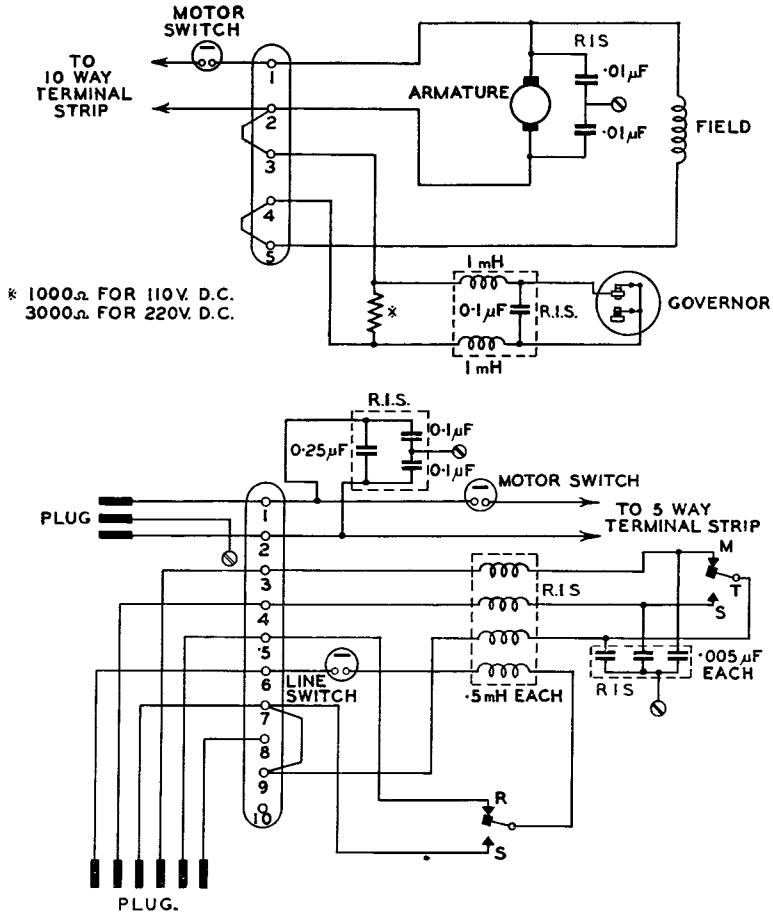


FIG. 11.136. AUTOMATIC TRANSMITTER NO. 1B: CIRCUIT CONNEXIONS

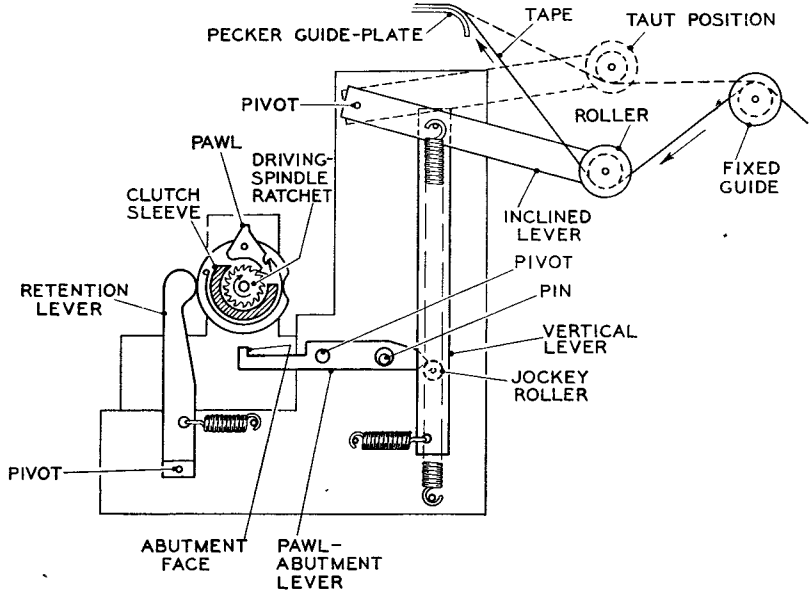


FIG. 11.137. AUTOMATIC TRANSMITTER NO. 1B: TAPE CONTROL UNIT

To begin transmission, the inclined lever is lowered by hand into its lowest position; this causes the jockey roller to bear on the lowest inclined surface of the pawl abutment lever, which is turned anti-clock wise thus leaving the pawls free to engage with the ratchet.

Whilst the transmitting head is being driven, i.e. transmission is in progress, the paper tape is pulled through the head and therefore it is necessary to arrange that, if the flow of tape to the head is checked for any reason, the head is declutched to prevent mutilation of the tape. Before passing through the transmitting head, the tape is fed over the fixed guide and then under a roller on the inclined lever, see Fig. 11.137. If the flow of tape is checked, the loop of tape in which the roller on the inclined lever rests is drawn tight and the roller is raised sufficiently to bring the jockey roller on to the middle inclined surface of the pawl abutment lever and the transmitting head is declutched. Should the tape become slack, the inclined lever is allowed to fall under the influence of its spring and the transmitting head is again operated.

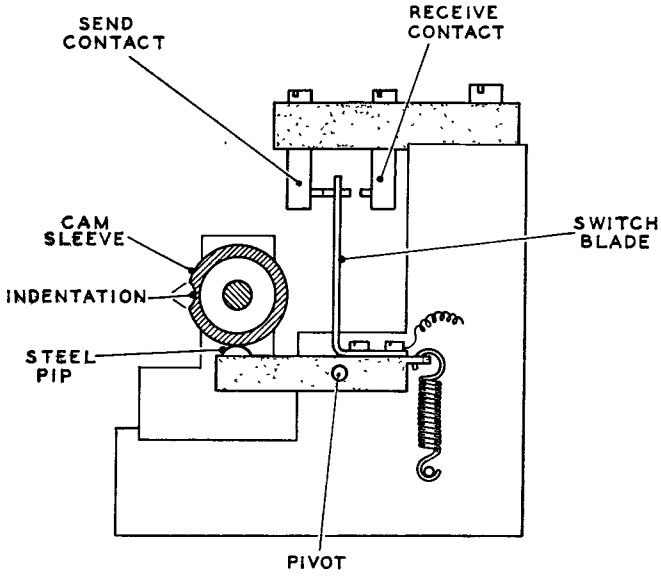


FIG. 11.138. AUTOMATIC TRANSMITTER NO. 1B: SEND AND RECEIVE SWITCH

A send-receive switch is fitted to enable the line to be connected to a receiving apparatus when the transmitter is at rest. The arrangement is illustrated in Fig. 11.138. When the transmitter is at rest the button on the end of the insulating bar rests in an indentation in the clutch sleeve and the switch blade rests against the receive contact; immediately the transmitting head is clutched to the motor for transmission to commence, the clutch sleeve rotates and the button rides out of the indentation causing the switch blade to change over to the send contact.

The Transmitting Head. The transmitting head comprises the mechanism for—

(*a*) Exploring the paper tape for perforations.

(*b*) Translating the perforations into electrical impulses corresponding to the code elements, the start and stop signals being automatically inserted.

(*c*) Feeding the paper tape forward so that each signal combination is transmitted in turn.

The transmitting head is mounted in the vertical circular casting seen on the left of Fig. 11.135 and a schematic of the assembly is shown in Fig. 11.139. The transmitting cam spindle is provided with a boss which fits into the open end of the clutch sleeve on the tape control unit and a stud on the boss engages with a slot in the sleeve thus providing a drive for the transmitting mechanism.

After passing over the rollers in the tape control unit, the perforated paper tape is inserted between the tape retaining plate and the pecker guide plate so that the centre feed holes engage with the sprockets on the tape feed wheel. The gearing of the tape feed is such that the tape is advanced the distance between two consecutive feed holes ($\frac{1}{10}$ in.) for each revolution of the cam. The tape feed is normally set up to accept centre line feed hole perforated tape but can be adjusted for advanced feed hole working.

The tape-retaining plate and pecker guide plate are each slotted to accommodate the tape feed wheel and provided with five holes for the pecker levers. Since the peckers rise successively and the tape moves uniformly, it is necessary to stagger the pecker holes across the plates, see Fig. 11.140. In addition, as each pecker rises it follows the tape, whether it passes into a perforation or not, and consequently the holes in the plates are elongated.

Fig. 11.141 illustrates a special type of tape retaining plate used when the automatic transmitter is required to work from chadless type perforated tape; a tape retaining plate of the normal type is also illustrated for comparison. It will be seen that the retaining plate for chadless working is made in the form of a grid which enables the hinged discs to be allowed to rise as the peckers sense the paper. This type of retaining plate can be used also with fully perforated tape. The plate is fixed to the same pivot on the transmitter head as the older type of retaining plate and carries an adjustable

guide plate which guides the paper on to the tape-feed star wheel. It is held down by a catch which engages with a pin on the cover plate.

in place of grooves with recesses and the shape of the levers is altered accordingly, see Fig. 11.142. The cam tracks are arranged so that the levers, if

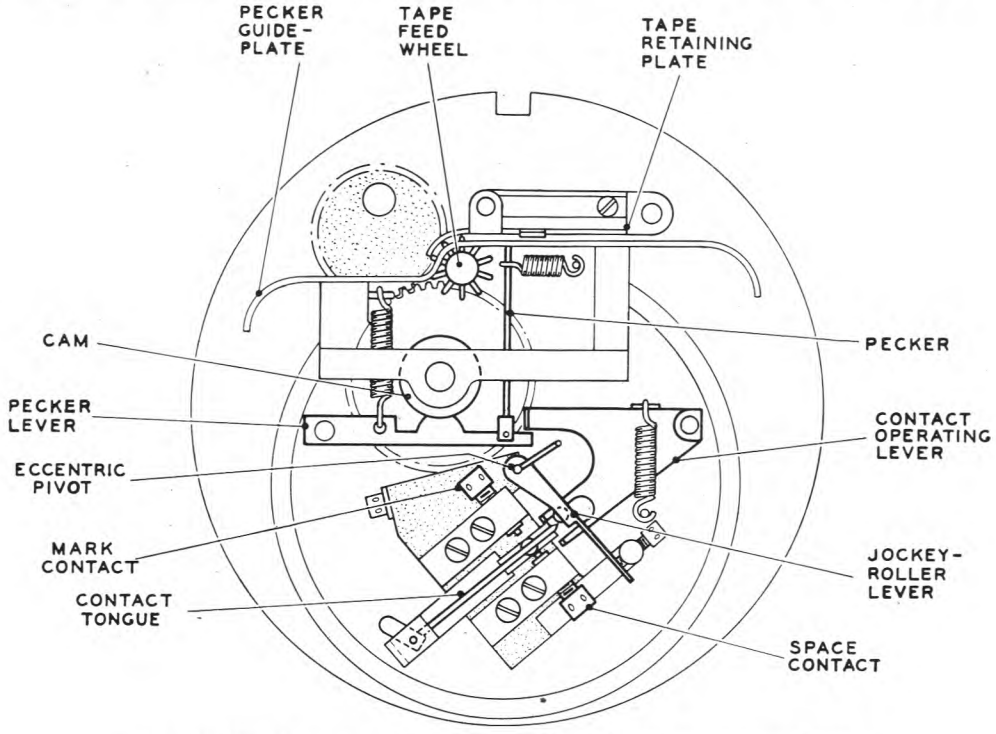


FIG. 11.139. AUTOMATIC TRANSMITTER NO. 1B: TRANSMITTING HEAD

The transmitting cam has six tracks cut into its surface; five of these accommodate the pecker levers and the start-stop lever rides in the sixth. On earlier models, each track consists of a groove with a portion of its base cut away so that when the cam is rotated the lever associated with the track will be drawn up into the recess under the tension

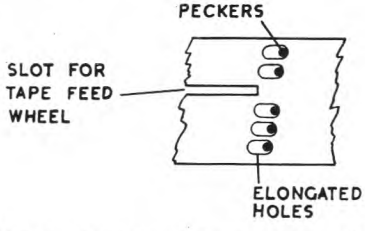


FIG. 11.140. AUTOMATIC TRANSMITTER NO. 1B: PECKER HOLES IN TAPE RETAINING PLATE

of its spring. Each of the pecker levers is provided with a hump, see Fig. 11.139. On later models a different arrangement is adopted in order to improve the signal output shape; the cam has flats

otherwise free to do so, are allowed to rise successively, and at the correct instants (20 msec intervals).

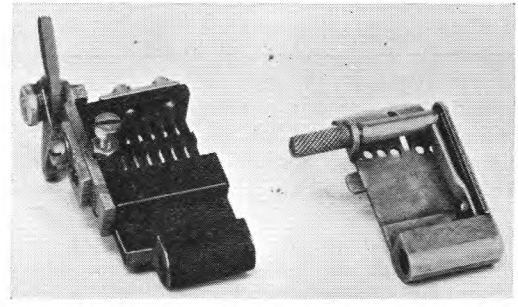


FIG. 11.141. AUTOMATIC TRANSMITTER NO. 1B: TAPE RETAINING PLATES

(By courtesy of H.M. Postmaster-General)

The five pecker levers, which are pivoted at their left-hand ends, lie under the cam and are held against their tracks by the upward pull of springs. At a short distance from the right-hand end of each

lever a pecker is pivoted, whilst the extreme right-hand end projects under an arm of the contact operating lever. Thus upward movement of the pecker levers is communicated to the contact operating lever.

The peckers are thin rods whose purpose is to sense the paper tape for perforations. The sensing is carried out by each pecker in turn as its associated lever is allowed to rise by the cam.

The start-stop lever is similar to the pecker levers

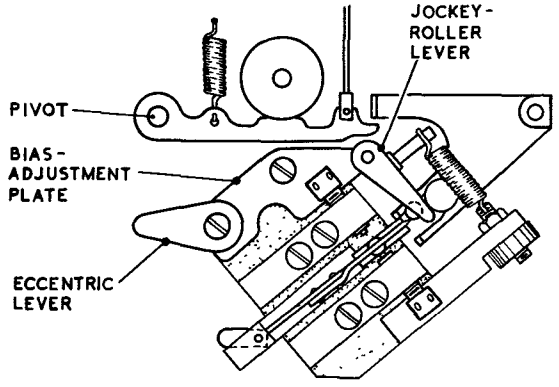


FIG. 11.142. AUTOMATIC TRANSMITTER NO. 1B: MARK II CONTACT BLOCK

except that it has no associated pecker; consequently it is free to rise once per revolution of the cam. It is situated between the third and fourth pecker levers, i.e. vertically under the train of feed holes in the tape. When the cam is at rest, i.e. the transmitting head is declutched from the drive, the start-stop lever is in its raised position.

The contact operating lever is pivoted at one end and has two arms one of which is forked and embraces the contact tongue and the other of which is engaged by the pecker levers and the start-stop lever as they rise. When it is not engaged by any raised lever, a spring turns it in an anti-clock wise direction and the contact tongue is held against the lower, spacing, contact. However, in the rest position of the cam, the start-stop lever is raised and the contact operating lever is moved clock wise so that the contact tongue is held on the upper, marking, contact.

The contact tongue and contact screws are similar to those used on the teleprinter. An adjustable jockey roller assembly is provided; it may be of the type shown in Fig. 11.139 or of the improved design shown in Fig. 11.142.

Operation. Before starting a transmission it should be checked that the inclined lever of the tape control unit is in its raised position. The motor should then be switched on and allowed to attain its full running speed. The paper tape should be threaded through the transmitting head and the transmission commenced by lowering the inclined lever by hand. The jockey roller on the vertical lever is transferred to the lowest inclined surface of the pawl abutment lever and the transmitting head is clutched to the motor drive.

Transmission takes place as follows—

(*a*) In the normal position of the transmitting cam the start-stop lever is raised and the contact operating lever is thus held at the limit of its clockwise position. The contact tongue is held against the marking contact.

(*b*) As the cam rotates the start-stop lever is lowered, the contact operating lever moves anti-clockwise under the tension of its spring and the contact tongue is moved over to the spacing contact, thus transmitting the start signal.

(*c*) As the cam continues to rotate, the first pecker lever, i.e. that nearest to the rear of the instrument, is allowed to rise under the influence of its spring and

(i) if there is a perforation in the tape over the associated pecker, it will rise fully and pass through the tape. The contact operating lever will be moved clock wise and the contact tongue will be moved to the marking contact.

(ii) if there is not a perforation in the tape over the associated pecker, its upward movement will be stopped by the paper tape. Hence, the pecker lever will not move the contact operating lever and the contact tongue will remain on the spacing contact.

(*d*) As the cam continues to rotate, pecker No. 1 is withdrawn from the tape and peckers Nos. 2 to 5 are presented to the tape in turn. The contact tongue will be operated between the contacts according to the perforations in the paper tape.

(*e*) After pecker No. 5 has been withdrawn from the tape, the start-stop lever is allowed to rise and consequently the contact operating lever moves or holds the contact tongue to the marking contact thus transmitting the stop signal. The tongue will remain on the marking contact until the start-stop lever moves to begin the start element of the next signal combination.

During recent years an improved model of the automatic transmitter has been introduced into service by the British Post Office known as the Automatic Transmitter No. 2D. It is manufactured by Creed & Co., Ltd. (model 6S/5) and is illustrated in Fig. 11.143 (*a*).

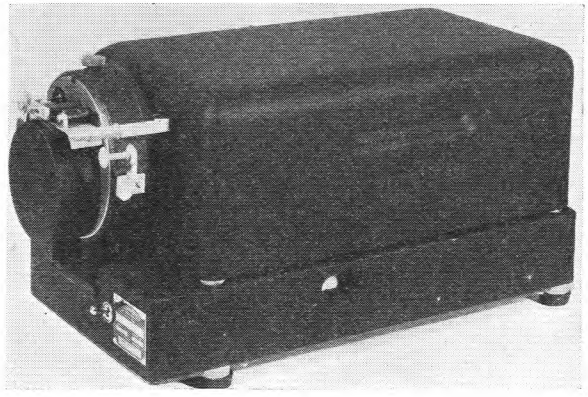
The main improvements over the Automatic Transmitter No. 1B are—

(*a*) The timing of the transmitting tongue is controlled by a striker-type mechanism which is

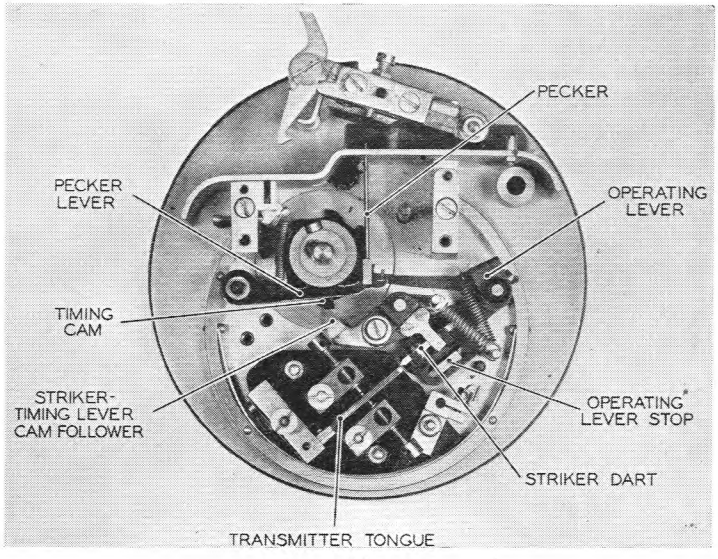
similar in principle to that employed on Teleprinters No. 7. Fig. 11.143 (*b*) shows the principal features of the transmitter head and a number of parts have been removed to give a better view of the mechanism.

These alterations result in a considerable improvement in signal accuracy and a much lower noise level when the machine is running.

Circuit modifications, mainly to the radio interference suppression units and motor governing circuit, have also been introduced and the base redesigned to house all subsidiary electrical components.



(*a*)



(*b*)

FIG. 11.143. AUTOMATIC TRANSMITTER NO. 2D

(*b*) The perforated tape is fed step-by-step instead of continuously.

(*c*) It is provided with a resiliently mounted dust cover which completely encloses the working parts with the exception of the transmitting head.

(*d*) A new design of motor with a governed speed of 1,500 r.p.m. is used.

The Teleprinter Reperforator

The standard machine used by the B.P.O. is designated the Reperforator No. 2. It is manufactured by Creed & Co., Ltd. (Creed Model No. 7 TR) and is

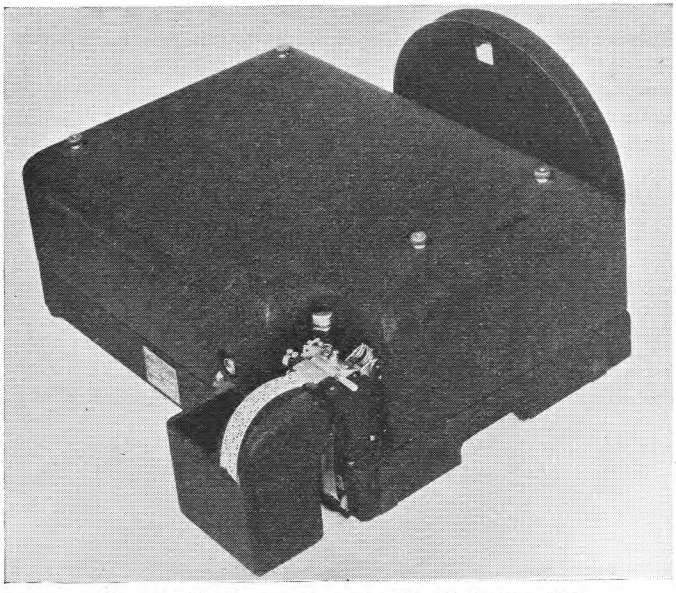


FIG. 11.144. REPERFORATOR NO. 2: COVER ON
(*By courtesy of H.M. Postmaster-General*)

illustrated in Figs 11.144 and 11.145. It consists of a main base on which are mounted the following units—

(*a*) Driving motor
(*b*) Receiving Electromagnet
(*c*) Selecting Mechanism
(*d*) Perforating Head
(*e*) Tape Roll Holder and
(*f*) Automatic Start-Stop switch.

The complete machine weighs 35 lb and has the following overall dimensions—

Height	$10\frac{1}{2}$ in.
Length	17 in.
Width	$15\frac{1}{2}$ in.

The receiving mechanism is arranged so that either 7 or $7\frac{1}{2}$ unit teleprinter signals can be received and translated correctly into equivalent perforations on a paper tape.

The circuit connexions of the reperforator are shown in Fig. 11.146 which also indicates the arrangements made for radio interference suppression.

The driving motor is a d.c. series wound motor similar to that used on the Teleprinter No. 7B and described on page 374, but its direction of rotation is reversed. It has a rated output of $\frac{1}{25}$ h.p. (30 W) and is suitable for use on voltages within the ranges 90–120 V and 150–265 V; an adjustable field tapping is provided for connexion according to the voltage range available.

The speed of the motor is maintained constant by a centrifugal governor of the type described on page 376, the speed being held sensibly constant at 3,000 r.p.m.

Receiving and Selecting Mechanism (see Fig. 11.147). The electromagnet is identical with that used on the Teleprinter No. 7B and described on page 390. The electromagnet armature is coupled, by a link, to the trip shaft. Consequently movements of the armature, in response to incoming signals, cause the trip shaft to be turned and the hammer-setting blade to take up one of two positions; it is raised for marking elements and deflected downwards for spacing elements.

The selecting mechanism is similar in general principles to that of the Teleprinter No. 7B except that, instead of setting five comb setting fingers, it positions five perforating hammers, each of which is associated with a punch, so that the paper is perforated in accordance with the signal combination received.

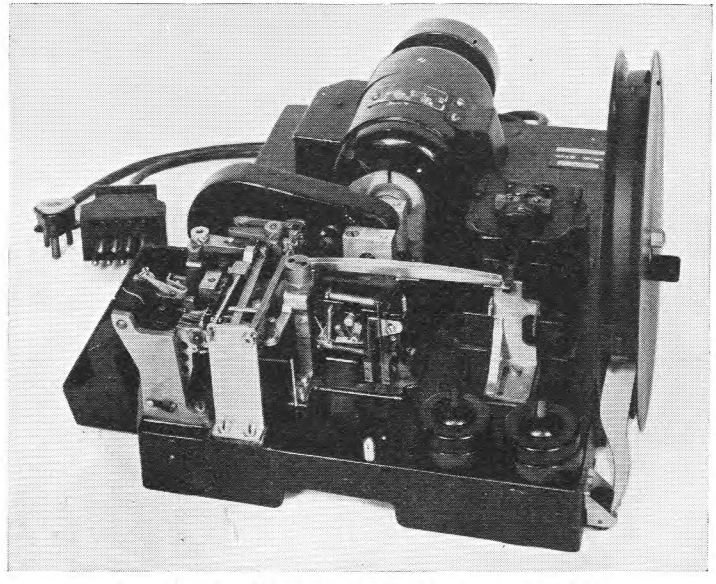


FIG. 11.145. REPERFORATOR NO. 2: COVER OFF
(*By courtesy of H.M. Postmaster-General*)

Rotation of the cam sleeve is dependent upon a ratchet and pawl clutch, similar to that used on the Teleprinter No. 7B, which is controlled by the pawl abutment, which, in turn, responds to the

movement of the trip shaft. The rotation of the cam sleeve is commenced by receipt of the start signal; the sleeve makes one complete revolution and is arrested during the stop signal (i.e. after 130 msec) by the pawl abutment which is set in the path of

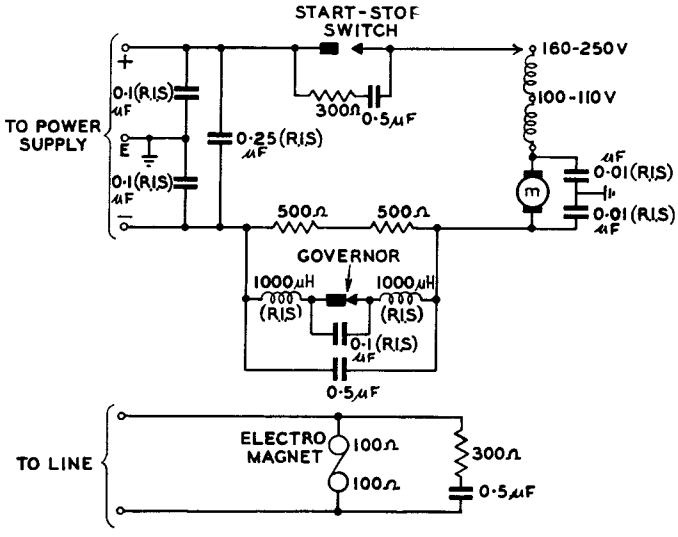


FIG. 11.146. REPERFORATOR NO. 2: CIRCUIT CONNEXIONS

and moves it towards the hammer-setting pin five times during each revolution of the cam sleeve. These movements occur when the pin is central with each hammer in turn and are timed so that they coincide with the centre portion of each code element of an undistorted signal combination. Thus for marking elements, the blade, in its raised position, strikes the pin and moves it towards the hammer, whilst for spacing elements the blade is tilted downwards and passes below the pin which is not moved. The pin, as it encounters the hammer during marking elements, causes the hammer to rotate anti-clockwise so that its horizontal projection is brought opposite the associated punch.

Track No. 2 operates the hammer resetting lever. It is arranged so that the resetting lever is operated during the reception of the start signal and engages the lower projections of those hammers which are in the marking position due to the selection for the preceding character combination. Thus the hammers are restored to normal in readiness for the setting up of the combination for the new character.

Track No. 3 operates the traversing lever which is

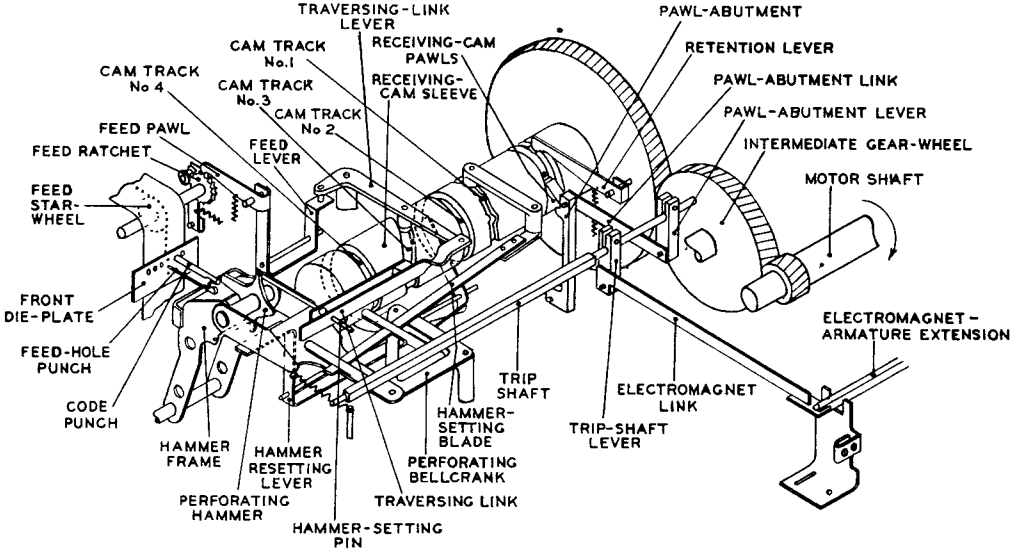


FIG. 11.147. REPERFORATOR NO. 2: RECEIVING AND SELECTING MECHANISM

the pawls by the electromagnet armature being on the marking stop.

The cam sleeve has four tracks which control the selecting operations in the following manner—

Track No. 1 operates the hammer-setting blade coupled to the traversing link and paper feed lever. The traversing lever makes one cycle of movement for each revolution of the cam sleeve, during which the hammer-setting pin carried by the traversing link is moved across the hammers in the following

sequence—from hammer No. 3 to hammer No. 1 during reception of the start element, from hammer No. 1 to hammer No. 5 during reception of the code elements, and then back to hammer No. 3 during reception of the stop element.

The reciprocating movement of the traversing lever operates the feed lever and causes the feed pawl to move forward one tooth on the ratchet and then move backwards; the paper is fed forward $\frac{1}{10}$ in. on the return movement of the pawl.

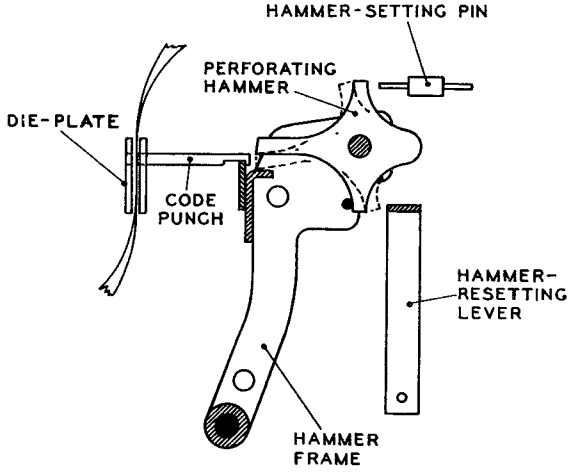


FIG. 11.148. REPERFORATOR NO. 2: PUNCH BLOCK

Track No. 4 operates the punching lever and therefore the punching hammer frame once per revolution of the cam sleeve. This occurs immediately after the setting of the hammers is completed and causes the frame to be moved forward so that those hammers, which have been set to the marking position, push the corresponding punches forward and force them through the paper tape. The feed hole punch is also operated direct from the hammer frame for each combination. The hammer frame is then returned to its normal position and, as this occurs, a projection on the frame engages with slots in the operated punches and withdraws them from the tape.

The perforating head comprises a casting on which the punches, die plates, paper feed mechanism and the punching hammer frame are assembled. The punches are supported in guide plates behind one of which is clamped a set of three die plates into which the punches penetrate after passing through the paper.

The punching hammer frame is pivoted at its lower end and the five punching hammers together with their damping spring assemblies are positioned on a spindle fixed at the top of the frame, see Fig. 11.148. Each hammer is associated with a code hole punch but the feed hole punch, which is required to be operated for each character, has no associated hammer and is operated directly by the frame.

The paper feed mechanism consists of the paper feed wheel which engages with the centre feed holes in the paper and the feed ratchet which is operated upon by the feed pawl and is provided with a retention roller. Located over the paper feed wheel is a hinged paper retaining plate.

The tape roll holder is mounted vertically on the right-hand side of the machine, see Fig. 11.145, which also shows how the paper tape is fed to the perforating head by passing it underneath the base of the machine.

The automatic start-stop switch is shown in Figs. 11.149 and 11.150; it automatically starts the motor on receipt of the first signal combination and again stops it if no signals are received during a period of approximately 30 seconds. Whilst the motor is running, the starter worm wheel is rotating continuously in an anti-clockwise direction. Providing the electromagnet armature is on the marking side, the pin on the contact operating block is forced into engagement with one of the slots in the wheel under the pressure of the control spring. Thus, if no signals are received and the electromagnet armature remains on the marking side, the end of the slot will engage the pin and cause the block also to be rotated. When the block meets and depresses the contact detent, the contacts are allowed to open under the action of their controlling springs, the motor circuit is disconnected and the motor stops.

When the electromagnet armature moves to the spacing side for the first start signal of the next train of signals, it operates the trip bell-crank which strikes the trip boss, so sliding the trip spindle axially. This causes the pin of the contact operating block to be withdrawn from the slot in the worm wheel and the block is returned clockwise, under the action of the trip spindle control spring, until it meets the ramp on the inner contact arm and operates the contacts which complete the motor circuit.

A trip lever, operated from track No. 3 of the receiving cam sleeve, is provided. It is operated once each revolution of the cam sleeve and strikes the trip boss thus preventing the pin from engaging in the slot of the worm wheel whilst signals are being received. In addition, in order to avoid unnecessary load on the trip bell-crank, and therefore the electromagnet, a portion of the trip boss is cut away so that, during reception of signals, the bell-crank does not strike against the boss which is in its

normal position with the cut away portion opposite the trip bell-crank.

The Printing Reperforator

The standard machines used by the B.P.O. are designated the Printing Reperforators Nos. 1 and 2 (Creed Models 85 and 85R) and are ingenious adaptations of the Teleprinter No. 7. Model No. 1, illustrated in Figs. 11.151 and 11.152, is equipped for transmitting and receiving whilst Model No. 2 is for receiving only and therefore is not fitted with a keyboard or a transmitting unit.

The machines, complete with dust cover, weigh 60 lb and 50 lb respectively and have the following dimensions—

	No. 1	No. 2
Height . . .	13 in.	10 in.
Length . . .	23 in.	23 in.
Width . . .	22 in.	15 in.

The machines are designed to prepare a chadless perforated tape in accordance with the five-unit code of incoming teleprinter signals and to print the received message on the same tape, as described on page 459. The design of the printing and perforating mechanisms is such that a printed character is displaced eight centre holes to the right, i.e. in retard from its corresponding perforations, and due regard has to be given to this when cutting the message tape.

The receiving and selecting mechanisms of the printing reperforators are of the standard teleprinter type with an orientation facility except that a special design of feed lever is provided to link up with the perforating unit which is used in place of the page printing attachment of the teleprinter.

The combination head unit, besides performing the normal teleprinter functions, also serves to accommodate a part of the special mechanisms necessary to transfer the code combination to the perforating unit.

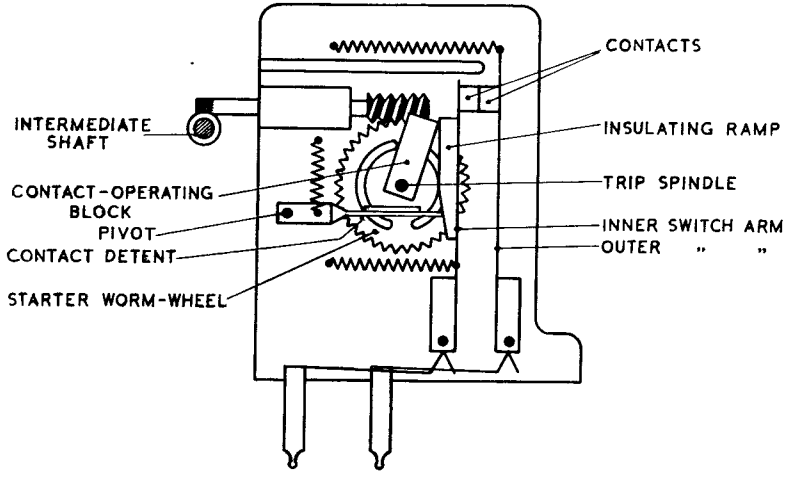


FIG. 11.149. REPERFORATOR NO. 2: AUTOMATIC START-STOP SWITCH

The remainder of the transfer mechanism is accommodated on a specially designed control lever unit which also acts as a mounting for the perforating unit. A tape roll holder is provided to accommodate a roll of parchmentized paper tape.

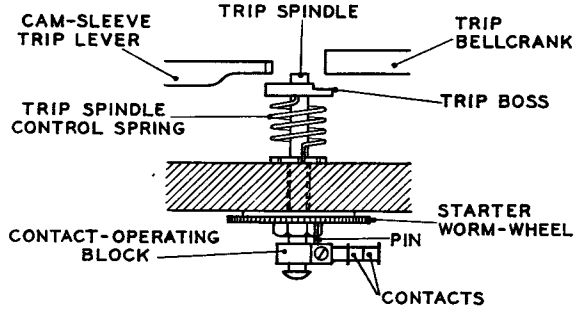


FIG. 11.150. REPERFORATOR NO. 2: AUTOMATIC START-STOP SWITCH

The type-head carries five special types for functional signals; these are illustrated in Fig. 11.153. Thus a character is printed on the tape for all perforated codes except that for the letter space combination.

When the printing reperforator is equipped for transmission, the standard Teleprinter No. 7 type keyboard and transmitting units are used. In addition, since the machine prints on a tape, it is

necessary to fit a letter counting device, so that, when transmitting to a page printing teleprinter, the operator is made aware when the end of line is approaching. The standard letter counting and warning lamp units, described on page 410 are fitted to the keyboard unit.

During reception of signals the selection on to the combination head unit and the printing of the character are performed in the manner already described for the Teleprinter No. 7, whilst the operations concerned in the perforating and feeding of the paper tape are described below.

During one revolution of the receiving cam sleeve, the operations concerned with perforating and feeding the tape occur as follows—

(*a*) whilst the selection of the received combination is taking place, i.e. during the forward travel of the traversing link, the paper tape is perforated in accordance with the selection set up for the preceding character combination received,

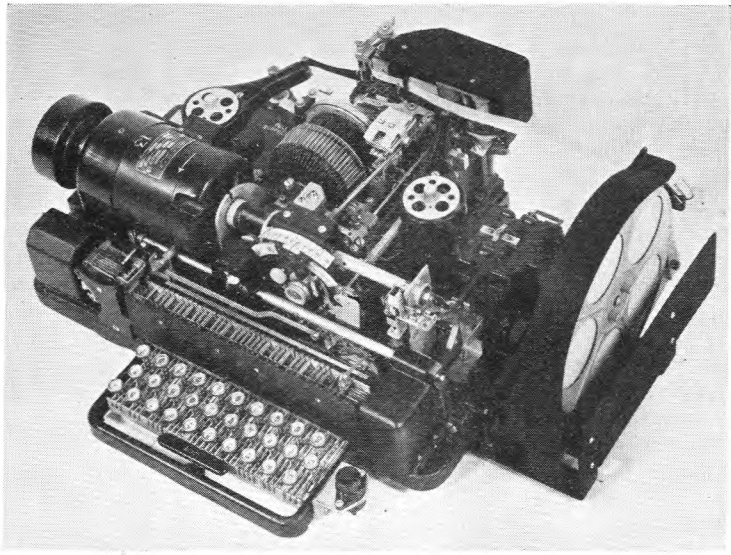


FIG. 11.151. PRINTING REPERFORATOR: FRONT VIEW
(*By courtesy of H.M. Postmaster-General*)

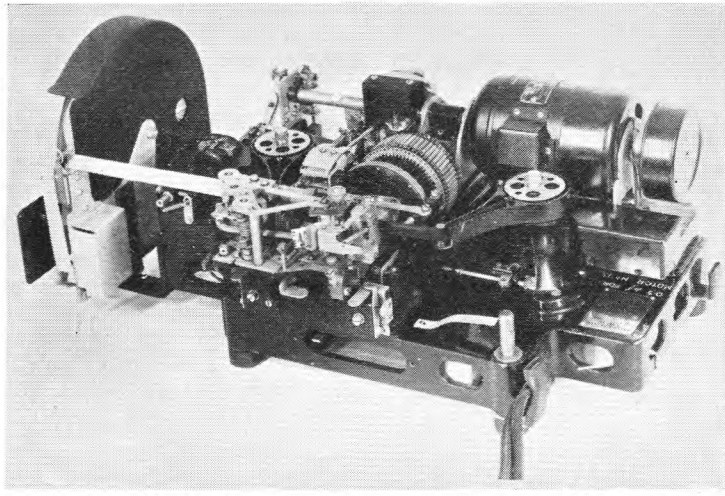


FIG. 11.152. PRINTING REPERFORATOR: REAR VIEW
(*By courtesy of H.M. Postmaster-General*)

(*b*) with the operation of the comb setting lever, the new selection is set up on the combination head and, at the same time, is transferred to the perforating unit, and

(*c*) during the stop signal the paper tape is fed forward.

The code selection is transferred to the perforating unit by means of a series of levers and push rods which can be seen in Fig. 11.154 and which are illustrated schematically in Fig. 11.155. Referring to Fig. 11.155, it will be seen that the five comb extensions, on the combination head, are shaped to provide locating points for the lower ends of five transfer push rods No. 1, the upper ends of which engage with five transfer rockers which are pivoted on a common bearing. The upper ends of five transfer push rods No. 2 engage the other sides of the transfer rockers and their lower ends engage with five setting bell-cranks.

With each setting bell-crank is associated a setting arm, both being pivoted on the same pivot and held in engagement with each other by means of a spring. Each setting bell-crank also has a restoring spring. The setting arms engage with five punching bars which can be seen in Fig. 11.154. These bars lie lengthwise between the punch block and the punching cam assembly and are arranged vertically one above the other. One end of each bar engages with a code hole punch and the other end is free to be moved into the path of a punching lever by its associated setting arm, see Fig. 11.156.

A marking element in the received combination results in the relative comb extension, on the combination head, being lifted by its associated comb setting finger. Consequently the punching bar is moved into the path of its punching lever via the feed hole punch, lies between the second and third code hole punching bars, see Fig. 11.154. A feed hole is punched for each character and therefore

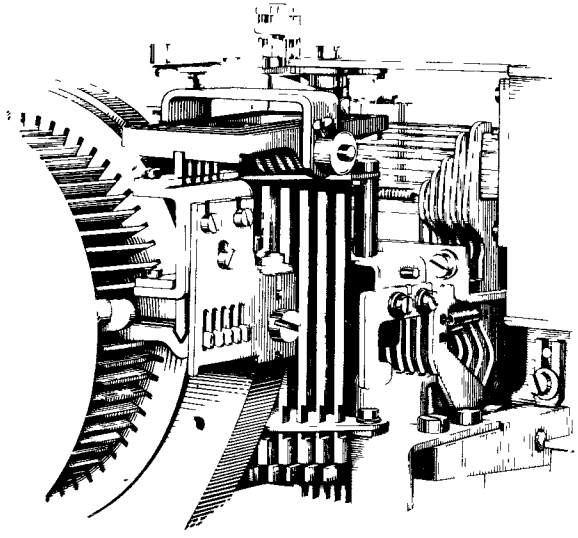


FIG. 11.154. PRINTING REPERFORATOR: PERFORATING HEAD

the feed hole punching bar is always held in the path of its associated punching lever.

Associated with each punching bar is a punching lever and punching cam, see Fig. 11.156. Each punching cam has six noses and is rotated through

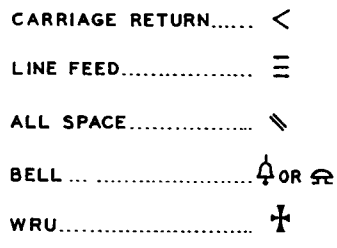


FIG. 11.153. PRINTING REPERFORATOR: SPECIAL TYPES

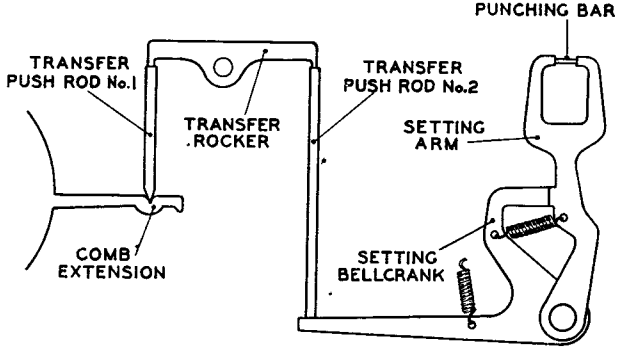


FIG. 11.155. PRINTING REPERFORATOR: TRANSFER PUSH RODS

agency of a push rod No. 1, transfer rocker, push rod No. 2, setting bell-crank and setting arm. For a spacing element, the comb extension is not lifted and the setting bell-crank due to the tension of its spring, positions the setting arm so that the punching bar is held out of the path of its punching lever.

A sixth punching bar, which engages with the one-sixth of a revolution for each character received. If a punching bar is in the operated, or mark, position, see Fig. 11.156, the punching lever as it is operated by the nose of the cam, moves the bar and thereby causes the punch to penetrate the paper and enter the die plate. If the punching bar is in the space position—shown dotted in Fig.

11.156—the punching lever will not engage with it and no perforation of the paper will be made.

The six punching cams are arranged on the cam shaft so that they operate the punching levers in sequence, thereby reducing the instantaneous load on the motor. The arrangement can be seen in Fig. 11.157.

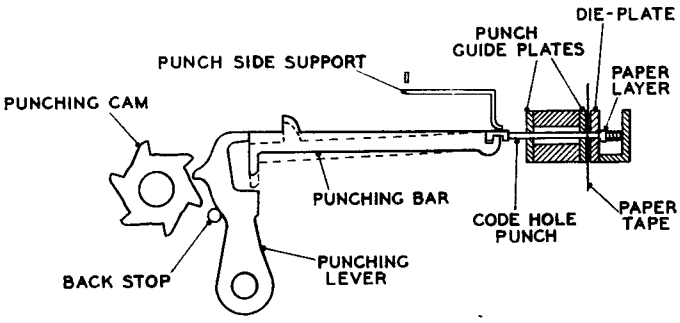


Fig. 11.156. Printing Reperforator: Punching Mechanism

The actuation of the punching cams is obtained from the receiving cam unit of the machine via the feed lever. When the traversing link moves forward along the comb setting fingers during selection, the feed lever, coupled to its end, swings the feed arm of the perforating unit in the direction shown by the arrow in Fig. 11.158. Consequently the cam feed sector rotates through an arc and causes the cam feed pinion to drive the cam feed pawl which is engaged with the feed ratchet. The ratchet has six teeth and is situated on the cam shaft below the punching cams which are therefore rotated through one-sixth of a revolution for every full stroke of the feed arm. A cam retention pawl, spring loaded against the ratchet, holds it in position when the feed pawl is withdrawn and dropped into the adjacent tooth, during the reverse stroke of the feed arm.

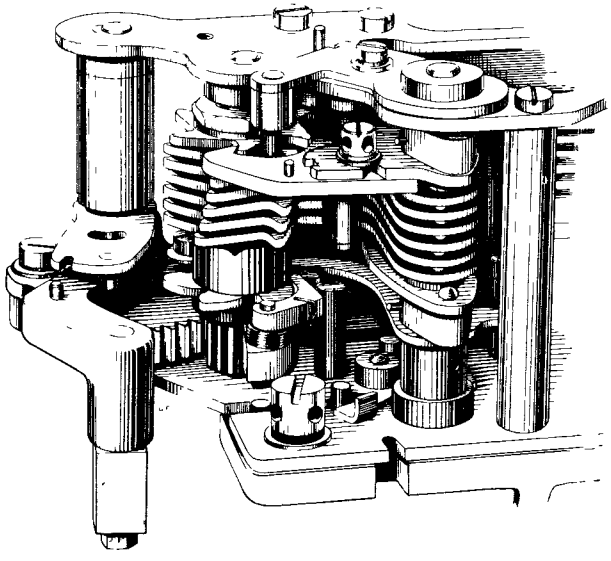


Fig. 11.157. Printing Reperforator: Punching Cams

The five code hole punches and the feed punch are carried by two punch guide plates secured to the punch mounting block. The punches are of circular cross-section, chadless perforation being obtained from the specially shaped die plate which is illustrated in Fig. 11.159. It will be seen that the plate is cut away along one side so that the cutting edges of the die plate holes are discontinuous, thereby providing incomplete perforation of the holes in the paper tape.

When the punches enter the die plate, they push against and depress the paper layers, see Figs. 11.156 and 11.159, which are spring loaded so that they normally lie flush with the surface of the die plate. Their function is to lay the paper lids (chads) back into the plane of the paper, when the punches are withdrawn, so that the paper lids are not torn by the die plate when the paper tape is fed forward.

The punches are withdrawn from the die plate by means of the reset cam which is arranged to come into action towards the end of the cam feed and approximately coincides with the printing operation of the machine. From Fig. 11.160, it will be seen that the cam, shown in the reset position, operates the resetting lever which engages both with the six punching levers and the six punching bars and restores them ready for the next selecting operation.

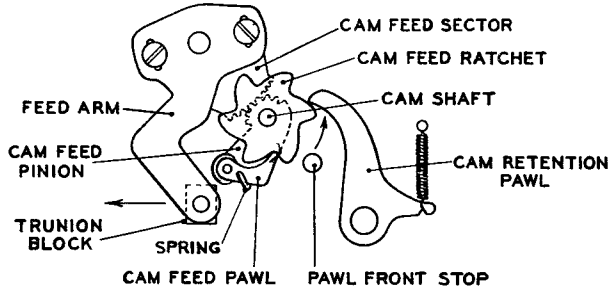


Fig. 11.158. Printing Reperforator: Feed Mechanism

The paper tape lies in front of the platen and die plate and passes between the tape feed roller and pressure roller as shown in Fig. 11.161. (*Note.* In

later models two pressure rollers are employed). These two rollers are knurled and the feed roller is rotated by a ratchet and pawl coupled to the feed

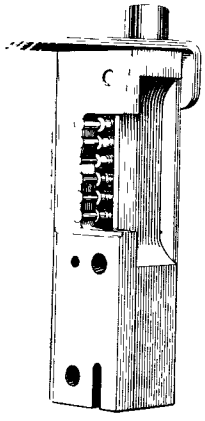


FIG. 11.159. PRINTING REPERFORATOR: PUNCH BLOCK

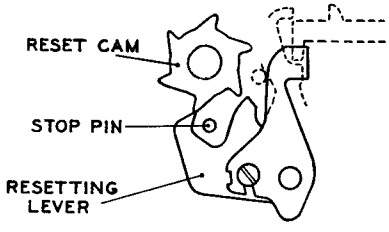


FIG. 11.160. PRINTING REPERFORATOR: RESETTING MECHANISM

arm. The pressure roller is spring loaded against the feed roller and thus gives a friction feed for the tape. The feed holes are not used to feed the tape from the machine and this feature enables the tape to be pulled through the perforating unit by hand when the end of a message has not been fed past the tape knife. The pressure roller can be latched away from the feed roller to facilitate insertion of the paper tape. The feed roller is accurately positioned after each feeding operation, by a jockey roller which engages with the teeth of a wheel on the tape feed spindle. Having passed between the rollers the tape is guided from the unit by a combined guide and tape knife.

A general view of the punch block and feed rollers is given in Fig. 11.162 whilst Fig. 11.163 shows the position of the platen on the perforating unit.

A tape roll holder is mounted vertically at the side of the machine, see Figs. 11.151 and 11.152 and consists of a mounting plate carrying the tape wheel, a guide for changing the direction of the tape when fed from the reel into the perforating unit and a tape exhaustion alarm mechanism for giving a warning when the roll of tape is becoming exhausted. The roll holder is illustrated in Fig. 11.164.

The tape exhaustion alarm mechanism consists of a follower arm having a roller which rests upon the roll of paper tape. When the paper tape has been used so that the diameter of the roll has decreased to a predetermined dimension, the follower arm causes the trip of a spring loaded lever which operates a pair of contacts to which an alarm circuit is connected. The trip mechanism is automatically reset when the follower arm is lifted by the insertion of a new roll of paper tape.

Creed & Co. have developed another model of the printing reperforator, designated the No. 86 and the No. 86R for the sending and receiving models respectively. These are basically the same as the machines described, but use a wider tape, $\frac{7}{8}$ in. wide. The code and feed holes are fully perforated, instead of being chadless, and the printing appears along the margin of the tape, below the fifth row of code holes. Automatic transmitters are available which can accept the wider tape.

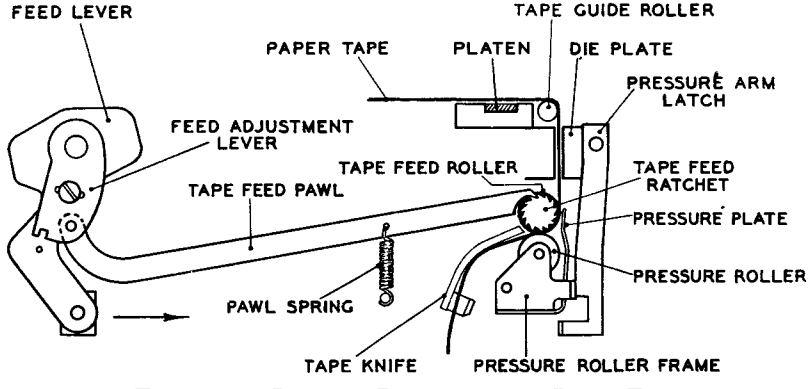


FIG. 11.161. PRINTING REPERFORATOR: PAPER FEED

Teleprinter No. 7B/RP

This machine was developed by Creed & Co., Ltd., so that a teleprinter could be employed occasionally as a perforator or, if desired, to perforate a copy of a message being transmitted or received on one circuit for retransmission on another circuit or circuits. The machine is particularly useful if a tabulated message has to be perforated since a local printed record on a page is obtained, thus facilitating the tabulating operations. It is fitted with a perforating unit which is remotely operated by means of control wires from the combination head and gives the following facilities—

(*a*) Preparation of a perforated tape with a local printed record of the perforated messages.

(*b*) Manual (keyboard) transmission with a printed record of the message, i.e. normal Teleprinter No. 7 facility.

(*c*) Manual (keyboard) transmission to line with a printed record of the message, and, in addition, a perforated tape in accordance with the transmitted message.

(*d*) Simultaneous production of a printed record and a perforated tape from received line signals.

The machine is shown in Fig. 11.165 and apart from the special keyboard unit with perforating attachment and control wires, it uses standard Teleprinter No. 7 mechanisms. The perforating facility is switched on or off by means of a mechanical switch.

The signalling connexions for the machine are made by means of a 9-way plug and cord and the power connexions via a 3-pin 5A plug and cord as shown in Figs. 11.166 and 11.167 respectively. These figures also indicate the components which are fitted to provide radio interference suppression.

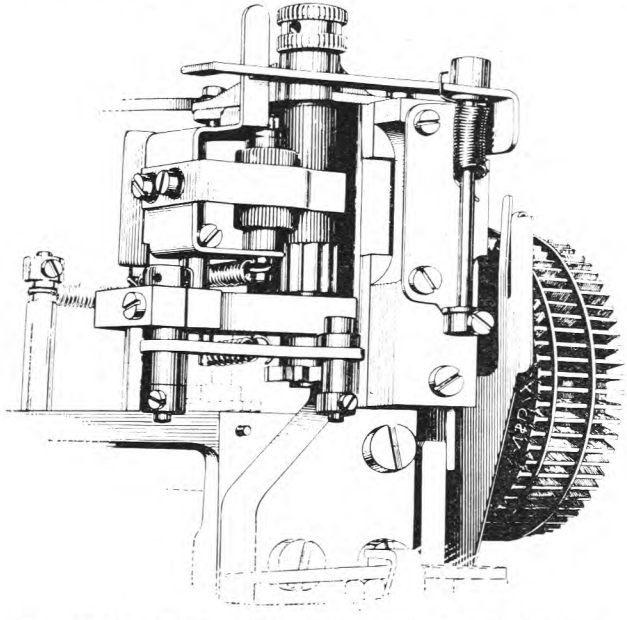


FIG. 11.162. PRINTING REPERFORATOR: FEED ROLLERS

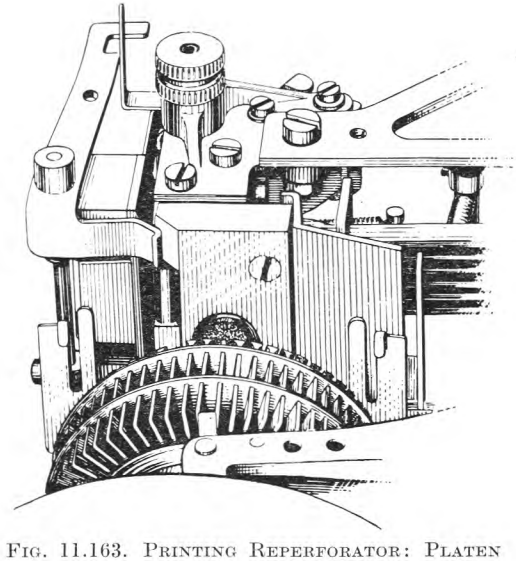


FIG. 11.163. PRINTING REPERFORATOR: PLATEN

Development Work. A marked feature of post-war

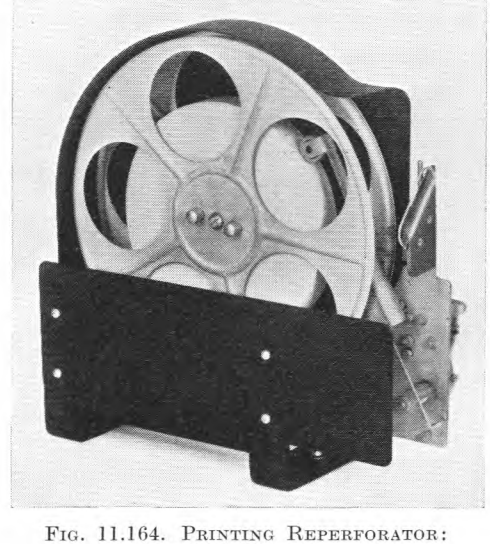


FIG. 11.164. PRINTING REPERFORATOR: TAPE ROLL-HOLDER

(*By courtesy of H.M. Postmaster-General*)

telegraph development has been the increasing use of No. 7 Page Teleprinters and five-unit automatic equipment by commercial and industrial organizations, either over their own private wire networks, or through the facilities of the B.P.O. Inland and International Telex Services.

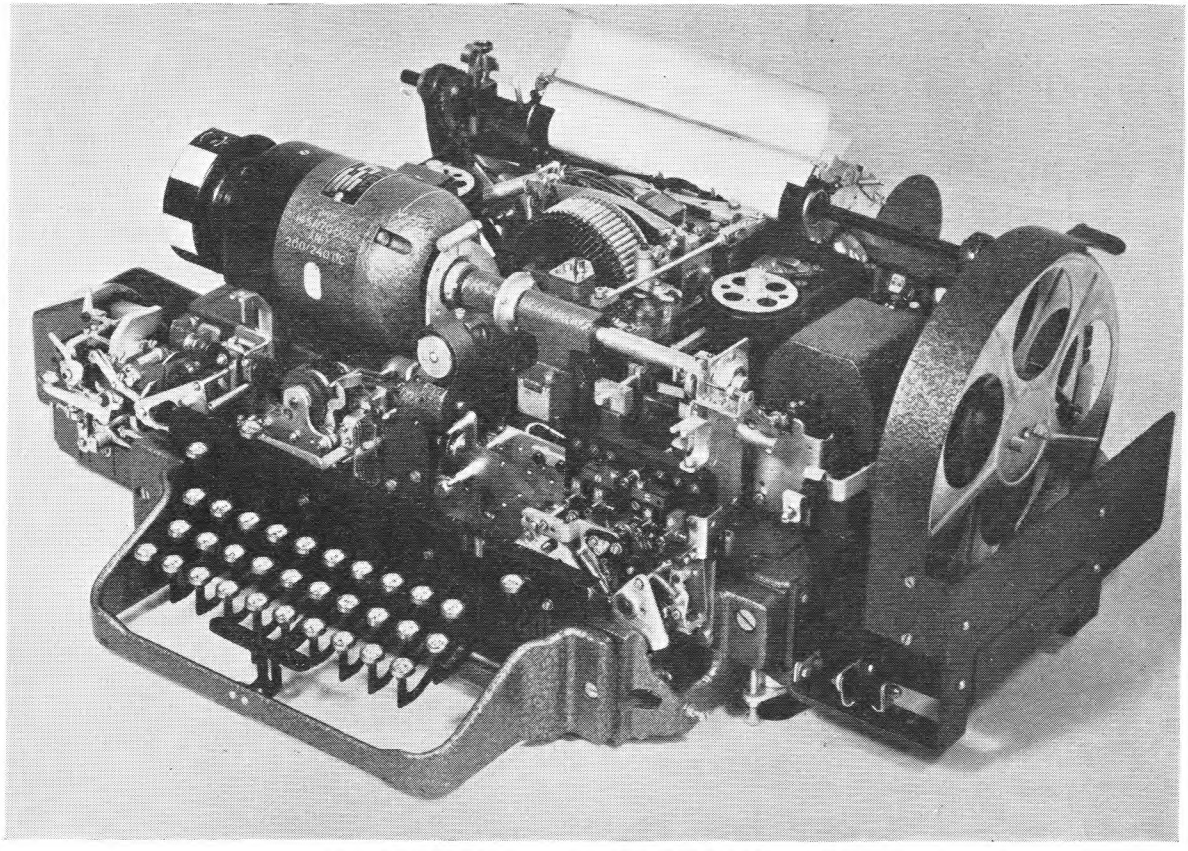


FIG. 11.165. TELEPRINTER NO. 7B/RP: COVER OFF
(By courtesy of H.M. Postmaster-General)

With the growth of these services certain new equipment and operating requirements have emerged and extensive development work has been undertaken to meet these new conditions.

Numerous new features have been introduced on the No. 7 Teleprinter—the more important of these being two-colour printing, whereby incoming messages are printed in black and outgoing messages in red on the local record copy; an overlap cam unit which increases the margin of the teleprinter to at least $\pm$ 40 per cent, and at the same time causes the printing of each character (or operation of each function) to take place immediately the corresponding key is depressed, instead of on the following key depression as with existing machines; and the reperforator attachment which permits both incoming and outgoing messages, printed in the normal way, to be simultaneously recorded in five-unit perforated tape for subsequent automatic transmission.

Automatic equipment has also received development attention, notably in the case of the tape transmitter where improved results have been obtained from the introduction of the striker type mechanism similar to that which has been used with such unqualified success on the Teleprinter No. 7 for many years. Various specialized forms of transmitters, for use in conjunction with tape relay systems, have also been evolved to provide automatic serial numbering of messages and other facilities.

Current development work is directed towards the production of improved forms of page

teleprinters and associated instruments giving comprehensive facilities, high quality performance and low maintenance costs.

Teleprinter Testing Equipment

One of the fundamental requirements in teleprinter working is accuracy of speed control. The motor speed determines the duration of the code signals emitted by the transmitter and also the

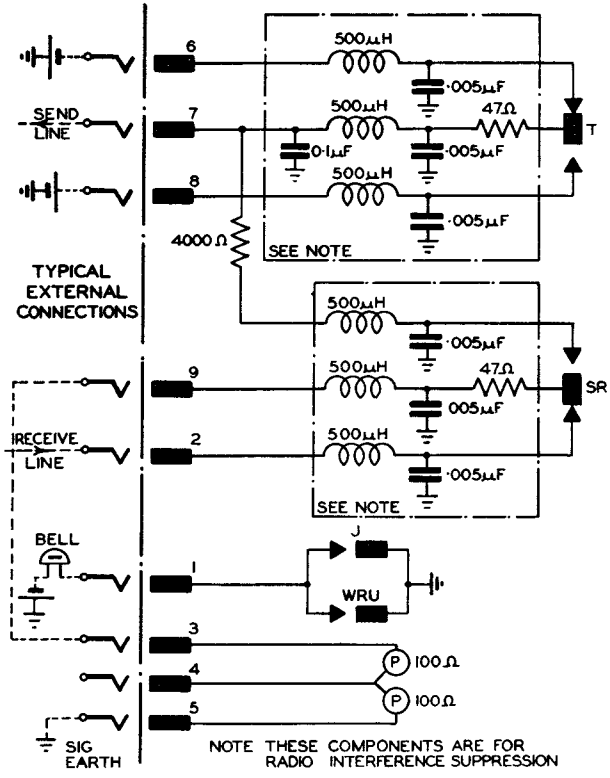


FIG. 11.166. TELEPRINTER NO. 7: SIGNALLING CONNEXIONS

timing of the selecting instants in the receiving mechanism. Any inaccuracy in speed therefore causes distortion in the transmitter and loss of margin in the receiver. For example, suppose in a 50 baud 7½ unit transmitter that the speed is 1 per cent slow, then if the instant corresponding to the commencement of the start signal equals 0 msec then the timing instant for the commencement of the subsequent signal elements will be as follows—

$$\text{1st element } 20 \times \frac{101}{100} = 20{\cdot}2 \text{ msec}$$

$$\text{2nd element } 40 \times \frac{101}{100} = 40{\cdot}4 \text{ msec}$$

$$\text{3rd element } 60 \times \frac{101}{100} = 60{\cdot}6 \text{ msec}$$

$$\text{4th element } 80 \times \frac{101}{100} = 80{\cdot}8 \text{ msec}$$

$$\text{5th element } 100 \times \frac{101}{100} = 101{\cdot}0 \text{ msec}$$

$$\text{stop element } 120 \times \frac{101}{100} = 121{\cdot}2 \text{ msec}$$

Thus the distortion of the signal elements is progressively worsened throughout each character, the distortion of the fifth code element being $\frac{101 - 100}{20} \times 100$ per cent $= 5$ per cent.

Similarly, in the receiver speed error causes the timing of the selecting instants to be early or late depending whether the speed of the receiver is fast or slow. If the receiver is for example 1 per cent fast then if the selecting instants take place theoretically in the middle of each element they will now occur as follows—

$$\text{1st element } 30 \times \frac{99}{100} = 29{\cdot}7 \text{ msec}$$

$$\text{2nd element } 50 \times \frac{99}{100} = 49{\cdot}5 \text{ msec}$$

$$\text{3rd element } 70 \times \frac{99}{100} = 69{\cdot}3 \text{ msec}$$

$$\text{4th element } 90 \times \frac{99}{100} = 89{\cdot}1 \text{ msec}$$

$$\text{5th element } 110 \times \frac{99}{100} = 108{\cdot}9 \text{ msec}$$

If the 1 per cent slow transmitter was sending to the 1 per cent fast receiver then the maximum "late" distortion which would be permissible on the fifth element would be—

$$\frac{108{\cdot}9 - 101}{20} \times 100 \text{ per cent} = \frac{7{\cdot}9}{20} \times 100 \text{ per cent} = 39{\cdot}5 \text{ per cent}$$

whereas theoretically, if the speed were correct the maximum distortion permissible in a perfect receiver would be

$$\frac{110 - 100}{20} \times 100 \text{ per cent} = 50 \text{ per cent}$$

It will thus be clear that the more accurately the speeds of the transmitters and receivers of tele-

printers, etc., can be maintained, the greater is the distortion which can be permitted to occur over the circuit, or alternatively the greater is the factor of safety in the operation of the circuit. In practice, means are provided to enable teleprinter speed to be checked and checks and readjustments are made on the occasion of any fault and also as a routine maintenance measure.

the extremity of the reed successively covers and uncovers an opening S in a viewing window affixed to the end of the tube. Thus, the viewing window is momentarily open for viewing the rotating teleprinter shaft once per vibration. If the speed of rotation of the shaft is precisely the same as the speed of vibration of the stroboscopic reed then the white spot on the shaft will appear to be stationary.

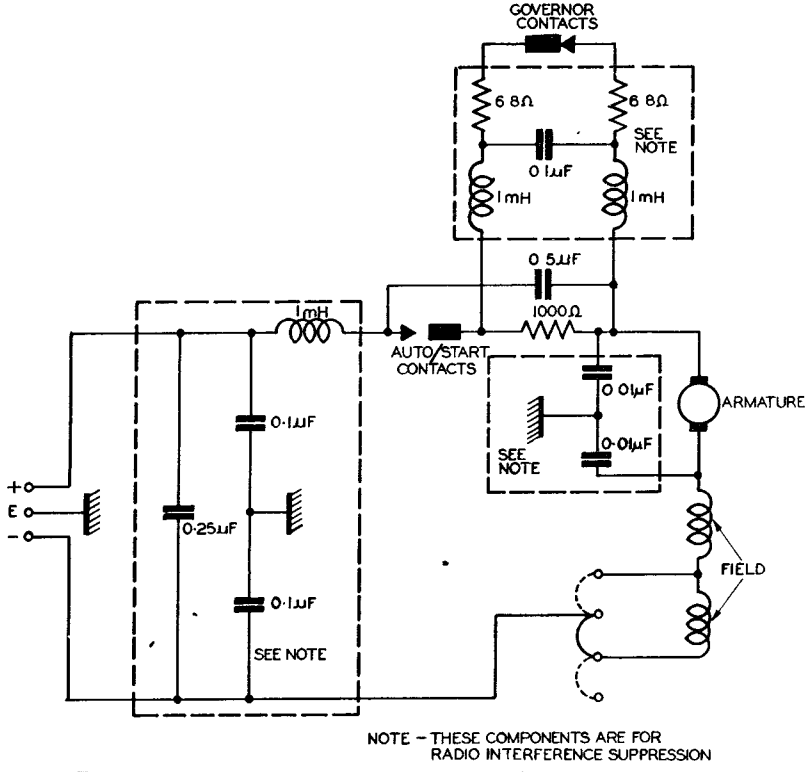


FIG. 11.167. TELEPRINTER NO. 7: MOTOR CIRCUIT CONNEXIONS

Mechanical Stroboscopes. One simple form of portable speed tester is the stroboscopic reed and this is widely used by teleprinter mechanics. It is illustrated in Fig. 11.168 and is used to view a white mark on a rotating shaft of the teleprinter through a window which is shuttered by the tuned vibrating reed VR. The stroboscope consists of a light metallic tube surrounding the flexible reed VR which is firmly clamped at the base of the tube and can thus vibrate as a cantilever. The reed is weighted at its free upper end and is tuned so that, when flicked, it vibrates at a fixed speed.

For Teleprinters No. 7 the reed has a natural frequency of vibration of 643 v.p.m. and for a Teleprinter No. 3, 630 v.p.m. which correspond to the speeds of revolution of the typehead shafts of the two types of teleprinter. When vibrating, If the shaft speed is fast, then since the spot is rotating clockwise it will appear to be advancing clockwise when viewed through the stroboscope. If the shaft speed is slow then the spot will appear to be rotating anti-clockwise. The apparent speed of rotation of the spot increases in direct proportion to the difference in speed between the teleprinter and the reed.

An experienced observer can very quickly judge the extent of speed inaccuracy and take the necessary corrective action by adjustment of the centrifugal governor on the teleprinter motor. In use, the stroboscope must be gripped firmly in the hand and held vertically before the eye with the thumb resting firmly against the top side. Even when correctly used the period of viewing is short as the vibrating reed is mechanically unbalanced. Because

of this it is preferable to use a tuning fork stroboscope. As the tines and shutters of the fork are mechanically balanced the period of vibration is much longer than a simple vibrating reed, furthermore it is not necessary to hold the fork upright for viewing. The ease and accuracy of observation is

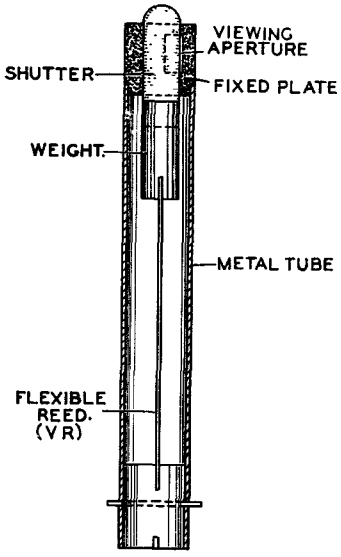


FIG. 11.168. VIBRATING REED STROBOSCOPE FOR SPEED TESTING

therefore much better and experience has shown that a tuning fork stroboscope maintains a high degree of accuracy over very long periods of maintenance use. Fig. 11.169 illustrates a typical tuning fork stroboscope.

line circuit. This is a great advantage where machines are installed in isolated offices or in renter's premises.

The synchroscope unit is shown diagrammatically in Fig. 11.170. A 10 pole synchronous motor is driven at a speed of 600 r.p.m. from a frequency controlled a.c. supply via a mains transformer. The motor spindle is fitted with two gear wheels, one of which is used when testing Teleprinters No. 3 and the other for testing Teleprinters No. 7 and No. 11.

A brush carrier fitted with two brushes rotates upon two metal rings, one ring being divided into 12 equal segments, insulated from each other and from the second ring, which is solid. The brush carrier engages with a gear wheel which is coupled to one of the two gear wheels on the motor spindle. The speed of rotation of the brush carrier is the same as the teleprinter transmitting cam. Six neon lamps are connected in parallel with six alternate segments of the segmented ring, one side of the lamps being commoned and connected to the contacts of relay A. One of the output terminals of the mains transformer is connected to the solid ring and the other to the local circuit of the relay *A*. If, therefore, the local circuit of the relay is closed during the rotation of the brushes, the lamps will be energized in turn during each revolution.

To check the speed of a teleprinter, the letter *V* is transmitted continuously from the machine under test. This signal consists of five consecutive marking and two consecutive spacing units, i.e. one reversal per revolution of the transmitting cam sleeve. The output of the teleprinter is connected to the line coils of relay *B* and this results in the relay tongue being moved to the spacing contact

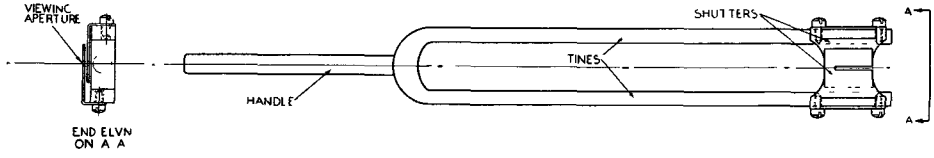


FIG. 11.169. TUNING FORK STROBOSCOPE FOR SPEED TESTING

The Synchroscope. When an a.c. supply of accurate frequency is available, e.g. frequency-controlled mains, or a 50 c/s valve-maintained tuning fork, it is possible to use a synchroscope for speed testing. This method has a high standard of accuracy and enables any erratic behaviour of the governing to be readily detected as the observation can be extended over any period desired. Another advantage of this method of testing is that the teleprinter to be tested may be either adjacent to, or remote from, the synchroscope, as the test is made from signals transmitted from the teleprinter over the

once per revolution of the transmitting cam shaft. Whilst the tongue of relay *B* rests on its spacing contact, relay *A* is also operated thus preparing a circuit for energizing the neon lamps.

If the speed of the teleprinter transmitter is the same as that of the rotating brushes on the synchroscope, the same lamp or lamps will flash at each revolution of the brushes. If, however, the speed is slow or fast, the flashes rotate in a clockwise or anti-clockwise direction respectively. The percentage variation from standard speed is readily determined by noting the time taken for the circle

of lamps to be flashed, each in turn. To assist this observation and calculation, a half-minute impulse circuit, served from a master clock, causes a timing lamp to flash on the test panel at each half minute interval.

It will be observed that this method of speed testing relies upon the accuracy of the a.c. mains supply. Normally experience has shown that this may be relied upon in the U.K. to 0·2 per cent, which is adequate for all practical purposes. Where a.c. frequency controlled mains are not available, a 50 cycle valve-maintained tuning fork unit can be operate at constant signalling speeds. In modern practice the efficiency of transmitters and circuits are accurately measured in terms of percentage distortion and the efficiency of receivers by measurement of their "margin," i.e. the maximum amount of distortion of signals which they will accept, compatible with perfect registration of the signals transmitted.

One form of distortion measuring set, employing a cathode ray tube and suitable for measuring channel distortion, is described in the chapter dealing with M.C.V.F. telegraph systems (Chapter 10).

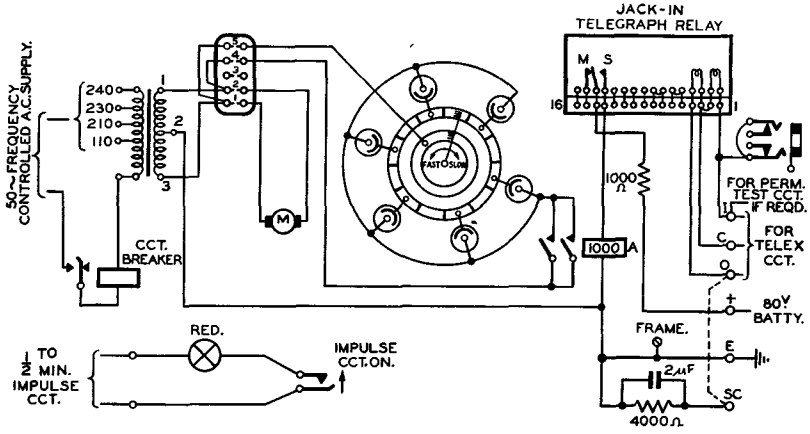


FIG. 11.170. SCHEMATIC DIAGRAM OF SYNCHROSCOPE

used and in recent years there has been an increasing tendency to use these in the B.P.O. so as to be independent of the mains supply frequency.

It might be thought that the solution to the question of teleprinter speed control could be found in the use of synchronous motors. There are however some difficult design problems to solve owing to the conflicting requirements of noise, space, heating, starting torque and hence starting time, and running torque. Furthermore, and probably most important, there needs to be assurance that the mains frequency will remain within close limits and an accurate alternative supply must be available for use in the event of mains failure. These considerations make it extremely unlikely that synchronous motors will ever be used on any scale for important circuits in the U.K.

Teleprinter Distortion and Margin Testing. In the early days of telegraphy when variable speed signalling systems, e.g. Wheatstone Morse, were extensively employed the maximum speed at which a circuit could be worked was used as the criterion of the circuit and instrument efficiency. This method, although useful in its day, is inexact and inappropriate for present day systems which Another form which will now be described is used primarily for checking the performance and measuring the distortion of start-stop transmitters and checking the performance and measuring the margin of start-stop receivers. This tester may also be used for measuring the distortion in lines and associated equipment.

The Jolley Telegraph Distortion and Margin Tester. This tester, which has been widely used for many years, was designed by E. H. Jolley of the B.P.O. and consists essentially of—

(*a*) A transmitter, for sending either perfect signals or signals in which a known amount of distortion is present, and

(*b*) A receiver, taking the form of a stroboscopic disc which enables the received signals to be examined. The complete group of signal-transits corresponding to all the elements of a teleprinter character code is displayed and this is often advantageous for fault diagnosis and experimental studies.

The Transmitter consists of a distributor plate and rotary brush (similar to a Baudot distributor), the brush being driven by a small electric motor. The speed of the distributor brush is accurately

controlled by a Mendonca-Doignon governor and may be varied continuously between 384 and 408 r.p.m. by means of a control knob, while the motor is running. Fig. 11.171 shows the connexions to the distributor. There is a seven segment ring on the distributor plate corresponding to the seven elements of the teleprinter code. The five code segments are wired to five keys (B, C, D, E, and F) by means of which the code combination for any character may be set up. A negative potential is used for marking signals and a positive potential for spacing signals. A centre-tapped potentiometer

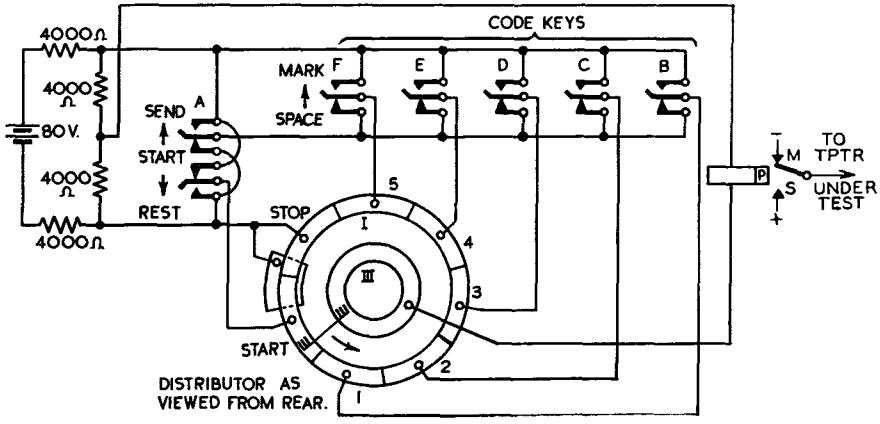


FIG. 11.171. TELEGRAPH DISTORTION AND MARGIN TESTER: DISTRIBUTOR AND CODE KEYS

comprising two 4,000 Ω resistors connected across the leads from an 80 V battery is employed for the signalling potentials so as to ensure accurately balanced positive and negative supplies. A 4,000 Ω resistor is also included in each of the *M* and *S* leads to limit the current.

A sliding segment, which is electrically connected to the stop segment, is arranged so that it can be moved over the stop and start segments but is insulated from the start segment. The start segment has a length equivalent to one and a half units whilst the stop and sliding segments are each equivalent to one unit. Thus by moving the sliding segment varying amounts of distortion may be introduced into the transmitted signals and, by sending these signals into a teleprinter, the limit of permissible distortion before errors occur may be measured. When the sliding segment is moved by means of the knob provided, a pointer is caused to move over a scale graduated in percentage distortion. When the pointer reads zero the sliding segment covers one-third of the start segment so that the start signal is now equal to one unit and the stop signal to one and a half units. By moving the sliding segment the start signal may be lengthened or shortened by varying amounts up to 50 per cent. A specially shaped brush is used to prevent bounce and hence interruption of the signal when the brush passes over the sliding segment.

The coils of the transmitting relay are connected between the centre point of the two 4,000 Ω resistors and Ring III of the distributor. Rings I and III are bridged via the distributor brush so that, as the brush rotates, the transmitting relay is operated by the marking and spacing potentials connected by means of the code keys to the segments on Ring I. (*Note.* Rings II and IV on the distributor are employed for generating reversals for use in line testing.)

Measuring the Margin of a Teleprinter. For this purpose it is essential that the circuit containing the electromagnet of the teleprinter is telegraphically distortionless so that the timing of the corresponding movements of the armature is in exact accordance with the signals. Using 80 V batteries a 4,000 Ω resistor shunted by a 2 μF capacitor and connected in series with the electromagnet has been found to give satisfactory results with Teleprinters No. 3, No. 7 and No. 11. The testing circuit employed is shown schematically in Fig. 11.172.

The code of signals for any letter is set up on the transmitter and sent continuously into the teleprinter. Because the transmitter of the tester is rotating continuously it is necessary to ensure that the teleprinter is only started by the true start signals and not by a spacing element of the signal code. A special key "Stop—Start—Send" is provided for this purpose. In the 'start' position of the key only the start signal is transmitted, so by putting the key momentarily in this position the teleprinter starts up correctly and when the key is moved to 'send' the teleprinter receives the test

signals in correct sequence. The sliding segment is then moved slowly forward, so causing shortening of the start signal, until a position is reached where

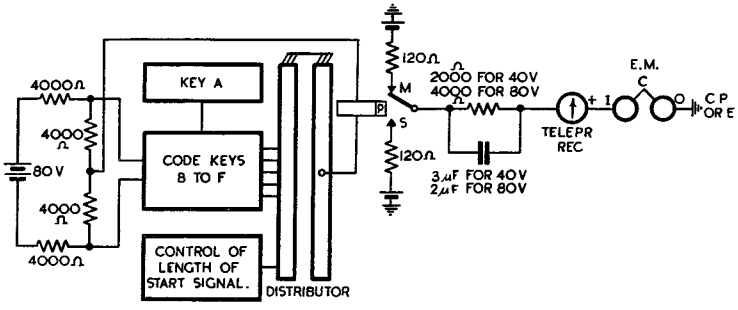


FIG. 11.172. MARGIN TESTING CIRCUIT

further movement causes errors in the operation of the teleprinter. A similar position is found when the sliding segment is moved slowly backwards and thus causes lengthening of the start signal. The readings obtained in these two positions as indicated by the pointer coupled to the control knob give the margin of the teleprinter for "early" and "late" signals respectively. The margin is usually measured in practice first for letter R and then for letter Y and the lowest readings obtained are regarded as the effective margin of the machine. The use of R and Y imposes the most critical check of the margin, as a reversal of polarity occurs for each successive code element; furthermore each code element is tested for a space to mark and a mark to space transition because R corresponds to SMSMS and Y corresponds to MSMSM.

The effect on the receiving mechanism of a teleprinter when the start signal is shortened or lengthened may be seen from Fig. 11.173. The shaded portions indicate the selecting periods in the receiver during which the electromagnet must be correctly set to the position required by the signalling code if the character is to be received correctly. It will be seen that altering the length of the start signal displaces the timing of all the code elements with respect to the selecting periods of the receiving mechanism of the machine.

The Receiver. The stroboscope on the receiver consists of a disc carrying a neon lamp, mounted behind a radial slot cut in the disc and rotating with it at the speed of the transmitter under test, i.e. one revolution per letter. When the set is connected to receive signals a momentary flash of the neon lamp is produced each time the armature of the receiving relay changes from spacing to marking or vice versa, due to the charging of one or other of the two capacitors associated with the contacts. When the tongue and a contact closes the associated capacitor is discharged.

Fig. 11.174 shows the circuit arrangement for testing the output from the distributor, on the stroboscope. Marks or spaces only may be observed when desired, by operating the key K so that one or other of the flashing capacitors is disconnected.

A scale surrounds the disc divided into 15 large divisions. Two of these divisions correspond to a unit signal, giving a total of $7\frac{1}{2}$ units. Each large division is subdivided into 10 small divisions each corresponding therefore to 5 per cent of a signal unit. If the speed of transmission is 50 bauds, as in the case of the Teleprinter No. 7, the unit signal has a duration of 20 msec, so that a small division is equivalent to 1 msec. The scale is movable, so that in a distortion measurement the flash indicating the commencement of the start signal may be made to coincide with one of the main divisions. The flash corresponding to the start signal can be readily picked out by inspection.

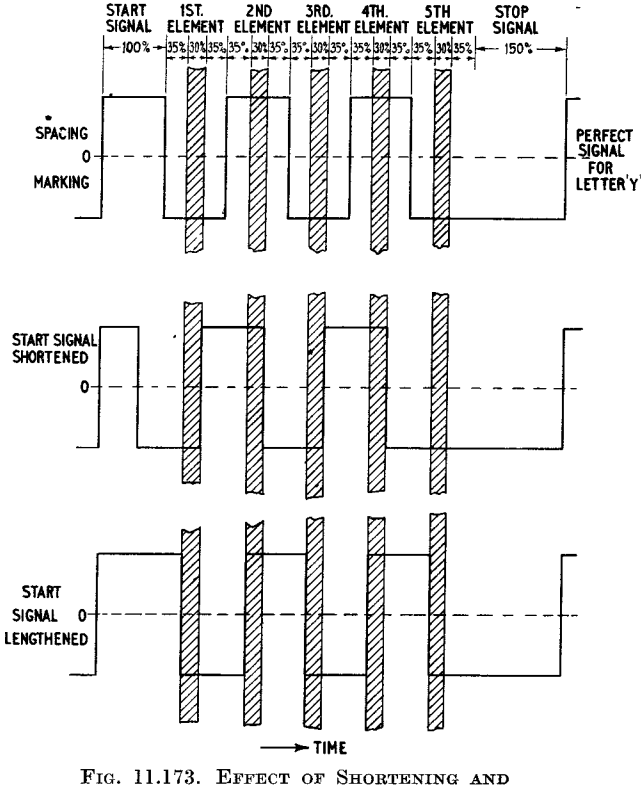


FIG. 11.173. EFFECT OF SHORTENING AND LENGTHENING START SIGNAL

Measurement of Distortion. To measure the distortion of a start-stop transmitter, or of a line, the signals to be tested are connected to the stroboscope relay (Fig. 11.175 refers). Flashes are thereby produced on the disc corresponding to the commencement of each signal element. Fig. 11.176 shows a typical display for the character R, the points at which the flashes would occur in an undistorted signal are shown dotted. No flash occurs at the beginning of the first code element since for letter R this element is of the same polarity as the start signal. The maximum distortion, i.e. relative to the beginning of the start signal, is shown occurring on the second code element and is 25 per cent. Bias distortion can be shown up on the tester by reversing the polarity of the transmitted signals. If bias is present, a change occurs in the length of the signal elements as indicated on the stroboscope display. Marking bias produces a lengthening of the marking elements and spacing bias a lengthening of the spacing elements.

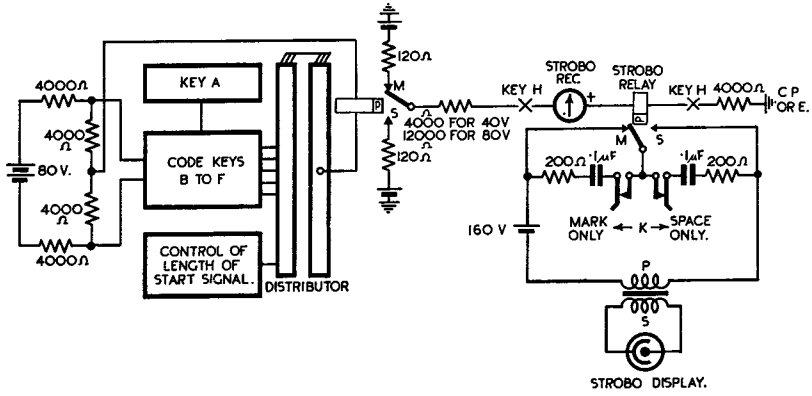


FIG. 11.174. TESTING DISTRIBUTOR OUTPUT ON THE NEON STROBOSCOPE

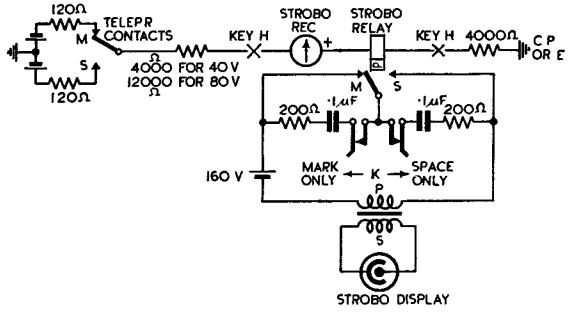


FIG. 11.175. MEASUREMENT OF TRANSMITTER OR LINE DISTORTION

Transit Time Test. For observing transit time strikes as soon as the tongue leaves the contact and is not extinguished until the tongue makes contact again. The breadth of the flash on the display disc will therefore indicate the transit time. If the tongue breaks contact or chatters, flashes are produced each time this occurs.

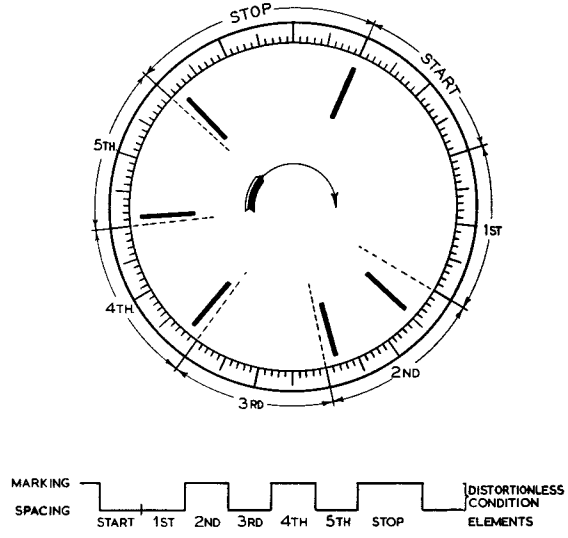


FIG. 11.176. TYPICAL DISTORTED SIGNAL DISPLAY

Test of Sensitivity and Neutrality of a Teleprinter Electromagnet. The circuit arrangement for testing the sensitivity and neutrality of a teleprinter electromagnet is shown in Fig. 11.178. The letter Y is

transmitted into the teleprinter electromagnet (with the electromagnet link disconnected) and the current through the coils is adjusted by means of the series rheostat until the armature just fails to respond to the signals. The electromagnet is then adjusted until the armature will remain on either side with the current just below the minimum operating value; it is then neutral.

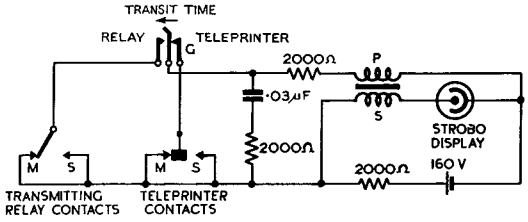


FIG. 11.177. TRANSIT TIME TEST

Distributor and Stroboscope Speed. The speed of the distributor and stroboscope for tests at 50 bauds (i.e. for Teleprinters No. 7) is 400 r.p.m. and for tests at 49 bauds (i.e. for Teleprinters No. 3) is 392 r.p.m.

The speed indicator consists of a rotating drum on which are two circles of spots. A neon lamp supplied from a 50 c/s frequency illuminates the part of the drum which is visible through an aperture in the front of the tester. See Fig. 11.179.

When the distributor and stroboscope are rotating at the correct speed for Teleprinters No. 7, the right-hand circle of spots appears stationary in the light of the neon lamp. At the correct speed for Teleprinters No. 3, the left-hand circle of spots appears stationary.

If the speed of the tester is incorrect, the error may be measured by counting the apparent rate at which the spots pass the aperture in a given time. If the spots pass at the rate of one per second the speed error is 1 per cent. Arrows painted above and below the viewing aperture indicate the apparent direction of movement of the spots, corresponding to the speed being fast or slow. The Mendonca-Doignon governor is readily adjusted by means of its control knob and gives a continuous range of adjustment of the tester between 384 and 408 r.p.m. Once set, a governor maintains the speed constant within 0·025 per cent.

Teleprinter Speed Check. (Fig. 11.180 refers.) To check the speed of a teleprinter the speed of the tester is first set to the correct nominal speed of the teleprinter. One character signal, e.g. R or Y, is then transmitted continuously from the teleprinter under test into the tester. If the flashes produced by the signals on the stroboscope disc are stationary the speed of the teleprinter is correct.

A clockwise movement of the flashes indicates that the teleprinter speed is slow whilst an anti-clockwise movement indicates the speed is fast. A speed error of 0·25 per cent will cause the flashes to rotate with an apparent speed of 1 r.p.m., i.e. they will take four seconds to travel the distance of one large division of the scale. The teleprinter governor should be adjusted so that the speed error does not exceed 0·25 per cent.

The distributor and stroboscope are illustrated in Fig. 11.179 whilst the test keys, relays, etc., mounted as a separate unit are shown in Fig. 11.181.

The teleprinter distortion and margin tester is used in all main B.P.O. teleprinter workshops for checking the transmitting and receiving mechanisms of teleprinters. It enables faults to be diagnosed more easily and accurately and is used for checking that the performance of machines after overhaul or repair is up to standard. It is also a very useful device in laboratory investigations and design work.

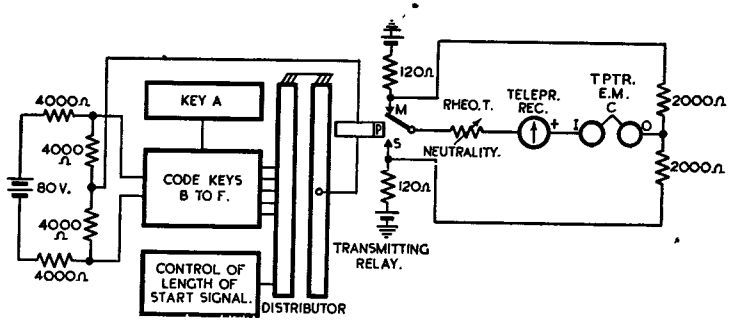


FIG. 11.178. SENSITIVITY AND NEUTRALITY OF TELEPRINTER ELECTROMAGNET

Electronic Start-stop Telegraph Distortion-measuring Set. Great advances have been made in recent years in electronic techniques and many designers have developed electronic equipment to

supersede electro-mechanical devices. The electronic start-stop telegraph distortion-measuring set is a good example of this trend and Fig. 11.182 and margin testing equipment already described. The instrument is compact and of pleasing design and very accurate in use.

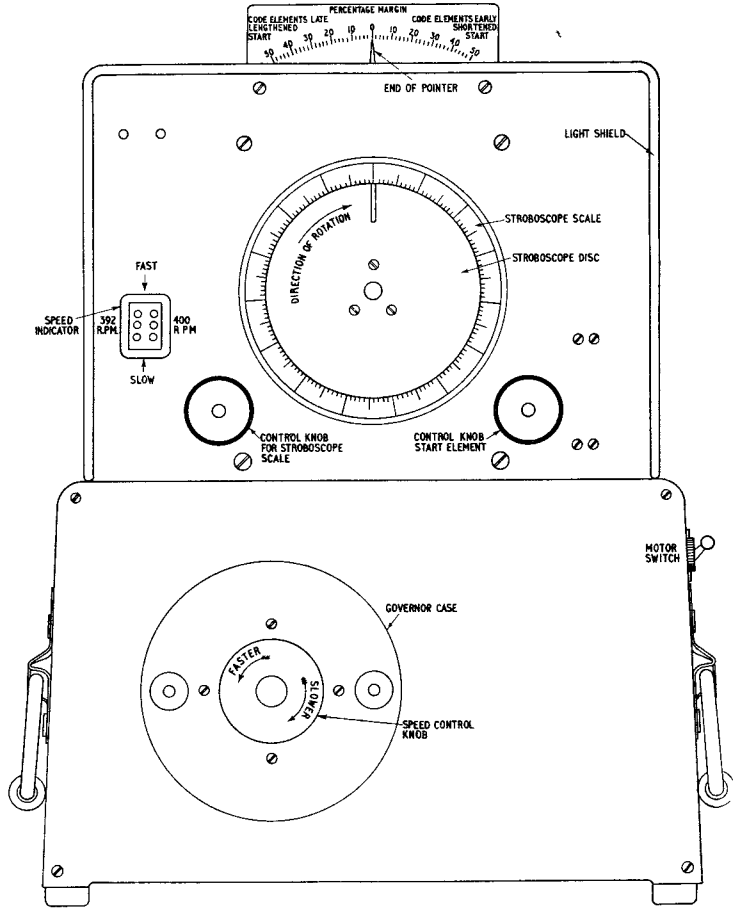


FIG. 11.179. DISTRIBUTOR TRANSMITTER AND STROBOSCOPE-TESTER TG 958

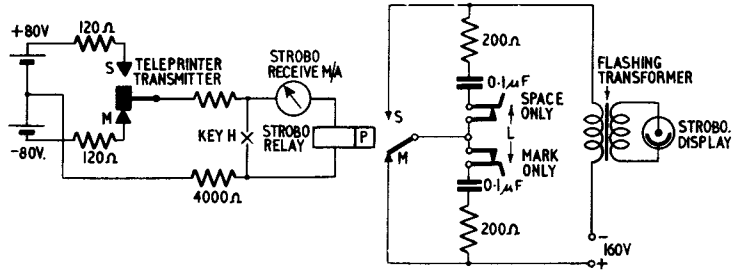


FIG. 11.180. SPEED TESTING

illustrates a typical set developed by the B.P.O. This set is used for telegraph transmission testing and will, in conjunction with other electronic equipment, in due course replace the telegraph distortion

The set incorporates a cathode ray oscilloscope with time-base circuits, the operation of which is initiated by the reception of the start element of a character. The primary time-base period is equal

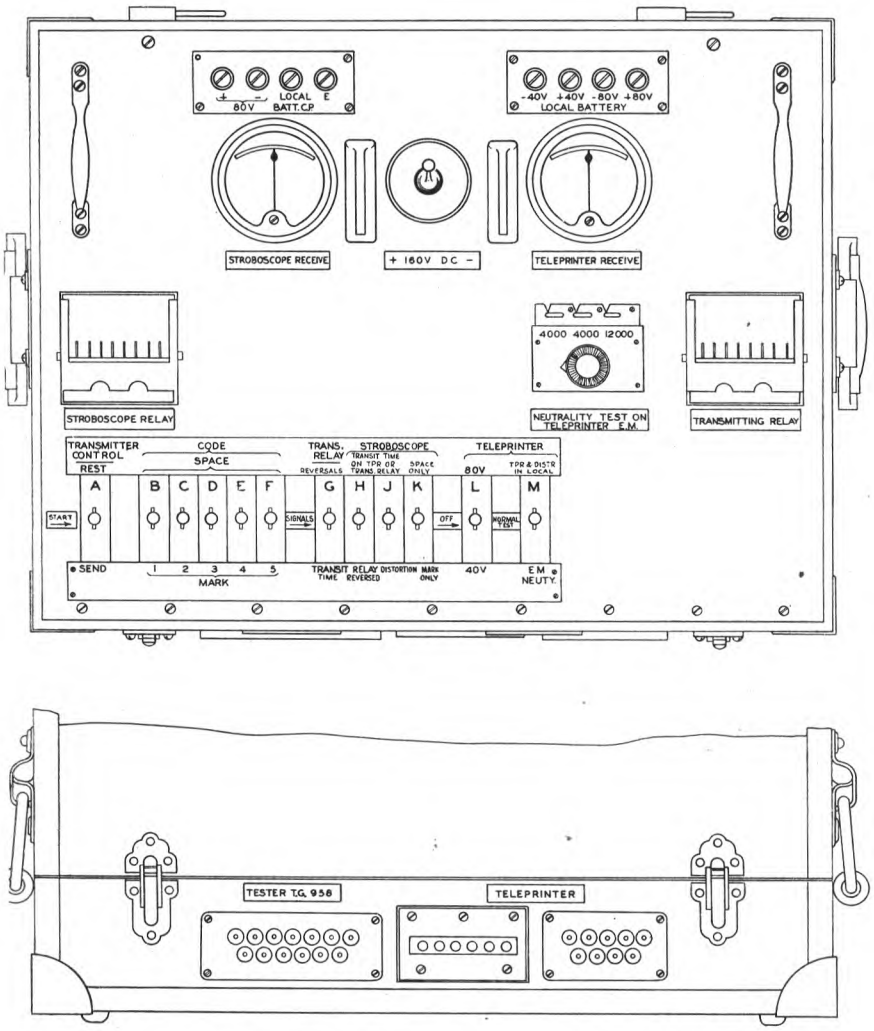


FIG. 11.181. DISTORTION AND MARGIN TESTER TG 957

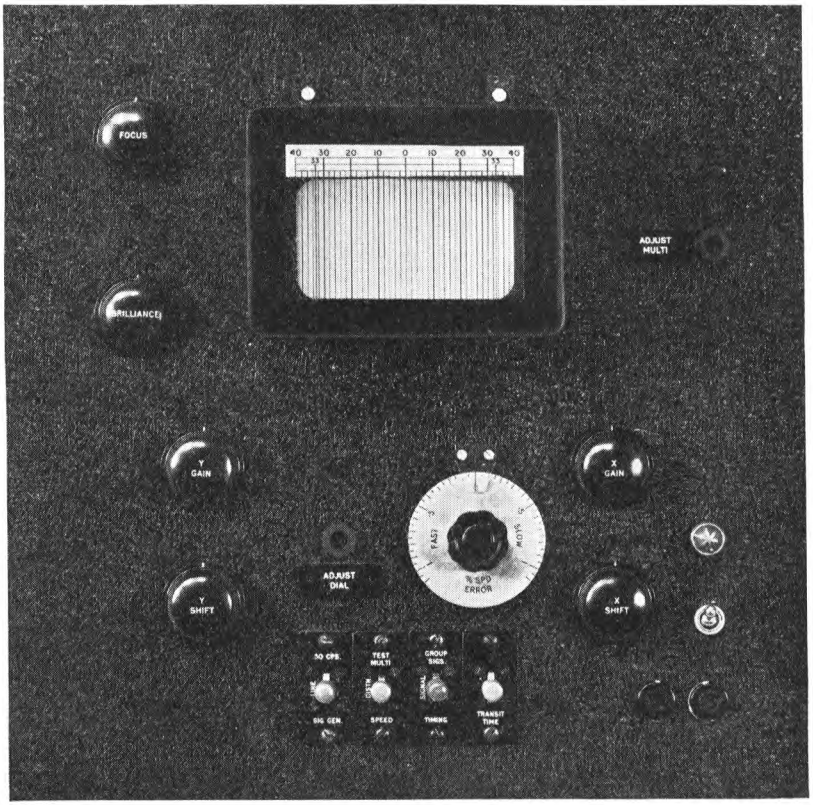


FIG. 11.182. ELECTRONIC START-STOP TELEGRAPH DISTORTION-MEASURING SET

(By courtesy of H.M. Postmaster-General)

to the nominal time of a unit signal element (20 msec for a telegraph speed of 50 bauds) and the cathode ray traverse is repeated for each possible signal transition during the reception of a character, i.e. six traverses. The occurrence of a signal transition causes the beam to be intensified to produce a

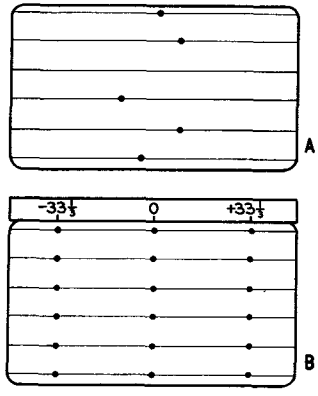


FIG. 11.183. TYPICAL SIGNALS DISPLAYED ON START-STOP TDMS

bright spot on the screen of the cathode ray tube. To permit observation of the distortion of the individual instants of modulation in a character, the 6 traces may be mutually displaced by a suitable vertical deflexion circuit so that the trace occurs on 6 separated horizontal lines. Fig. 11.183 (*A*) shows a typical display produced by a distorted character.

The repetition rate of the time base is controlled by an oscillator which is started when the start element of each character is received, and stopped when the correct number of beam traverses has occurred. To facilitate reading of the distortion of the instants of modulation, which may be either advanced or retarded with respect to their nominal positions, the commencement of the cycle is delayed by half a unit period so that undistorted signals are indicated at the centre of each traverse. Transit time and bounce of transmitting contact units can be displayed, the trace being deflected vertically to indicate the break and make of the side contacts.

The use of a rectilinear as opposed to a circular beam-sweep entails the provision of means of calibration to ensure that a linear measurement of the horizontal traverse against a fixed scale represents accurately a time interval. This is provided by making the frequency of the time base controlling oscillator six times that of the time base so that signal indications which are accurately 0, + 33⅓ and − 33⅓ per cent relative to perfect signals can be used to mark the trace. By manipulation of the horizontal shift and gain controls these markers may be positioned to agree with corresponding points on the fixed scale as shown at *B* in Fig. 11.183.

The speed of continuous signals may be compared with that of the time base, by eliminating the start-stop action. A calibrated frequency control enables speed error to be measured. Provision is also made for checking the oscillator frequency against an external standard. A more detailed description of this instrument has been published in the British Post Office Electrical Engineer's Journal, Vol. 43, Part 1, April 1950.

CHAPTER 12

MORSE AND HELLSCHREIBER INSTRUMENTS

SOME account has already been given in Chapters 1 and 2 of Morse and Hellschreiber systems and this chapter deals in greater detail with the principles of operation of the types of instruments employed in these systems.

In the past, very considerable use has been made of Morse systems of working but for some years now the tendency throughout the world has been to supersede Morse by five-unit systems employing in the main, start-stop instruments. In the U.K. for example, start-stop working in accordance with C.C.I.T. standards is universally employed on all land-lines and cross-channel European telegraph circuits. Morse in the form of Wheatstone, cable code or double-current cable code is still retained on many of the long distance telegraph circuits of the B.P.O. Cable and Wireless Service but steps are being taken to convert these circuits as far as possible to five-unit working so as to secure a greater measure of standardization and facilitate the interchange of traffic between land-line, submarine cable and radio-telegraph circuits. For long submarine cables and radio circuits it is probable that synchronous systems will predominate as these enable greater economy to be made in the use of line time and also give greater stability in the working of radio circuits in the presence of noise and fading, etc.

Synchronous systems employing error detecting codes and giving automatic correction of errors by repetition, or other methods, are finding increasing application on radio links and eventually will probably completely replace the Wheatstone Morse and double-current cable code synchronous systems at present employed. Nevertheless, it will probably be many years before automatic Morse systems of working are completely replaced throughout the world and it is therefore essential for the telegraph engineer to have a sound grasp of the principles employed in the various main types of instruments in use.

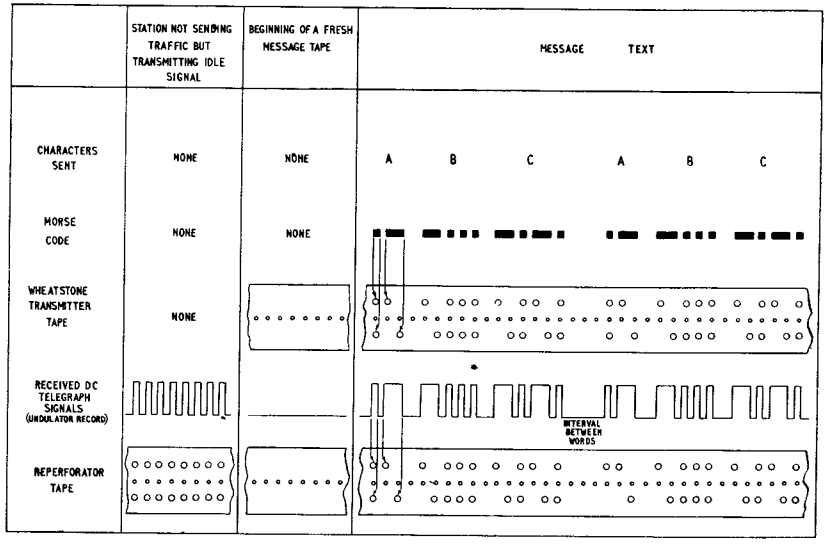


FIG. 12.1. SIGNALS USED IN AUTOMATIC MORSE TRANSMISSION

The Morse Keyboard Perforator. This is an instrument having a typewriter type of keyboard which is used to translate messages into the form of perforations in a paper tape. The perforations for each character are produced automatically by the perforator when the key corresponding to the character is depressed and the perforations so produced are in accordance with the conventions employed in the Wheatstone Automatic Morse System. The Morse code is fully described in Chapter 1 and the conventions employed in the perforated slip for dot, dash and space are illustrated in Fig. 2.29. Fig. 12.1 illustrates the signals used in automatic Morse transmission, indicates the signal waveforms corresponding to the various signalling conditions

at the transmitter, e.g. "idle," "beginning of message," and "text," and shows the record that would be produced by these signals on an undulator and a receiving reperforator. The tape produced by a Morse keyboard perforator is used to control the transmission of telegraph signals from an automatic Wheatstone Morse transmitter, which will be described later in this chapter; it may also be used for controlling an automatic cable code transmitter, as used for example on submarine telegraph cables

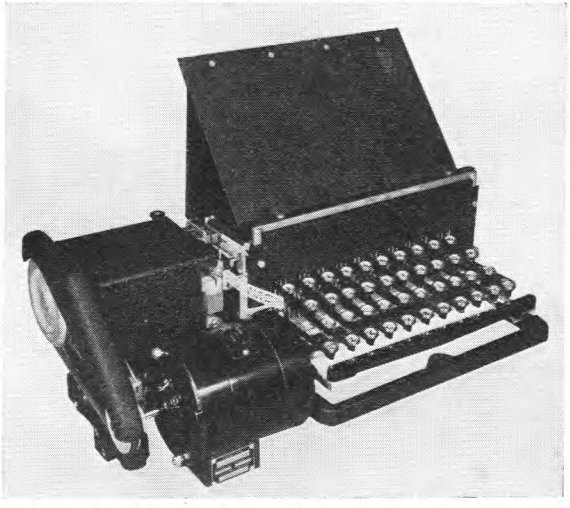


FIG. 12.2. CREED MORSE KEYBOARD PERFORATOR
(By courtesy of Creed & Co., Ltd.)

in the B.P.O. Cable and Wireless Service, which transmits a three-condition signalling code, i.e. positive, negative and earth.

Fig. 12.2 illustrates a typical Creed Morse Keyboard Perforator. The perforator consists essentially of a driving motor and cam assembly, a keyboard, combination and space-stop bars, a punch block, and a tape roll holder mounted at the rear of the machine. A letter counter or end-of-line indicator can be fitted to the keyboard perforator if desired to facilitate preparation of tapes destined for transmission to a Morse page printer.

The fractional h.p. driving motor may be either a single-phase a.c. capacitor motor or a d.c. shunt wound motor. The connexions for these two types are shown in Fig. 12.3(*a*) and 12.3(*b*) respectively. The drive from the motor is transmitted to a cam shaft, see Fig. 12.2, by a belt which embraces pulleys on the motor and cam shafts. The cam shaft is supported by two bearings and revolves continuously whilst the motor is running. A ratchet is fitted to the cam shaft.

Enveloping the cam shaft is a cam sleeve which is cut with three grooves (cam tracks) which are shaped to give the necessary timed movements to the punching, feeding and combination bar resetting mechanisms.

As on teleprinters, the cam sleeve also carries at one end two pivoted pawls, see Fig. 12.4, the teeth of which, under the action of a spring, are pressed in towards the shaft where they engage with the teeth of the rotating ratchet. However, they are normally held out of engagement by the pawl abutment so that the cam sleeve remains stationary.

The trip lever is held in engagement with the abutment by a small spring but, each time a keybar on the keyboard is depressed, the resulting movement of the trip rod (see Fig. 12.5) causes the trip lever to rotate the abutment on its pivot and so release the pawls which are pressed into engagement with the ratchet, under the influence of the pawl spring, causing the cam sleeve to rotate.

The end of the trip lever passes underneath an eccentric portion of the cam sleeve and, when the cam sleeve rotates, this eccentric causes the trip lever to be carried out of engagement with the abutment. This allows the abutment to drop into its original position in the path of the pawls before the cam shaft and sleeve have completed one revolution. When the pawls encounter the abutment they are lifted clear of the ratchet and thus the cam sleeve makes only one revolution for each depression of a keybar.

The punch block, Fig. 12.5, which is controlled by the right-hand groove on the cam sleeve, is mounted on a pivoted link so that it can oscillate from left to right. It carries the punches and dies, arranged so that the paper tape can be fed transversely between them, i.e. from the back of the machine to the front. The code punches are arranged in two horizontal rows of 10 in each row. There are also 10 feed hole punches which form a horizontal row between the two rows of code punches, see Fig. 12.5. The ends of the code punches, which are movable in the block, extend to the right where they line up with the ends of 20 combination bars, of which two only are shown in Fig. 12.5. The feed punches are fixed in the block.

The keybars are mounted at right angles to the combination bars and are arranged so that their upper extensions will engage tooth notches on the combination bars when a key is depressed. The tooth notches in the combination bars are so cut that those engaged by each keybar correspond to the Morse code for the character on that keybar. The arrangement of the keyboard is very similar to that used on teleprinters.

When a keybar is depressed its upper extension engages the associated notches on the combination

bars and so prevents certain of the bars from being pushed back by the punches when the punch block is moved by the cam. The trip rod is also operated and this in turn releases the pawls, causing the cam sleeve to rotate and the

The differential paper feed, necessitated by the varying length of the Morse code for different characters, is carried out by a permissive spacing mechanism. In addition to the combination bars, there are 10 other bars mounted in front of them

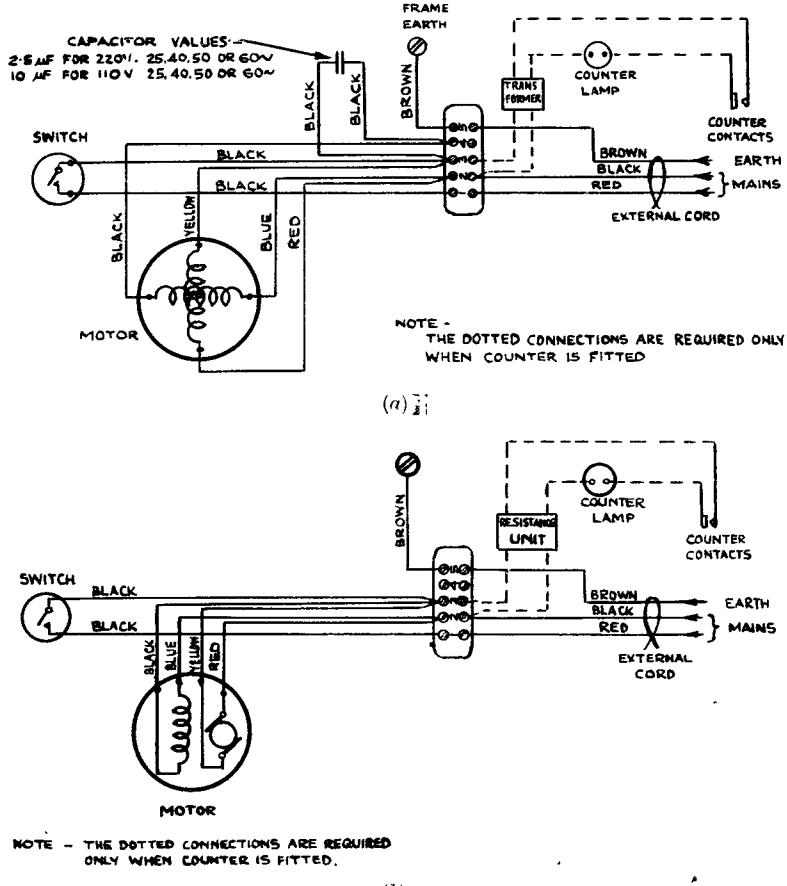


FIG. 12.3.

(*a*) Wiring of a single-phase a.c. capacitor type motor for a Morse keyboard perforator
(*b*) Wiring of a d.c. shunt motor for a Morse keyboard perforator

punch block is pushed against the ends of the combination bars. The selected bars (according to the character code) are arrested by the depressed keybar and the punches corresponding to these bars are therefore pushed through the paper tape (the corresponding feed hole punches also perforate the tape). The remaining combination bars are not arrested by the depressed keybar and are pushed to the right by the punches so that the tape is not perforated in the positions corresponding to them. Immediately punching of the character code on the tape is completed, the punch block is returned to its normal position by the cam sleeve.

and also lying under the upper extensions of the keybars, see Figs. 12.5 and 12.6. These 10 space-stop bars tend to move to the right under the influence of springs but are normally held to the left by a rectangular lever which is operated by a rod controlled by the centre cam track. They are separated from each other by $\frac{1}{10}$ in. which is the distance between two adjacent centre feed holes of the perforated tape.

The upper edges of the 10 space-stop bars are cut with teeth so that, on depression of a keybar, only one bar, according to the length of the character code, is allowed to move to the right under the

influence of its spring, the others being held by the upper extension of the depressed keybar. To the left-hand end of the space-stop bars are connected

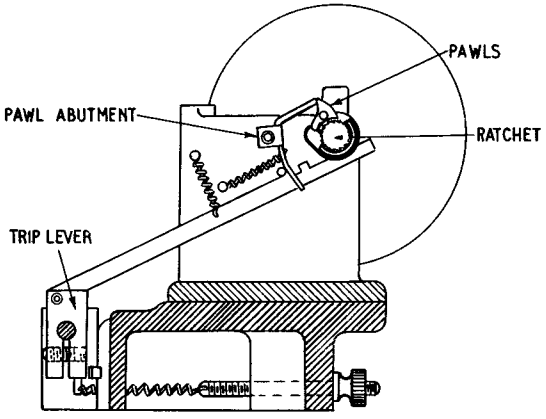


FIG. 12.4. RATCHET DRIVE FOR CAMSLEEVE OF CREED MORSE KEYBOARD PERFORATOR

10 space stops carried in the space-stop rack. In addition to the 10 slots carrying the space-stops, this rack also has a transverse slot cut in it in such a position that, when the selected space-stop bar moves to the right, the associated space stop is set across it.

The feeding of the paper is carried out by a rake which is moved backwards and forwards in the transverse groove of the space stop rack. It obtains its movement from the left-hand cam track by means of the spacing lever and spacing lever blade. This movement is applied permissively in the backward direction, the amount of movement being determined by the selected space-stop. The spacing lever blade flexes to take up the lost motion.

The complete cycle of operations in the perforator for the perforation of a character may be summarized as follows—

A keybar is depressed and its upper extension engages with the slots in the combination and space-stop bars. Depression of the keybar also operates the trip rod which in turn operates the pawl abutment and the pawls are allowed to engage with the teeth of the ratchet on the revolving cam shaft. The cam sleeve commences to revolve and first operates the rod which pushes to the right the rectangular lever so as to leave space for the combination and space-stop bars to operate.

As the rectangular lever moves, the space-stop bar corresponding to the character of the depressed keybar will follow it and carry the associated space-stop into the path of the feed rake. The punch-block carrying the tape and the punches is then moved to the right by the cam sleeve. Certain of

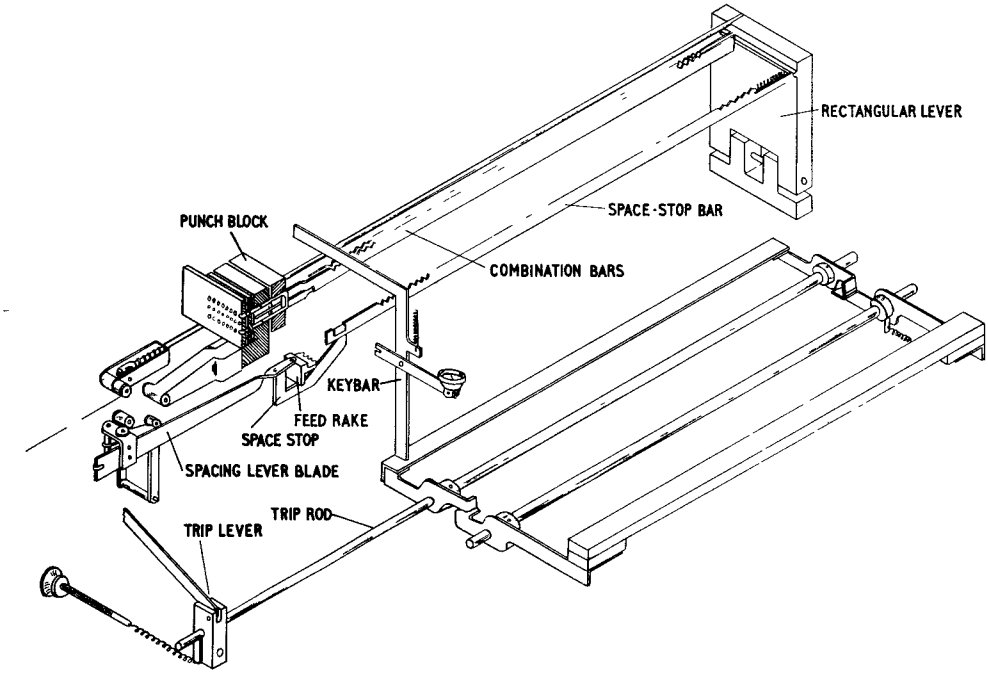


FIG. 12.5. PRINCIPLE OF OPERATION OF CREED MORSE KEYBOARD PERFORATOR

the combination bars are arrested by the depressed keybar and consequently the corresponding punches are forced through the paper tape. Those combination bars which are not arrested are moved by the corresponding punches and no perforation of the paper is made in these positions. The feed hole punches also penetrate the paper tape.

The movement of the punch-block disengages the feed rake from the paper tape and, when this abutment and are freed from the ratchet and the cam sleeve is brought to rest after one complete cycle.

The Wheatstone Morse Transmitter. The function of the Wheatstone Morse transmitter is to accept a perforated paper tape, which has been prepared on a Morse perforator or reperforator, and to translate the perforations into corresponding telegraph signals which may be sent to line either directly or via a transmitting relay.

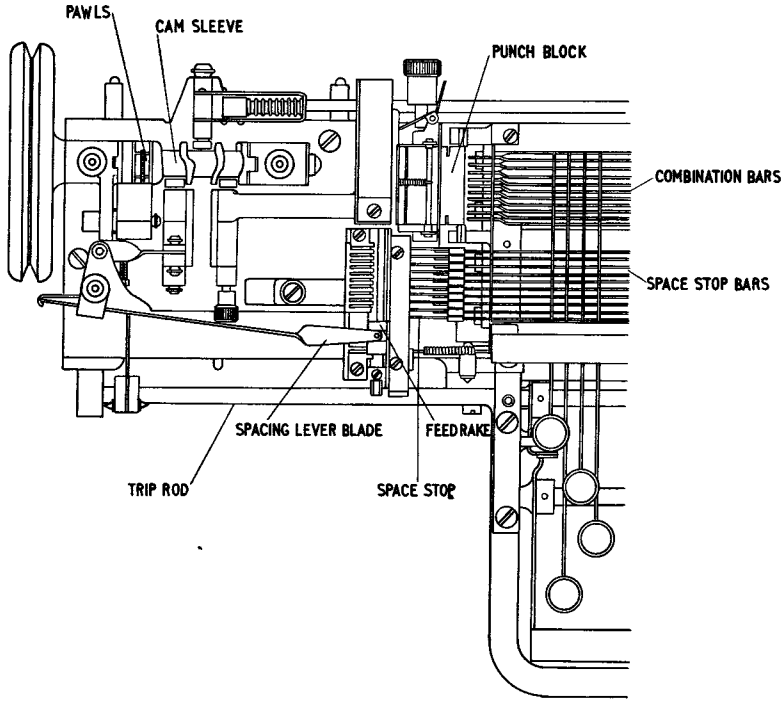


FIG. 12.6. LAYOUT OF MECHANISM OF CREED MORSE KEYBOARD PERFORATOR

has taken place, the cam track operates the spacing lever blade and carries the feed rake towards the punch-block. The rake travels down its path until it meets the selected space-stop which determines the length of tape to be fed forwards subsequently.

As the cam sleeve continues to revolve, the punch-block is returned to its normal position and this causes the paper tape to move away from the selected punches and to again engage with the feed rake which in turn is moved by the cam sleeve to its normal position, thus feeding the required amount of paper tape.

When this operation is completed, the rectangular lever is operated by the cam sleeve and restores the combination and space-stop bars to their rest positions. The pawls then engage with the pawl

The transmitter consists of a driving unit, a means of speed control and the transmitting mechanism.

On the earlier models (see Chapter 2, page 43) the driving unit consisted of a clockwork mechanism driven by the gradual descent of a heavy weight and a key was provided by means of which the mechanism could be wound up and the weight raised periodically as required. On the later models the driving power is supplied by a small motor. Fig. 12.7 is an illustration of the motor driven transmitter in which the motor drives the transmitting mechanism through a variable friction drive. The motor shaft carries a large metal disc which drives a small friction disc attached to the transmitter driving spindle, and alterations in signalling speed

are effected by varying the position of the friction disc in relation to the axis of the driving disc.

The transmitting mechanism may be described as the equivalent of a mechanically operated

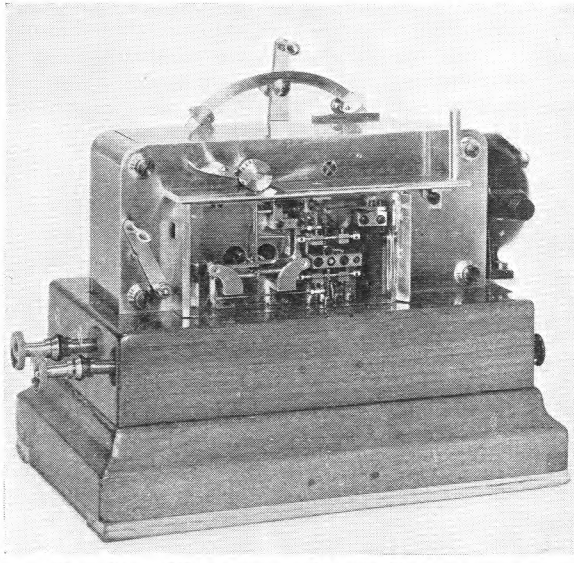


FIG. 12.7. WHEATSTONE MORSE TRANSMITTER (MOTOR DRIVEN)

(By courtesy of H.M. Postmaster-General)

double-current key and is shown schematically in Fig. 12.8.

The positive pole of the battery is connected to the contacts S and the negative pole to contacts M. Between these contacts the compound lever oscillates. The compound lever is in two parts insulated from each other, one part (D) being connected to the line A wire, and the other part (U) to the line B wire. (*Note:* see Fig. 2.30 which shows alternative line signalling arrangements.) When D makes contact with M, U is in contact with S and when D moves to S, U goes over to M. In this way positive and negative currents are alternately sent to line.

A jockey wheel presses against the knife edge at the upper end of the compound lever and holds it firmly against the contacts after each operation, so preventing its remaining in the intermediate position. In one pattern of the Wheatstone transmitter the function of the jockey wheel is performed by a permanent magnet. The bell crank levers are the means by which the required movements of the compound lever are effected through rods R and collets K. The rocking beam, which is movable on a central pivot, has two projecting pins $P1$ and $P2$ against which the bell crank levers are normally maintained by the action of the springs T.

The rods SP and MP are situated one on each side of the star wheel, the rod MP being spaced one half a feed hole behind the rod SP in the direction of tape movement. The rocking beam and the star wheel are so geared that the rods SP and MP are offered to the perforations, once for each half feed hole distance moved by the tape. The star wheel engages with the feed holes in the perforated tape which is therefore fed forward continuously during transmission. When the transmitter is switched on to run without tape the rocking beam oscillates on its pivot causing $P1$ to descend and lower the rod SP. By the movement of $P2$ which is raised, MP is free to rise and the top of the compound lever is deflected to the right. The succeeding movement of the rocking beam depresses $P2$ and allows $P1$ and SP to rise, thus bringing the bottom of the compound lever to the right and reversing the current to line.

If tape, perforated for example with the letter A (i.e. dot, dash) is inserted, then, when rod MP rises it will be free to pass through the first upper hole, the compound lever will be moved and will send a marking current; when the reverse movement of the rocking beam takes place, rod SP will be free to pass through the first lower hole and the current sent by the lever will be reversed; a dot will therefore have been sent. The dash is transmitted in a similar manner, the interval between MP entering the tape and SP entering being in this case equivalent to three half-feed holes. The perforated tape is

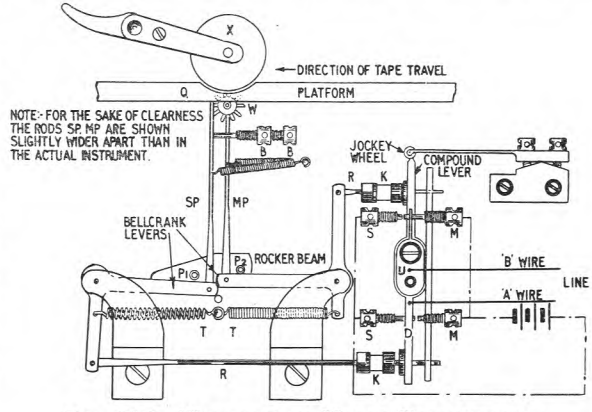


FIG. 12.8. WHEATSTONE MORSE TRANSMITTER: PRINCIPLE OF MECHANISM

kept in position by a roller X which gears with the star wheel W. The position of the roller is limited so that it does not press upon the paper but only prevents it from rising. The central portion of the roller is toothed, but on each side of the teeth space is provided to allow of the free upward movement of the rods SP and MP.

From the foregoing it will be seen that the perforations in the tape determine the movement of the rods which, in turn, control the polarity and time duration of the signals transmitted, i.e. dot, dash, space, letter space and word space.

If there is no paper tape in the instrument a continuous train of "reversals" will be transmitted.

A Modern Wheatstone Transmitter. Although many years have elapsed since Sir Charles Wheatstone introduced his automatic Morse system, the design of the transmitter has remained substantially unchanged until recent years, with the exception of the change to the motor drive. Some years ago however The Great Northern Telegraph Co., Ltd. of Denmark brought out a new design which is an excellent example of a modern Wheatstone Morse Transmitter. This instrument, which is illustrated in Fig. 12.9, incorporates greatly improved arrangements for speed control and gives improved signal performance. The instrument has a speed range of 13–250 w.p.m. with a dial control and a variation of only $\pm \frac{1}{2}$ per cent at any setting of the dial. A specially designed contact mechanism ensures a very short transit time and minimum contact bounce.

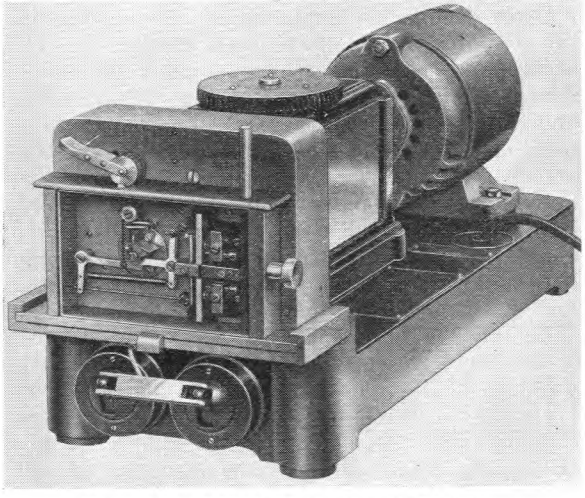


FIG. 12.9. G.N.T. WHEATSTONE MORSE TRANSMITTER

(By courtesy of The Great Northern Telegraph Co., Ltd.)

The motor, the speed regulator and the transmitting mechanism are mounted on a main base.

A shunt motor is used for d.c. mains and an induction motor for a.c. mains. Both motors run at 2,850 r.p.m. and a fixed gear in the speed regulator ensures that the regulator main shaft speed is well in excess of the maximum speed of the transmitter spindle. The design of the speed regulator is based on the fact that a centrifugal governor, operating in conjunction with a slipping clutch, ensures a remarkably constant speed for

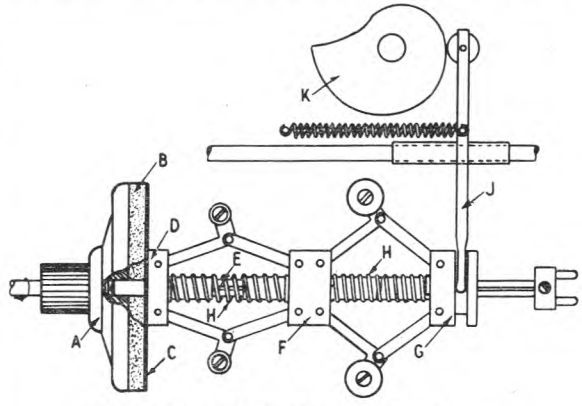


FIG. 12.10. G.N.T. WHEATSTONE MORSE TRANSMITTER: GOVERNOR MECHANISM

light drives. In order to obtain the very wide range required, two centrifugal governors are combined, one controlling the speed from 13 to about 80 w.p.m. and the other operating over the remaining part of the speed range.

Fig. 12.10 is a schematic diagram of the speed regulator mechanism. A driving disc *A* is mounted on the end of the motor shaft and has a cork face *B* which makes frictional contact with a light friction disc *C* mounted on collar *D*. The governor spindle *E* has one bearing in the driving disc while the other end of the spindle has a bearing in the outer frame (not shown). On the governor spindle are mounted, in addition to the friction disc collar *D*, the centre collar *F* and the control collar *G*. In the spindle is a groove and in the control collar *G* a feather key, so that the spindle rotates with the revolving governor. All the collars are free to move along the spindle and between each pair is a spring *H*.

In the control collar *G* is a groove into which fit the prongs of a fork-shaped control bar *J* which is able to slide on a fixed spindle parallel with the governor spindle. A spring pulls the control bar towards the left until a roller on the bar stops against the speed setting cam *K*. As the motor rotates, it will drive the governor unit at a speed determined by the position of cam *K*. In whatever position the control bar *J* is set, the friction between *B* and *C* will drive the centrifugal unit at such a speed that the centrifugal force acting on the governor masses nearly balances the compression of the governor springs. The centrifugal

force acting on the governor masses will tend to draw the collars of the governor sections together against the force of the governor springs. The pressure of the friction disc against the cork disc will thus decrease and adjust the friction to a value which will drive the centrifugal unit at a constant speed. The further the control bar J is allowed to move to the left by the cam K, the greater the centrifugal force (and therefore speed)

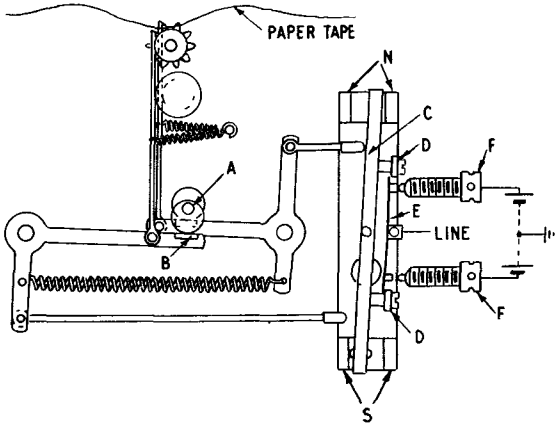


FIG. 12.11. G.N.T. WHEATSTONE MORSE TRANSMITTER: TRANSMITTER MECHANISM

required to compress the governor spring so that slipping takes place.

The two governor springs are similar, but the masses of the governor section nearer the control collar G are 16 times heavier than the masses of the other section. At low speeds the high speed section masses will hardly be deflected, the heavier masses alone performing the governing action. At a speed of about 2,000 r.p.m., i.e. 80 w.p.m., the low speed section closes up and the high speed section comes into operation and controls governing over the rest of the speed range.

The control cam K is connected to a dial by rotation of which the cam can be set to give any desired speed. The cam is cut so that the speed, as indicated on the dial, can be varied in steps of 1 w.p.m. between 13 and 30 w.p.m. and in steps of 5 w.p.m. between 35 and 250 w.p.m. The speed calibration on the dial is based on a standard word equal in length to 25 centre holes of tape. The transmitter mechanism differs from the earlier forms of Wheatstone transmitter in that the rocking beam has been dispensed with and replaced by a twin eccentric operating direct on the bell-cranks.

The transmitting mechanism is shown in Fig. 12.11. A magnetic bias adjustment of the transmitter tongue is employed instead of using a jockey roller; it is claimed that this lessens wear and so reduces maintenance replacements of parts. The twin eccentric is shown at A. Sapphires B are fitted in the bell-cranks to withstand wear. Push-rods fitted to the bell-cranks are able to move the armature C against either of the two prongs of the lower pole S of the bias magnet, the north pole N of which is also bifurcated to accommodate the other end of the armature without this touching the prongs. The magnet is pivoted at a point away from its centre to allow of adjustment to the neutral position.

The armature C carries two sapphires D which are fitted with screws having insulated distance sleeves. Behind each of these sapphires lie the ends of the contact spring E. This spring is independently pivoted and carries two platinum iridium contacts which connect with the contact screws F, the armature being connected to line and the contact screws to the positive and negative batteries as indicated.

The action in reading the perforated tape is similar to that already described for the earlier form of Wheatstone transmitter.

Cable Code Morse Transmitter. Many long distance submarine telegraph circuits employ cable code Morse signalling which requires the use of three signalling conditions, i.e. positive, negative and earth. If cable code Morse signals are sent by hand using a two-key commutator the dots, dashes and spaces are made of equal time duration. When, however, the signals are sent from an automatic transmitter controlled by a perforated tape, spaces are only necessary between characters and between words, and the spaces between the signalling elements of a character are omitted. In practice, the duration of the space between characters forming one word is the same as the duration of a dot or a dash signal and the space between words is equal to the duration of three dots or dashes. Cable code Morse signals in which the spaces between the signal elements of each character are omitted are termed "block signals" and the signalling wave form is shown in Fig. 12.12(c). In practice an earthing period is employed for the last 15–25 per cent of each dot and dash thus giving a wave form as illustrated in Fig. 12.12(b).

If the cable code signals have to be transmitted to the sea cable via a V.F. channel which only transmits two signalling conditions, then double-current cable code as illustrated in Fig. 12.12(d) is employed over the land-line section of the circuit.

In practice it is essential to obtain the maximum

traffic carrying capacity of a cable and this necessitates the use of automatic transmitters which ensure that the signal elements are transmitted as rapidly as possible and are precisely timed, including the correct earthing period following each dot and dash signal. A good example of a cable code Morse transmitter is that employed in the similar in appearance to Wheatstone perforated tape but the perforating conventions employed are different, as follows—

A dot is denoted by a single code-hole punched above a centre feed hole.

A dash is denoted by a single code-hole punched below a centre feed hole.

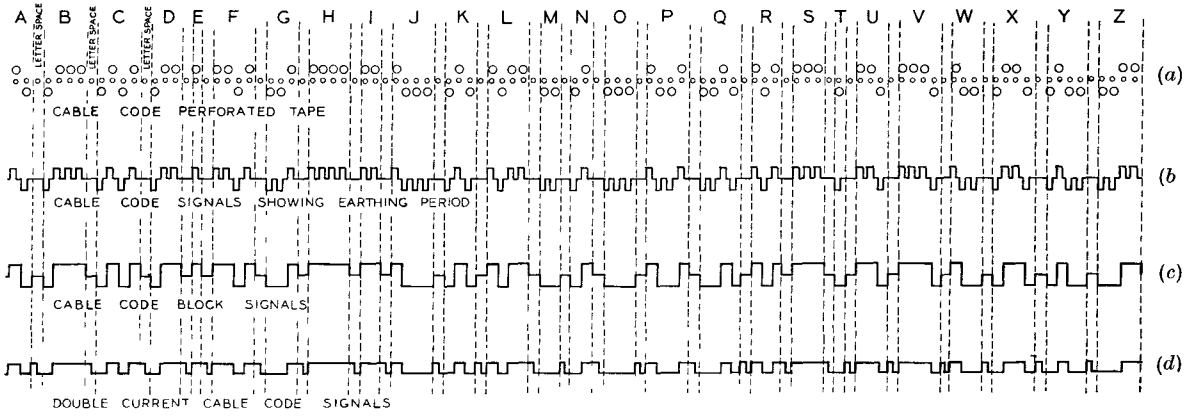


FIG. 12.12.

(*a*) Cable code perforated tape
(*b*) Cable code signals showing earthing period
(*c*) Cable code block signals
(*d*) Double current cable code (D.C.C.C.)

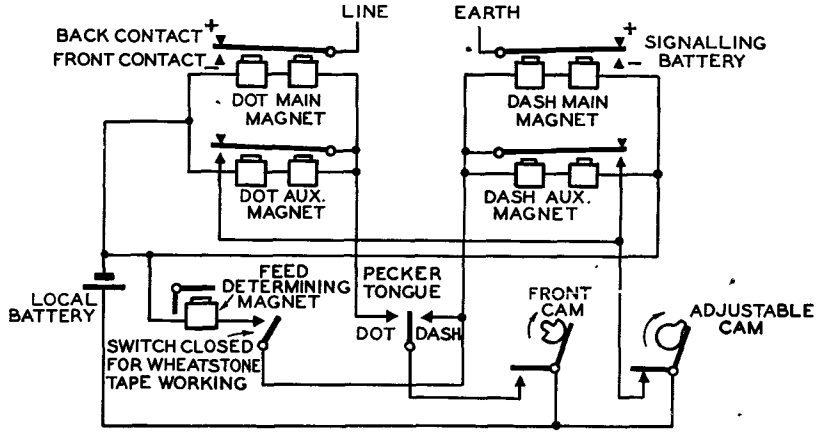


FIG. 12.13. PRINCIPLE OF OPERATION OF CABLE CODE AUTOMATIC TRANSMITTER

B.P.O. Cable and Wireless Service. This type of transmitter, known as the Judd and Fraser transmitter, is designed so that it will accept either cable code or Wheatstone Morse perforated tape, the change from one method of operation to the other being made simply by operating a switch. This feature is invaluable in offices handling both types of Morse signalling.

Cable code morse perforated tape is generally

A space is denoted by unperforated paper above and below a centre hole.

Fig. 12.12(*a*) illustrates cable code Morse perforated tape. The principle of operation of the cable code automatic transmitter is shown schematically in Fig. 12.13. The transmitter is driven by a phonic motor which derives its power from a very accurately controlled frequency source. The cable signalling speed is obtained by suitable

gearing between the motor and the signalling mechanism. The perforated tape is fed through the automatic transmitter by a ratchet mechanism which steps the tape synchronously one centre hole at a time except when Wheatstone tape is being used in which case the mechanism is so arranged that for a Wheatstone dash the ratchet feed mechanism jumps two centre holes, the second hole of the Wheatstone dash is thus missed and performs no useful function. When used with a cable code Morse transmitter, Wheatstone tape must be inserted upside down as compared with its use in Wheatstone transmitters in order that the code hole corresponding to the beginning of a dash shall be below its centre feed hole.

Two light peckers press on the perforated tape as it is drawn through the instrument. When one of the peckers passes through a perforation in the tape a dot or dash signal is initiated, as the case may be. When blank tape is passing, the peckers thrust on the underside of the paper as each centre hole is reached but as there are no perforations through which the peckers can rise, the pecker tongue is maintained in a central position between its contacts and the line therefore remains connected to earth via the armature and back contact of the dot-main electromagnet.

When a dot perforation is fed over the peckers, the dot pecker is allowed to rise through the hole in the tape and this causes the pecker tongue to move over and make contact with its left hand (i.e. dot) contact. This prepares the circuit for the operation of the dot main and dot auxiliary electromagnet from the local battery, as soon as the front cam allows its associated switching lever to make contact, which occurs a short interval after the pecker tongue has made. The front cam therefore determines the instant of commencement of each signal element. Operation of the armature of the dot main electromagnet connects the negative pole of the line signalling battery to line for the transmission of the dot signal. It should be noted that the positive pole of the battery remains connected to earth via the armature of the dash main electromagnet.

Operation of the dot auxiliary electromagnet completes a locking circuit for both the dot main and dot auxiliary electromagnets via the adjustable cam contact to the positive pole of the local battery. The locking circuit thus maintains the dot main and auxiliary electromagnets operated until the adjustable cam causes its lever to break contact. This time is adjustable by means of the cam to suit the particular conditions of the cable to which the automatic transmitter is connected. When the locking circuit is broken, the armatures of the dot main and auxiliary electromagnets return to their back contacts and this causes the line to be reconnected to the positive pole of the signalling battery which is earthed via the dash main armature. This earthing period persists until the beginning of the next dot or dash signal.

Assuming a dash perforation follows the dot perforation, then the dash pecker will rise and cause the pecker tongue to operate to its right hand (i.e. dash) contact. This prepares the dash main and auxiliary electromagnets for operation immediately the front cam contact makes and when this occurs the armature of the dash main electromagnet transfers the earth connexion from the positive pole of the signalling battery to the negative pole. Thus positive battery is transmitted to line for the dash signal. The duration of this signal and the subsequent earthing period is controlled by the dash auxiliary electromagnet and the locking circuit via the adjustable cam contacts, in a similar manner to that already described for a dot signal.

Thus to summarize, it will be seen that—

(*a*) The perforations in the tape determine the sense of the signal to be transmitted, i.e. dot, dash or space.

(*b*) The front cam controls the instant of commencement of each signal element and as it rotates once per centre hole it determines the rate at which successive signal elements are transmitted.

(*c*) The adjustable cam determines the instant, during a dot or a dash signal, at which the signalling voltage is disconnected from line and the earthing period is commenced.

When Wheatstone Morse tape is being used, a switch on the cable code transmitter is closed in the circuit of a feed determining electromagnet. The feed determining electromagnet is then actuated each time a dash signal is transmitted and this causes the tape to be fed forwards two centre holes.

Morse Signal Receivers

One of the earliest forms of instrument employed for obtaining a permanent record of hand speed Morse signals received from a line was the Direct Morse Inker (or Writer) which is described in Chapter 2 and illustrated in Fig. 2.9.

The Wheatstone Receiver. The Wheatstone Receiver was a development of the Morse Inker designed to have increased sensitivity and to cater for the higher signalling speeds employed in the Wheatstone Automatic Morse System. As in the Wheatstone transmitter, the earlier models derived their motive power from a weight driven clockwork mechanism (see Fig. 2.26). Later models are motor

driven and Fig. 12.14 is an illustration of a typical motor driven model.

The Siphon Recorder. The Siphon recorder is an extremely sensitive receiving instrument employed in submarine cable telegraphy for recording Morse or cable code Morse signals in the form of an ink trace on a moving paper tape. The principles of operation of this type of instrument is described in Chapter 2 and illustrated in Fig. 2.10.

The Undulator is a modern development of the Siphon recorder. It is less sensitive than the Siphon recorder but is much more robust and has many practical uses. It is eminently suitable for recording Morse signals from land-line or radio telegraph circuits and may be used for operation up to signalling speeds of 300 w.p.m.

A good example of a modern undulator is that manufactured by The Great Northern Telegraph Co., Ltd. and illustrated in Fig. 12.15. On the main base are mounted the front plate with driving gear and recording mechanism, the motor and speed regulator and a pair of tape wheels.

For d.c. mains operation a shunt wound motor is employed, and for a.c. mains an induction motor is used. The speed regulator is a centrifugal governor similar to that used on the G.N.T. Co.'s. Morse transmitter, see page 497, but has one governor section only.

The tape drive consists of a self-aligning pressure roller and a driving roller coupled to the speed regulator which is driven by the motor. By

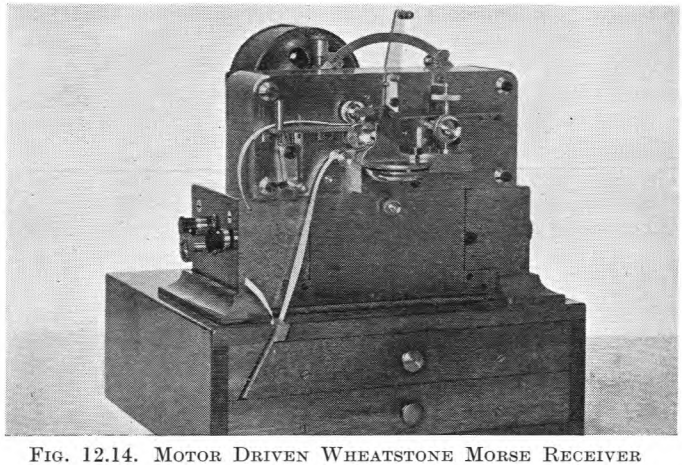


FIG. 12.14. MOTOR DRIVEN WHEATSTONE MORSE RECEIVER
(By courtesy of H.M. Postmaster-General)

altering the setting of the regulator dial, the speed at which the tape is fed may be varied within the limits of 7–45 ft per minute and the speed regulator ensures constancy of speed at any setting.

Fig. 12.16 is a schematic of the receiving portion of the instrument. The electromagnet system consists of two laminated U shaped yokes with a line coil embracing the extremity of each limb. The

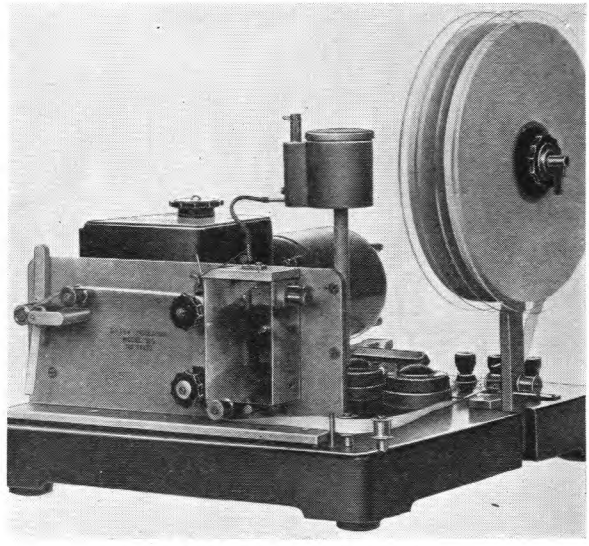


FIG. 12.15. G.N.T. UNDULATOR
(By courtesy of The Great Northern Telegraph Co., Ltd.)

four line coils are connected in series so that their fluxes are additive. The yokes are mounted in a vertical plane with their ends facing, so forming an air gap at the top and bottom between the horizontal pole shoes. In these gaps are located the ends of the armature assembly. The armature assembly consists of two long and thin permanent magnets mounted on either side of a vertical spindle so as to obtain a low moment of inertia. The spindle is pivoted in sapphire bearings at top and bottom and carries a re-inforced stainless steel or nickel siphon tube. The magnets are mounted so that opposite poles are brought together at the top and bottom of the armature.

In each of the gaps between the yokes there is, therefore, a N and S pole and thus a torque is set up on the armature assembly due to the interaction between the poles and the armature magnets and the field produced by the current in the line coils. From consideration it will be seen that as the polarities of the armature poles in the top gap are the reverse of those in the lower gap and also the direction of the electromagnet flux in the top gap is the reverse of that in the lower gap, the torques produced by the two gaps are additive in their

effect on the spindle. The spindle will thus be turned clockwise or anti-clockwise depending upon the direction of the line current.

The upper end of the spindle passes through its bearing to form a vertical extension to which the

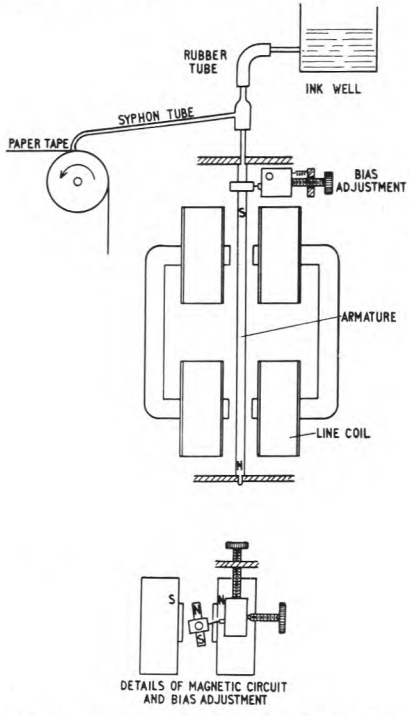


FIG. 12.16. PRINCIPLE OF G.N.T. UNDULATOR

siphon tube is fixed. The free end of the siphon tube moves to and fro, according to the movements of the armature, within the tapered cut away portion of a stop plate. The travel of the siphon tube, and thus the amplitude of the signal trace, can be regulated by moving the stop plate so that it presents a wider or narrower gap to the siphon tube.

Bias control is obtained by a narrow leaf spring clamped to the armature spindle and projecting at right angles to it. By moving an adjusting screw the spring moves the armature which can be set neutral in the gap or given a bias, if required. For double-current working the siphon tube is adjusted by means of the bias adjusting screw to trace a line in the centre of the recording tape when no current is received, whereas, for single-current operation the siphon tube may, if desired, be biased towards the front edge of the tape under the same conditions.

The Morse Reperforator is a machine which will convert direct current Wheatstone Morse signals received from a line or radio link into the equivalent perforations in a paper tape. The perforated tape so produced may then be used either (*a*) in conjunction with a Morse printer to produce a printed record of the message or (*b*) to retransmit the message to another office by passing it through an automatic transmitter on another circuit.

One type of Morse reperforator which has been extensively used for many years is that manufactured by Messrs. Creed & Co., Ltd. and illustrated in Fig. 12.17. It consists essentially of a main base on which is mounted a driving motor, an operating magnet, an escapement mechanism, a perforating head and the mechanism required for feeding and controlling the movement of the paper tape. Under the baseboard a drawer is fitted to carry the roll of paper tape which is supplied with the centre feed holes already punched.

The driving motor is a shunt wound d.c. motor ($\frac{1}{8}$ h.p.) and is supplied for two nominal voltages, viz. 110 V and 220 V. To enable the speed to be adjusted, so that it is approximately in synchronism with the distant transmitter, a rheostat is connected in the motor field circuit. Small or intermittent variations of speed, or irregularities of received signals, can be accommodated by the reperforator mechanism. A three speed gear is fitted and gives a speed range of 35–150 w p.m. with the normal motor; speeds up to 200 w.p.m.

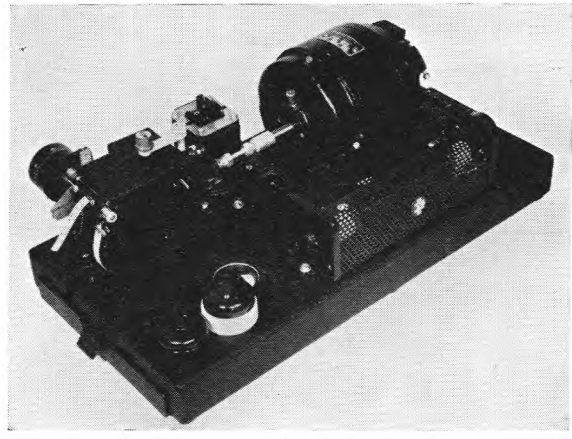


FIG. 12.17. CREED MORSE REPERFORATOR
(*By courtesy of Creed & Co., Ltd.*)

can be catered for by fitting a high speed motor. A speed indicator is fitted to facilitate accurate speed adjustment and provides a continuous visual indication of any speed differences between the reperforator and the distant transmitter.

The received signals operate a line relay which repeats them to the operating magnet. The line

relay is necessary because the operating magnet requires a current of 150 mA when connected to a 110 V supply, or 75 mA when connected to a 220 V supply.

Fig. 12.18 gives a schematic representation of the reperforator mechanism. The main shaft gear wheel A is driven by the motor and drives the gear wheel B on the clutch shaft which in turn rotates the cam via a friction clutch. Revolving with the cam and situated between the cam and the clutch is a detent, or escapement mechanism, whose movements are controlled by the operating magnet (not shown) by means of the armature extension and the yoke to which are fixed two detent plates, shown in detail in Fig. 12.19. Thus each time the armature moves from mark to space or vice versa, the inner edge of one of the detent plates disengages with the detent and the cam is permitted to revolve in an anti-clockwise direction for one half revolution, until the detent meets the inner edge of the other detent plate which has been moved into its path by the movement of the armature; the detent is then held and causes the driven portion of the friction clutch to slip. The cam moves from a position equivalent to 9 o'clock to that corresponding to 3 o'clock for a space signal and from 3 to 9 o'clock for a mark. When a dot signal is received the half revolution corresponding to mark is followed immediately by the half revolution corresponding to space, but when a dash is received the half revolution for space is delayed until the tape feed wheel has moved the tape a distance of one feed hole.

The cam has two tracks, the front track controlling the movements of the corrector rods and the rear track controlling the punches. Before the paper tape can be perforated, it is necessary in order to avoid tearing the paper during punching that its forward feeding motion shall be arrested and the tape correctly positioned. To achieve this the cam tracks are designed to allow the appropriate corrector rod to be advanced into engagement with the corresponding corrector wheel on the tape feed spindle before the punch touches the paper, and to remain in engagement until the punch is withdrawn. The tape feed spindle and tape feed wheel are driven from the motor through gears and a small friction clutch as shown. This friction clutch, on the end of the tape feed spindle, is provided to allow the paper to be held up by the corrector rods during punching, it also enables the correcting action of the corrector rods and wheels to function as explained later.

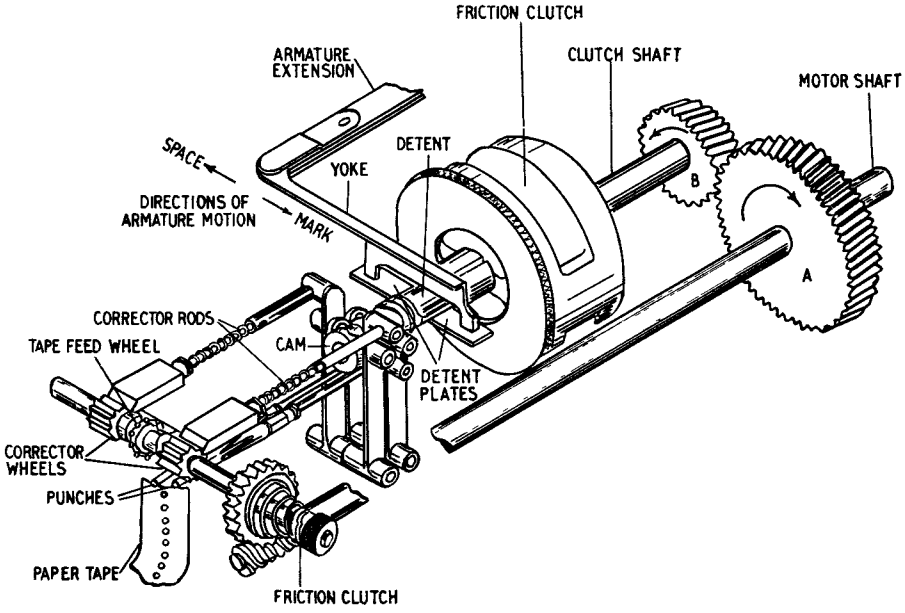


FIG. 12.18. PRINCIPLE OF CREED MORSE REPERFORATOR

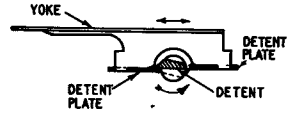


FIG. 12.19. CREED MORSE REPERFORATOR: CONTROL OF CAM BY DETENT

In the case of a dot signal, the armature of the operating magnet is operated to the marking side for one signal element and this moves the yoke and detent plates so releasing the shaft detent and cam which makes one half revolution in an anti-clock wise direction. Rotation of the cam records the marking perforations in the paper tape. When the marking impulse ceases, the armature and detent plates are returned by the succeeding spacing impulse and the second half revolution takes place and records the spacing perforation on the tape.

In the case of a dash signal, the armature is operated and held for the duration of three signal elements during which time the centre holed tape is feeding forward; consequently the spacing perforation recorded on the return of the armature will be perforated opposite the next centre hole to that facing the marking perforation. The function of the corrector rods is to compensate for distortion in the received signal; the mechanism is able to advance or retard the tape to perforate correctly signals which are either late or early. Accurate synchronism between the transmitter and the receiver is not absolutely necessary. Provided that the detent and cam are revolved at a speed which admits of two successive half revolutions being completed approximately within a period equivalent to that of a complete "reversal" the conditions for accurate reception exist. It is necessary for the centre hole in the tape to be as near as possible in line with the corrector rod at the moment of engagement. An error of 20 per cent is, however, permissible and this is taken up by the corrector rod sliding down the face of the V-groove in the corrector wheel and correcting it either forward or backward. In order to allow for the resultant movement of the tape between the withdrawal of the marking corrector and the advancement of the spacing corrector, the spacing corrector wheel is staggered by one half tooth pitch with respect to the marking corrector wheel and the spacing punch is placed $\frac{1}{20}$ in. higher than the marking punch.

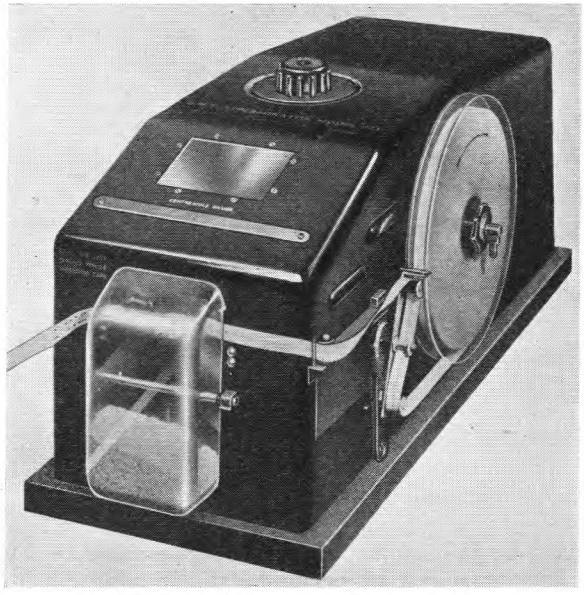


FIG. 12.20. G.N.T. MORSE REPERFORATOR: MAIN COVER ON

(By courtesy of The Great Northern Telegraph Co., Ltd.)

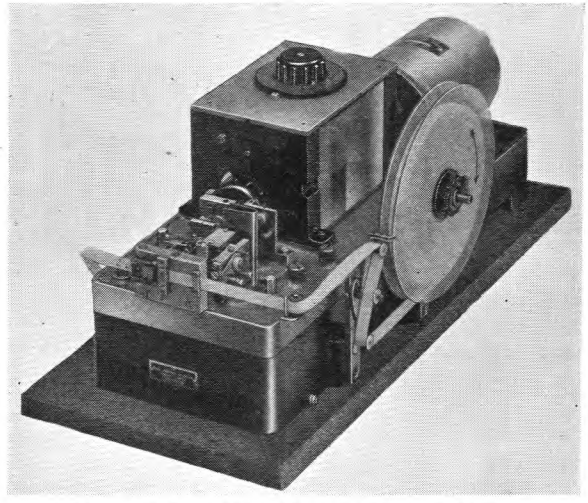


FIG. 12.21. G.N.T. MORSE REPERFORATOR: MAIN COVER REMOVED

(By courtesy of The Great Northern Telegraph Co., Ltd.)

Another design of Morse reperforator having a number of ingenious features is that manufactured by the Great Northern Telegraph Co., Ltd., this is illustrated in Figs. 12.20 and 12.21. Several improvements have been incorporated in the design of this machine, viz.—

(*a*) The instrument is designed so that signal "extras" appearing at a time when they could not have been originated by the transmitter are ignored. (This point is explained in detail later.)

(*b*) The speed range of the instrument is 40–200 w.p.m. and any speed within this range is obtained, without gear changes or stopping the motor, by turning a single control knob which is calibrated in words per minute. When the speed has been roughly set by this knob, the instrument automatically synchronizes its speed to that of the incoming signals and will automatically correct for any changes in speed of the incoming signals.

The perforating unit, synchronizing mechanism, speed regulator and motor are all fitted to the main base and housed under a common silencing cover. The tape wheel is mounted on the base but projects outside the cover. The two relays, one controlling the selector mechanism and the other the synchronizing mechanism, are mounted in the base casting and are wired in series. They are both operated by the received signals via a line relay. For a.c. mains a $\frac{1}{8}$ h.p. 200/240 V 50 c.p.s. single-phase induction motor is used and for d.c. mains a 110/160 V shunt wound motor is used. The motor drives the mechanisms via a centrifugal speed regulator which is similar in design to that described on page 497 for use with the G.N.T. Morse Transmitter but differs in that it has only one governing section. It is depicted schematically in Fig. 12.27.

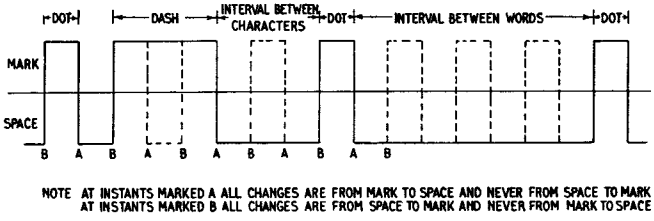


FIG. 12.22. CHARACTERISTICS OF MORSE SIGNALS

To understand the principle of operation of the instrument it is desirable to visualize clearly the nature of the signals produced by an automatic Morse transmitter. It will be remembered from page 497, that when the transmitter is running and no tape is being fed through it, signal reversals of marking and spacing are produced, i.e. a continuous series of dots. When punched tape is fed through the transmitter, the effect is to suppress the transmission of selected half-cycles. Thus, if a spacing half-cycle is suppressed, a dash is sent out and if all spacing half-cycles are suppressed a continuous marking signal is transmitted. Suppression of one marking half-cycle gives the interval between characters, i.e. three half-cycles of spacing and suppression of three marking half-cycles gives the interval between words, i.e. seven half-cycles of spacing.

Reference to Fig. 12.22 shows how perfect signals are formed. It will be seen that marking elements always occur in intervals *B–A*, whilst spacing elements always occur in intervals *A–B*, except in dashes. For a top (marking) hole to be recorded by the reperforator, part of a marking element must always extend into a region *B–A*. Similarly for a bottom (spacing) hole to be recorded, a part of a spacing element must always extend into a region *A–B*. Thus, if a marking element is received wholely within an *A–B* interval, it is clearly not in accordance with the signal sent from the distant transmitter and is treated as false, and not recorded, by the reperforator. The same applies to a spacing element occurring wholely within a *B–A* interval. This facility for detecting and ignoring spurious signals is achieved by blocking the selecting mechanism as explained later. It avoids false recording due to the reception of split dots, or dashes split at the beginning or end of the signal.

When the receiver is running in synchronism with the distant transmitter, all change-overs of signalling condition will occur at the correct instants in the revolution of the receiving mechanism. However, if the receiver is not running at quite the same speed as the transmitter, a growing phase (i.e. time) difference will arise between the incoming signals and the receiving mechanism. In the G.N.T. reperforator this phase difference is used to—

(*a*) shift the receiving cam shaft relative to the driving mechanism to correct for the phase difference and

(*b*) to correct the setting of the speed regulator.

These actions will be explained later.

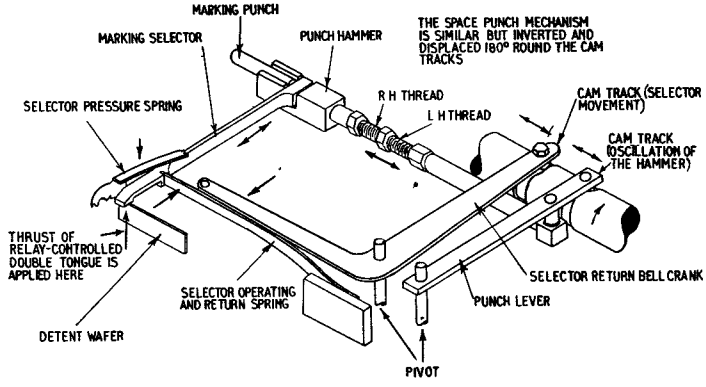


FIG. 12.23. G.N.T. MORSE REPERFORATOR: ACTION OF PERFORATING UNIT MARKING PUNCH

The perforating mechanism is shown in Figs. 12.21 and 12.23. The receiving cam rotates synchronously with the transmitter and makes one revolution for each complete dot; it is provided with four cam tracks. The track nearest the back bearing causes the two punch hammers to move forward and backward alternately once per

revolution. A punch hammer is in its forward position during a small portion of the revolution only.

If plain tape is used, so that the reperforator has to produce centre holes, the centre hole punch is

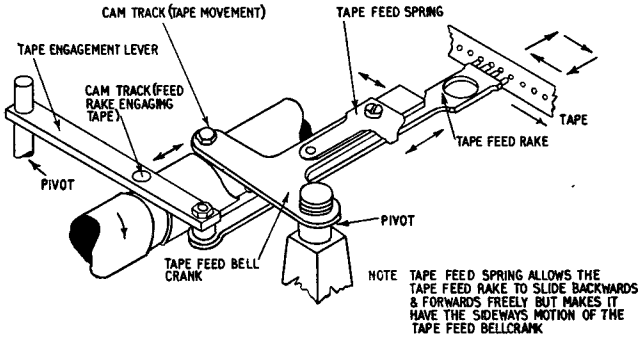


FIG. 12.24. G.N.T. MORSE REPERFORATOR: ACTION OF TAPE FEED MECHANISM

fitted to the mark hammer and consequently a centre hole is produced each time this punch hammer travels forwards, i.e. once per revolution, irrespective of whether a marking signal hole is perforated or not. However, if desired, the centre hole punch may be removed and paper tape, with pre-punched centre holes, used.

The rear end of each signal-hole-punch lies loosely in the slot in its punch hammer and is shaped so that the punch is always retracted when the hammer is retracted and will be pushed forward to perforate only when a selector has previously entered the gap in the hammer behind the punch, this happens only when the selector is released by the perforating relay.

The second track from the back operates two return bell cranks which cause the two selectors alternately to be kept retracted from the path of the punches for about a half of a revolution. The return bell-cranks thus serve the double purpose of returning the selectors to normal after a perforation and of providing a blocked interval during which faulty signals will not be accepted.

During the next half revolution, the return bell-cranks allow a spring pressure to be applied to the selectors, tending to make them enter behind the punches. If, during the period when this pressure is applied, a selector is released by the perforating relay the selector will enter behind the punch end and, at the end of the period, cause a signal hole to be perforated, whereupon the selector will be retracted for the next half revolution.

The third and fourth cam tracks are provided for the tape feed arrangement, see Fig. 12.24. The third track controls the engagement of the tape feed rake with the centre holes in the paper tape and the fourth track operates the tape feed bell-crank which feeds the tape forward, one centre hole at a time, while the rake is in engagement, and returns the rake to its starting position when it is disengaged from the paper tape.

The feed takes place in the interval between the moments when a spacing hole and a marking hole are, or can be, perforated, the tape being at rest for about 290° of a revolution. The selecting mechanism is shown in Figs. 12.25 and 12.26. On the side of the perforating unit is mounted the selector head on which a thin steel plate, the double tongue, is pivoted on a horizontal pin. The downward extending part of the tongue can move between two adjustable stops and is provided with a stud which engages with the tongue of the perforating relay. The forward extending horizontal part of the tongue is thus moved up and down as the relay moves the lower part in response to the received signals. The horizontal part is split into two blades, which are rigid in the direction of travel but separately resilient when pushed sideways.

The ends of the two selectors slide in the selector

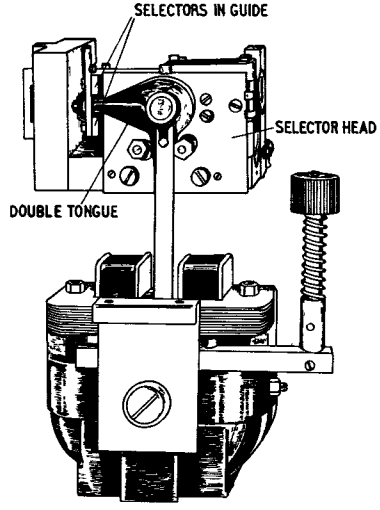


FIG. 12.25. G.N.T. MORSE REPERFORATOR: RELAY AND SELECTOR DOUBLE TONGUE

guide on the selector head. The previously mentioned alternate spring loading of the selectors is timed to synchronize with the marking and spacing periods of the reversals from the distant transmitter, but as the selectors are provided with detent notches near their ends, see Fig. 12.26, and are constantly spring loaded towards the detent

wafer in the selector head, they will move in behind the punches only when pushed off the detent by the double tongue.

Fig. 12.26/1 shows the double tongue in the spacing position ready to throw the marking selector off its detent, and if this happens at any time during the 180° where the selector is spring loaded, the selector will move in behind the punch, the double tongue will complete its travel and the lower blade will move in above the opposite selector end, ready to throw the selector off.

At the end of the 180° period, a marking hole will be perforated and the marking selector will be retracted under the action of the second cam track, the end of the selector will bend back the upper blade of the double tongue and the selector will finally catch on the detent.

The cycle of operations described is depicted in Figs. 12.26/1 to 12.26/6 which will assist in following the sequence.

If the electrical impulse causing the movement of the double tongue had started, and again ceased, within the period when the marking selector was retracted and blocked by the action of the second cam track, the sequence of events described could not have been completed, the end of the marking selector would have remained in the path of the double tongue which therefore could not have completed its movement and the lower blade would not have moved off the end of the spacing selector. It will be seen, therefore, that a signal is ignored when it could not have been initiated by a synchronous transmitter and that the punching of marking and spacing holes must alternate.

If, however, the electrical impulse causing the movement of the double tongue had started during the period when the marking selector was retracted and blocked, but had not ceased until just after the marking selector became spring loaded (and no longer blocked), the double tongue would throw the selector off its detent at the moment spring loading occurs and a hole would be punched.

Whilst a correctly placed impulse of about two milliseconds duration will be recorded, an "extra" of a duration corresponding to a complete signal element will be entirely ignored if 180° out of phase.

The arrangement of the synchronizing mechanism is shown in Fig. 12.27. Synchronization is obtained automatically from the received signals which control the operation of an epicyclic gear which adjusts the phase of the output spindle in accordance with the signals received. In addition, the speed of the speed regulator is automatically corrected to coincide with the speed of the signals being received so that correct phase and speed are maintained.

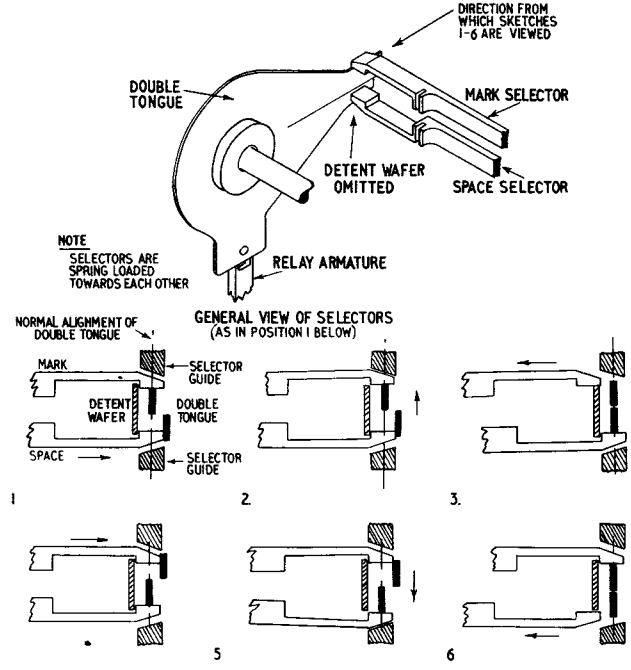


FIG. 12.26. G.N.T. MORSE REPERFORATOR: ACTION OF THE SELECTOR DOUBLE TONGUE

1. Space selector just returned and is retained by the detent wafer. Double tongue ready to dislodge mark selector.
2. Space-mark signal received. Double tongue moves upwards releasing mark selector from detent wafer.
3. Mark selector moves in behind mark punch due to the pressure of the selector operating and return spring. Double tongue completes its upward movement and the space blade of double tongue can assume its natural alignment.
4. Mark selector returned by action of selector bell crank and selector return spring and is retained by the detent wafer. Double tongue has its mark blade pushed back but its space blade is ready to dislodge the space selector.
5. Mark-space signal received. Double tongue moves downwards releasing space selector from detent wafer.
6. Space selector moves in behind space punch due to the pressure of the selector operating and return spring. Double tongue completes its downward movement and the mark blade of the double tongue is free to assume its natural alignment again.

The epicyclic gear body, and with it the bearings of the planet wheels, is normally held stationary by the worm wheel, mounted on the forward end of the body and engaging with the normally stationary horizontal corrector worm spindle. This spindle comprises a ten toothed star wheel, the worm and a ten toothed ratchet wheel with square teeth. The star wheel engages with a spring-loaded retention roller whereby the corrector worm spindle is firmly positioned for each one-tenth of a revolution. The double pawl is pivoted in the end of the

synchronizing cam lever and is given a reciprocating motion by the synchronizing cam. The two pawls, on the prongs of the double pawl, are thus oscillating on either side of the ratchet wheel, normally without actuating it, but if the double pawl is deflected at a suitable moment a pawl will

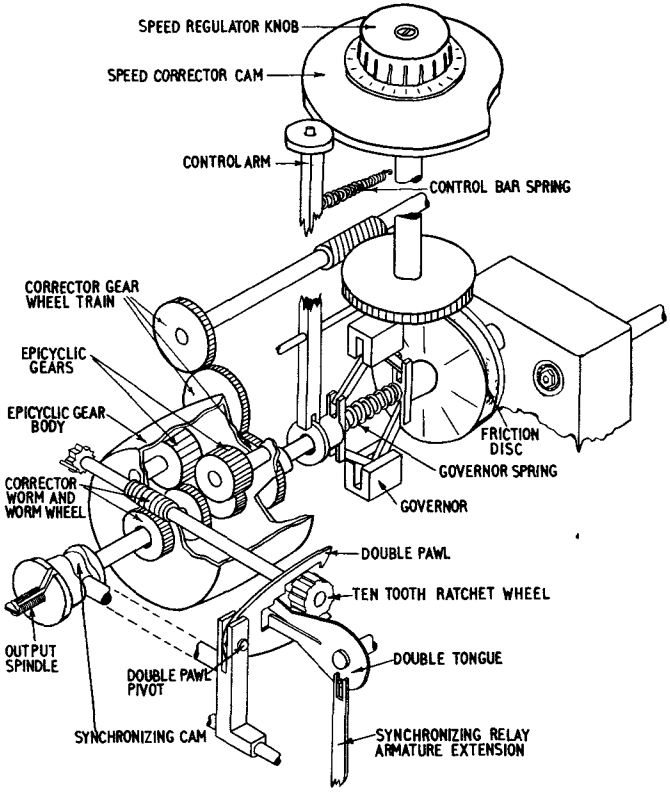


FIG. 12.27. G.N.T. MORSE REPERFORATOR: PRINCIPLE OF SYNCHRONIZING MECHANISM

engage and turn the ratchet wheel. As a consequence, the epicyclic wheel is turned and the output spindle, driving the synchronizing and perforating cams, is advanced or retarded in phase in relation to the input spindle.

About half-way between the pivot and the pawls, the fork of the double pawl is provided with vertical steps making the space between the prongs narrow towards the pivot. Into this space extends, at right angles, a thin, flat double tongue similar to that used on the selector head. This tongue is operated by the synchronizing relay.

The steps of the double pawl can touch the tongue only during part of the double pawl's travel. When not touching, the tongue can start and complete its motion without moving the pawl up or down.

When the tongue is at rest against either stop, one of the steps will continually bend one blade to and fro as the pawls oscillate. The position and width of the blades in conjunction with the heights of the horizontal parts of the steps ensure a strictly horizontal oscillation of the pawls so that the ratchet wheel cannot be engaged.

A synchronous signal with its phase correct will not influence the pawls, because the blade spacing to marking movement occurs in the wider gap of the forked pawls, just before the steps can touch, and a marking to spacing movement occurs just as the upper pawl has missed its opportunity of engaging a tooth. Should, however, marking to spacing have occurred somewhat earlier in the cycle, e.g. due to the reperforator running slow, the double pawl would have been pressed downwards and the upper pawl would have engaged the tooth of the ratchet wheel, turning it one-tenth of a revolution and, through the epicyclic gear, advancing the phase of the perforating unit by 6°.

A spacing to marking movement of the blades occurring a little late, e.g. due to the reperforator running fast, will no longer be completed at once, because the upper blade will then meet the horizontal part of the upper step, tending to lift the double pawl and keep on lifting until the lower ratchet engages on the pawl's next working stroke, thus ultimately causing the phase to be set back by 6°. If not counteracted in the meantime by a new marking to spacing movement, the original spacing to marking movement of the blades will be completed when the wider gap in the double pawl is reached.

The epicyclic gear body carries a wheel which, through a reduction worm gear and a friction plate, turns the dial of the speed regulator, altering the governed speed slightly in such a direction that the phase correction will tend to cease.

The Morse Printer is a machine which when fed with a Wheatstone Morse perforated tape, prepared on either a Morse perforator or a Morse reperforator, senses the character combinations of the perforations and translates them into printed characters on either a paper tape or in page form on a paper roll. Thus it consists essentially of mechanism to feed and control the perforated tape, a selecting mechanism, a translating and printing mechanism, a paper tape or page unit and a driving motor.

Fig. 12.28 is an illustration of the tape printing type of Morse Printer manufactured by Creed &

Co., Ltd. The motor and the functional mechanisms are mounted on the main base as shown. It is designed to operate at speeds up to 100 w.p.m.

The motor is a shunt wound d.c. motor, $\frac{1}{8}$ h.p., and is supplied for two nominal voltages, viz. 110 V and 220 V.

The machine will print one character, or one space, per revolution independent of the length of the character combination received, i.e. it will print O, the longest character combination in the Morse code, in the same time as E, the shortest character combination.

Fig. 12.29 is a schematic representation of the tape feeding, the selecting and translating and printing mechanisms. The perforated tape is fed forward, by a pinion wheel, in a guide-way over a series of ten pairs of selectors (one pair of which is shown). When a selection is being made these selectors are permitted to rise, under the action of springs, until their ends either come into contact with the paper tape or pass through a perforation in it. Thus, those selectors which correspond to perforations in the tape move upwards further than the others which are blocked by the tape. Engaging with each selector is an actuating lever, pivoted at its centre on the actuating lever carriage. As a result of the upward movement of the selectors, the further extremities of the actuating levers are set in one of two positions, depending upon whether the selectors controlling them have passed

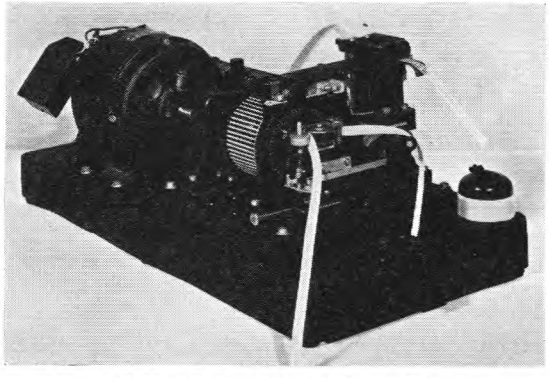


FIG. 12.28. CREED MORSE TAPE PRINTER
(By courtesy of Creed & Co., Ltd.)

through a perforation. When moved to the lower position, by the selector passing through a perforation, they are brought into line with the tops of the extensions of the combination combs and, on being moved to the left by the actuating lever carriage, turn these combs through a small angle. When in the upper position, the extremities of the actuating levers, in their movement to the left, pass over the comb extensions and the combs are not moved.

The combination head is similar to those used on teleprinters, and for each character the combs are set so that a channel, or slot, through the set of combs is presented to the bell-crank corresponding

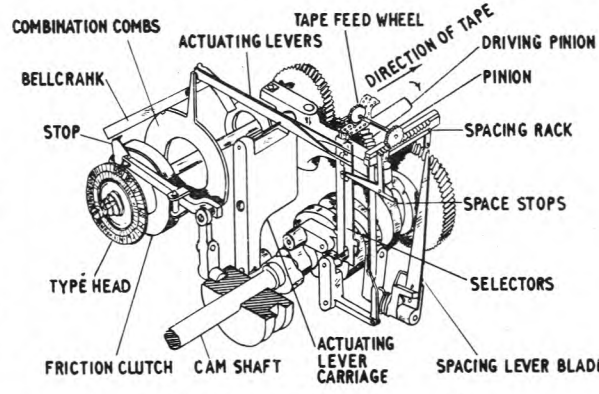


FIG. 12.29. PRINCIPLE OF CREED MORSE PRINTER

to the character. The bell-crank drops into this slot under the action of its spring. The combination head spindle is driven through gears by the motor and rotates the type-head and type-stop friction clutch.

When the selected bell-crank has dropped into its slot its outer end projects into the path of the type stop and thus the rotation of the type-head is arrested causing the clutch to slip. Immediately after the type-head has ceased to rotate, a type-hammer, operated from the cam on the main shaft, strikes the back of the type directly opposite the paper tape which passes round a rubber faced platen positioned in front of the top of the type-head. Thus the selected character is printed. The types are inked by means of small rollers charged with ink which can be readily changed when exhausted.

The platen is rotated one letter space per revolution of the camshaft by a feed pawl working on a ratchet wheel and the paper tape is moved forward ready for the succeeding character to be printed. After the operations of selecting and printing are completed, the bell-crank is restored by a suitable cam motion, and the stop and type-head again revolve until the next character is selected. The perforated tape is positioned in a guide plate and is fed forward by a star-wheel which engages with the feed holes and which is fitted to a small spindle carrying a toothed wheel which is rotated as required by the movements of a cam-controlled rack. (*Note.* As in the case of the Morse perforator, a

variable feed is required to cater for the differences in the number of signal elements for the various characters.) The rack is given a forward motion by means of the spacing lever blade for feeding purposes, but is disengaged from the toothed wheel on its return so that the tape is fed only in the forward direction.

The extent of the forward movement of the rack is controlled by its preceding backward movement and this is limited by the distance to the first space

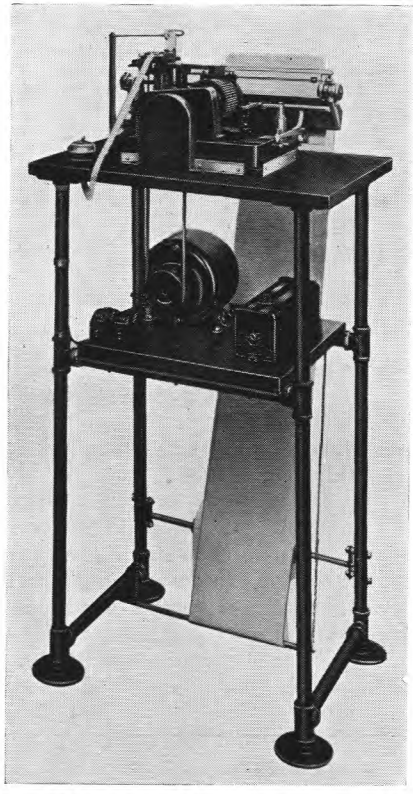


FIG. 12.30. CREED MORSE PAGE PRINTER
(By courtesy of Creed & Co., Ltd.)

signal, that is, the length of the character combination concerned. To provide for this limit, there is a group of ten space levers, or space-stops, normally in the path of the rack and preventing its backward movement. Only one of these space stops is shown in Fig. 12.29. Each space-stop is also in the path of one pair of selectors and, when either selector of a pair passes through a perforation in the tape, the corresponding space-stop is moved out of the path of the rack. Hence, with any letter or figure of the Morse code, there is a clear backward path for the feed rack until it reaches a space signal, or a portion of the perforated tape bearing centre holes only, in which case no space stops are moved. It will be seen that the length of the forward feeding movement is controlled by the distance the rack travels back to the first unmoved space-stop. The lost motion on short character combinations is taken up by the flexible spacing lever blade.

On the page printer, in place of the small circular platen, is a long platen, similar to those used on page teleprinters, mounted on a suitable carriage which enables the platen to be moved clear of the type-head to facilitate the renewal of the ink rollers and cleaning of the types. Fig. 12.30 gives a view of a Creed Morse Page Printer. The mechanism of the page printing unit is similar in principle to that used on the Teleprinter No. 7 (see Chapter 11) and is connected to the main feed lever on the base of the machine through a universal joint. When the printer is in operation the carriage is fed along, one character at a time, for each revolution of the camshaft and in doing so winds up the carriage return spring. On arrival of the carriage return signal the carriage is returned to its normal position under the influence of the carriage return spring and an automatic line feed is also given.

Code Converters

These equipments were developed some years ago by the B.P.O. primarily for use at stations connecting networks using morse and teleprinter codes, e.g. stations in the Cable and Wireless Service. By the use of code converters the retransmission of traffic from a circuit using five-unit code to one using Morse code, or vice versa, can be done automatically, thus saving time and operating expense.

Because the only relationship between Morse and teleprinter codes is through the characters they represent, code conversion in these instances is essentially a process of decoding and recoding. Also whilst Morse is a code with characters of non-uniform duration (i.e. variable number of code elements) and there is no standard speed of transmission, in contrast, teleprinter character signals have a constant number of elements and the speed of transmission is standardized. Because of this, some form of message storage is necessary and, as it is the Morse code which has the variable characteristics, it is most convenient to store the messages as Morse code punched in paper tape.

Other problems arise from the fact that Morse does not require the use of case-shift signals and only uses one code for brackets and one for combined line-feed and carriage-return when page

printing is used. Five-unit code on the other hand has two cases (viz. Figures and Letters), two bracket codes and separate codes for line-feed and carriage-return.

The code converters which have been adopted by the B.P.O. comprise a combination of mechanical and electronic techniques. There is no doubt that a wholly mechanical solution is practicable and indeed certain manufacturers, e.g. the Great Northern Telegraph Co., have developed such models in more recent years. The B.P.O. design is the easiest expedient using standard existing machines (i.e. Morse Keyboard Perforators and Creed Morse Printers), to perform the essentially mechanical functions. Moreover, the use of electronic techniques facilitates the performance of several desirable functions in conversion.

Five-unit to Morse Converter. This equipment, shown in Fig. 12.31, receives five-unit teleprinter signals from line, or from an automatic transmitter, and produces a paper tape perforated in Morse code. The converter can, if desired, be easily modified to produce a paper tape perforated in cable code.

Provision has been made for the conversion of all the characters of the Teleprinter No. 7 except WRU, %, @, £, Bell and =.

Line-feed and/or carriage-return may be converted to $\overline{\text{BT}}$ which gives a combined carriage-return and line-feed on Morse page printers. If the Morse is required for aural reception, carriage-return and/or line-feed may be converted to word space. A key has been provided to give this facility. The sign + is converted to $\overline{\text{AR}}$ whilst the opening bracket, (, and closing bracket,), are both converted to ().

The equipment consists essentially of five basic units—

1. A distributor.
2. A Five-unit code and case register.
3. First stage decoder.
4. Final stage decoder.
5. Perforating unit.

The distributor consists of six cold-cathode valves arranged as a chain counting circuit. A train of timing impulses at the correct transmission speed and phased to occur at the nominal mid-instants of the incoming signal elements operate the counter. Each valve in the distributor is thus associated with a particular signal element (including the start element), at the nominal mid-instant of which it strikes and produces a positive impulse. The impulses from the code element valves of the distributor are fed to the primers of the corresponding valves in the register and are used for examining the polarity of the incoming signals.

The register has five pairs of cold-cathode valves which correspond to the five code elements. One valve of each pair is used to record marking signals and the other to record spacing signals. The incoming signals are fed to the appropriate register valve, mark (M) or space (S), which will strike and become conducting when the impulse is received from the distributor. The code represented by the incoming signals is thus recorded on the valves of the register. The register has another pair of valves

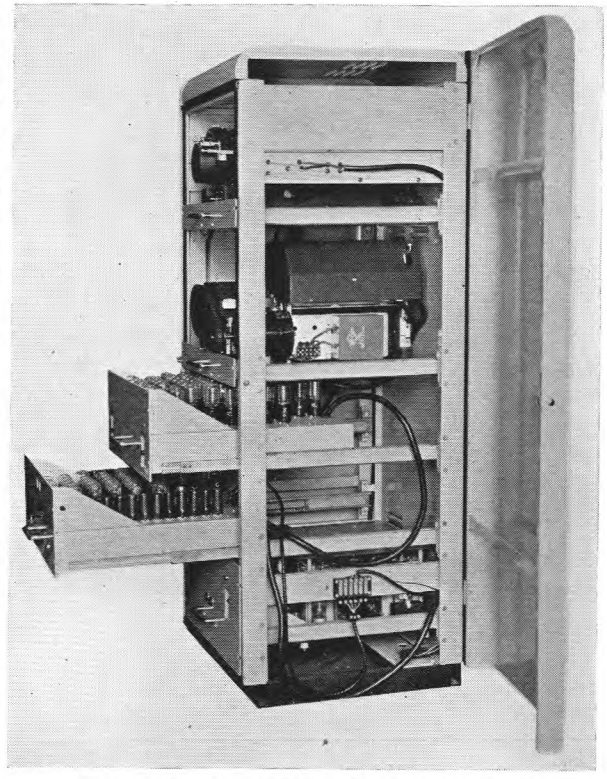


FIG. 12.31. BRITISH POST OFFICE 5-UNIT TO MORSE CODE CONVERTER
(By courtesy of H.M. Postmaster-General)

which are used to record the "case," i.e. letters (L) or figures (F), of the incoming signals.

The cathodes of the register valves are connected via networks of resistors, rectifiers and capacitors to the primers of two groups of "first stage" decoding valves. The case, and first and second element register valves are connected to one group of eight first stage decoding valves, similarly the register valves corresponding to code elements three, four and five are connected to the second group of eight cold cathode valves. The interconnexions between the register and first stage

decoding valves are so arranged that for any received character combination one valve only will strike in each first stage decoding group.

The "final stage" decoder consists of eight rows of eight cold-cathode valves with the anodes of most valves connected to special electromagnets associated with character selector bars on the Morse perforator. Each valve of the final decoder

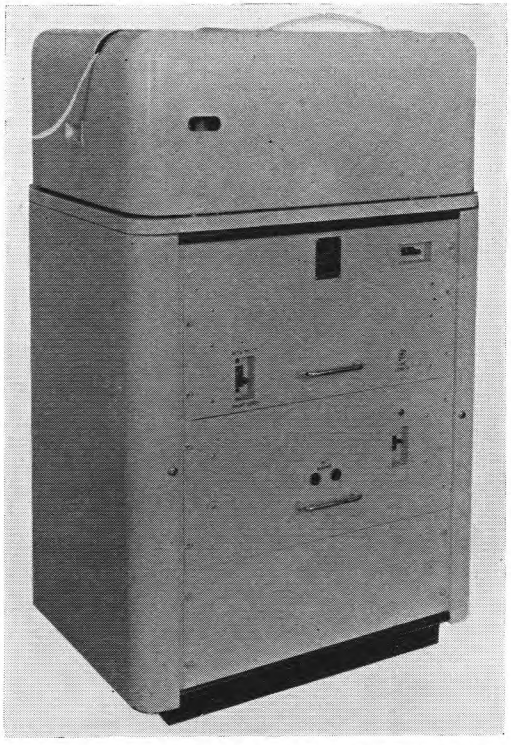


FIG. 12.32. BRITISH POST OFFICE MORSE TO 5-UNIT CODE CONVERTER
(By courtesy of H.M. Postmaster-General)

unit corresponds to one teleprinter character. The primers of the final stage decoder valves are connected down the rows, via resistors, to the cathodes of the eight valves of the first group of first stage decoding valves, and across the rows, via capacitors, to the eight cathodes of the second group. Thus when the first stage decoding valve in the first group strikes, it applies a positive bias to the primers of the eight valves in the appropriate row down the final decoder. Later in the receiving cycle when the valve in the second group of first stage decoding valves strikes, it applies a positive impulse to the primers of one row of valves across the final decoder. Only one final decoding valve, which corresponds to the received character, receives both the positive bias and the impulse which cause it to strike and energize its associated electromagnet fitted on the modified Creed Morse Perforator, so operating the appropriate selector bar. At the same time a clutch electromagnet is energized to release the perforating mechanism.

As can be seen from Fig. 12.31, the receiving unit (distributor, register and first stage decoder), the final decoder unit and the power unit have been made in the form of drawer units which mount on runners fitted in a steel cabinet. Similar drawer units have been fitted for the perforator and for an automatic transmitter. The interconnexions between the various units are made by flexible cords which are of such a length that the converter can be operated with any individual unit withdrawn to the full extent or even removed from the cabinet. These arrangements provide excellent accessibility for maintenance purposes.

The converter requires an a.c. mains supply of 200–250 V, 50 c/s and consumes about 200 W for the electronic apparatus and 65 W for the perforator motor.

Morse to Five-unit Code Converter. A view of this converter is shown in Fig. 12.32. It is designed to accept a Wheatstone Morse perforated tape and produces the corresponding five-unit start-stop signals at the output.

Provision has been made for the conversion of all the characters used on the teleprinter No. 7 except WRU, %, @, £ and Bell. $\overline{\text{BT}}$ (=) and $\overline{\text{AR}}$ (+) are both converted to carriage-return, line-feed, although they may be converted to = and + respectively if the equipment is to operate to a tape teleprinter. Brackets, (), is converted alternately to the opening bracket, (, and closing bracket,). Case-shift signals are inserted automatically, the input tape feed being arrested for one character period. Character counting with automatic insertion of carriage-return and line-feed at the first space following a predetermined number of feed characters is also provided.

The decoding of the Morse is effected by the mechanism of a Creed Morse Printer which is modified for this purpose as follows. The normal motor is replaced by a governed motor with a speed of 3,000 r.p.m. which, via an additional gear unit, drives the normal selecting mechanism of the printer and also an output distributor. The type-head of the printer is removed and replaced by a rotary selector, called the decoder distributor, which is fixed to the stop arm of the normal clutch assembly. This decoder distributor has one outlet for each position of the type-head, i.e. for each character. The printer is fitted also with an output, or transmitter distributor, which is a $7\frac{1}{2}$ unit distributor and is driven at a speed of 400 r.p.m., i.e.

signalling speed 50 bauds. A five-unit electronic coder, consisting of miniature cold-cathode gas-filled diodes, is mounted on the base of the printer.

As can be seen from Fig. 12.32, the modified printer sits on top of a steel cabinet which houses the remainder of the electronic equipment and the power unit in drawer units similar to those already described for the five-unit to morse converter.

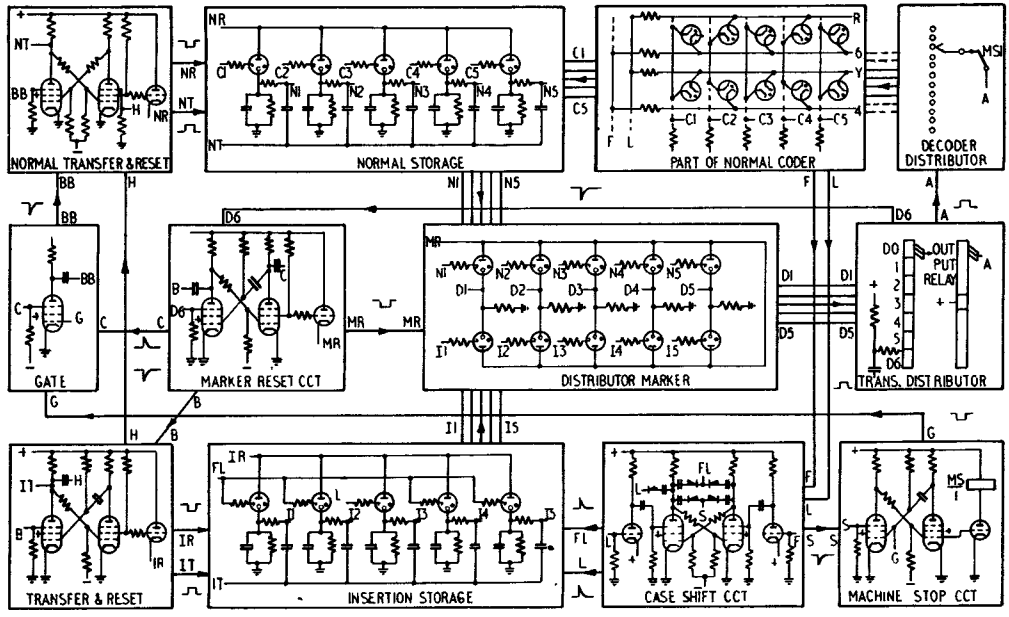


FIG. 12.33. MORSE TO 5-UNIT CODE CONVERTER: BLOCK SCHEMATIC CIRCUIT DIAGRAM

The mechanical portion is provided with a metal cover.

The power supply for the electronic equipment is derived from 50 c/s mains, 200/250 V, the consumption being about 90 W. The motor and line current supplies are the same as for the Teleprinter No. 7.

To assist the understanding of the functioning of the converter a block schematic circuit is shown in Fig. 12.33.

When a Morse tape is fed into the modified printer, and a character is read, the brush arm of the decoder distributor comes to rest on the outlet proper to the selected character. The outlets of the decoder distributor are connected to the electronic coder which converts to the five-unit code for the character concerned. The coder has two groups of cold-cathode valves to cater for the letter case and figure case, and when a character is selected by the decoder distributor, the valves, in the correct case group, corresponding to marking elements of the five-unit character code, are energized and their outputs cause the corresponding valves in the normal storage unit to strike.

When the previous character has been transmitted, the passage of the transmitter distributor brush over the stop element segment operates the marker reset circuit which, in sequence, operates the normal transfer and reset circuit. This latter causes a transfer pulse to be applied to the storage stages so that the conditions stored there are transferred to the distributor marker and, at the same time, the storage valves are extinguished to await a new selection. The valves which are struck in the distributor marker apply a positive potential to the corresponding segments of the transmitter distributor. The brush arm of the distributor is connected to line via an output relay and as the brush arm traverses the segments of the distributor the five-unit code, together with the start and stop signals, is transmitted to line as double-current signals.

When a case-shift occurs, the case-shift circuit sets up the appropriate shift code in the insertion storage unit and also operates the machine stop circuit; this causes the tape feed to be interrupted for a character period and breaks the pulsing circuit to the decoder distributor. In addition, the gate between the marker reset and normal transfer circuit is closed so that the character requiring

the case change is retained in the normal storage unit until the case-shift code has been transmitted. Normal action is then restored.

The facility of automatic insertion of carriage-return and line-feed is provided, this occurring at the first space after a predetermined number of characters. The space outlet from the tape reader is not connected to the normal coder, but is connected with the alternative coder in which cold-cathode triodes are used instead of diodes. In this,

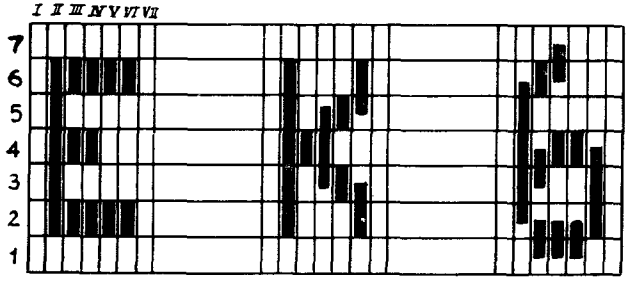


FIG. 12.34. CHARACTER FORMS USED FOR E, K AND 6 IN A 7-LINE HELL PRINTER

only valves which are already primed will operate, so that the code which is set up is controlled by other circuits besides the selection of the space outlet. Ordinarily the space code is set up in the normal storage, but when the counter has reached its preset limit, the space connexion is switched to set up carriage-return in the insertion storage and line-feed in the normal storage, the following action being similar to that for shift insertion. The setting up of the code resets the counter. If the Morse tape contains the carriage-return code, this operates the counter to the limit immediately and the operation is initiated by the space following it. The brackets code is also dealt with in the alternative coder, the translation being switched alternately to give opening and closing brackets.

Hell Telegraph Instruments. The basic principles of the Siemens-Hell telegraph system have been explained in Chapter 1. This method of working, although not used very extensively, has proved of value on certain forms of telegraph communications over radio circuits, e.g. long distance radio broadcasting of press messages. It gives a printed record of the messages received and is capable of operating satisfactorily even under adverse radio propagation conditions. The radio receiving equipment required is not elaborate and the printer is simple and easy to maintain. The principal disadvantage compared with other telegraph systems, e.g. Morse and five-unit, is that it involves the use of high baud speed, and this is the fundamental factor which has restricted the field of the use of the system.

The apparatus employed consists of a sender, i.e. a transmitter, a printer and a thermionic receiving relay device.

The Hell printer translates the received signals into printed characters on a paper tape, each character being built up within a rectangle which may be imagined to be divided into seven horizontal and seven vertical strips so as to form 49 rectangular elemental areas (see Fig. 12.34). The first and last (I and VII) vertical columns are always left blank to maintain separation between characters and the top and bottom rows are also (with exceptions) left blank to give marginal spaces, thus the actual printed character is contained in an area of 5×5, i.e. 25 elements of area in any of which a mark can be made.

Fig. 12.34 shows the make-up of the characters E, K and 6. The black portions, which represent the actual character, correspond to the current impulses (i.e. marking signals) received on the printer as a result of the operations of the sender. The blank spaces correspond to the intermediate no-current periods (i.e. spacing signals).

A pictorial representation of the current impulse sequence sent out by the transmitter for each character may be obtained if the seven vertical columns (I to VII) are arranged in numerical order from left to right one after another in a straight line, each column being numbered from the lower end. In this manner the current diagrams shown in Fig. 12.35 are derived from the character diagram given in Fig. 12.34.

The Hell sender is available in two basic forms, i.e. one which is keyboard operated and one which is controlled by a perforated tape and is thus an automatic sender. In each case the current sequences of the various characters are produced mechanically by means of circular cam discs. A typical cam disc for the letter E is shown in Fig. 12.36 and should be compared with the current diagram for letter E given in Fig. 12.35.

The cam discs for all the characters are mounted adjacent to one another on a common shaft which, driven by a motor, revolves continuously at a predetermined speed. On the keyboard operated model the speed of the cam shaft is 2·5 r.p.s. and thus the telegraph speed is $49 \times 2{\cdot}5 = 122{\cdot}5$ bauds. On the automatic model the cam shaft speed is 5 r.p.s. and the telegraph speed is thus 245 bauds.

Over each cam disc is mounted a pair of contact springs, open when at rest, in such a position that normally they are not affected by the humps of the cam disc. However, when a key on the keyboard is depressed or, in the automatic model, a character combination on the perforated tape is interpreted,

an operating arm is inserted between the cam and the contact springs of the appropriate character and, as the cam rotates, the humps cause the contact springs to be closed and a current sequence is sent to line according to the contour of the cam disc. The pairs of contacts for all cam discs are wired in parallel and connected in the line, or line relay, circuit. In order that the signals shall always be transmitted in the correct sequence for each character, i.e. not begin out of phase, the mechanism is arranged so that the operating arm only comes into operation when the beginning of the cam disc, i.e. the beginning of sector 1 in Fig. 12.36, reaches the contacts. During the transmission of any one character sequence, the keyboard of the hand operated model is locked to prevent premature operation of another key, thus it will be seen that the keyboard needs to be operated rhythmically and a skilled operator is essential. It is also arranged that the holding down of a key for longer than one cam revolution will not cause the repeated transmission of the same character.

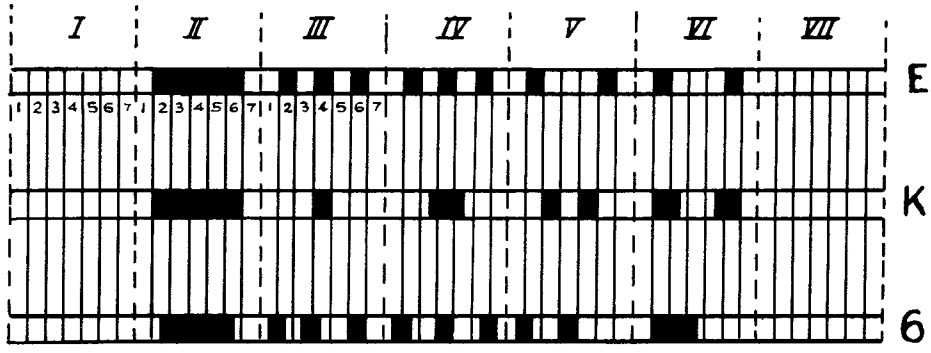


FIG. 12.35. CURRENT ELEMENT SEQUENCES FOR E, K, AND 6 IN HELL SYSTEM

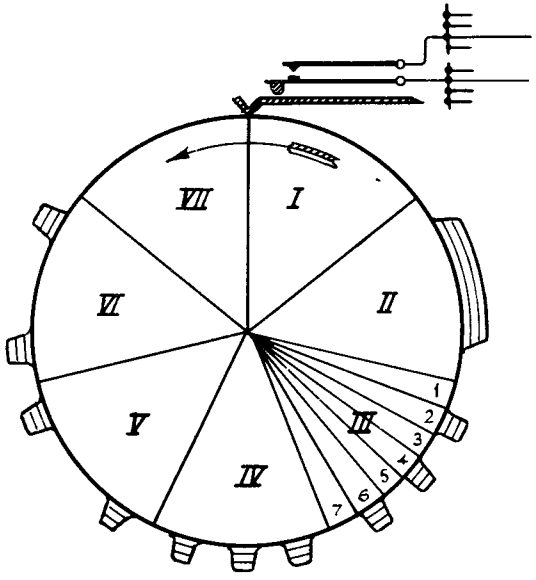


FIG. 12.36. HELL SYSTEM: CONTACT CAM FOR LETTER E

On the keyboard sender a keyboard similar in layout to those used on teleprinters is fitted on the front of the main base, on which are mounted the system of levers associated with the keys, the assembly of cam discs and contact spring sets and the driving motor which is fitted with a centrifugal type governor.

Fig. 12.37 gives a schematic representation of the mechanism and the key for the letter E is shown operated (i.e. depressed). It will be seen that depression of the key lever has caused the release lever to be rotated on its pivot thus releasing the control lever which has moved under the influence of its spring and caused the operating arm to be moved so that its end is between the cam and the

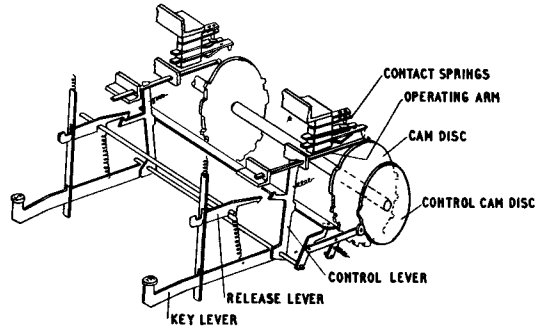


FIG. 12.37. PRINCIPLE OF HELL KEYBOARD TRANSMITTER, KEYBAR FOR LETTER E DEPRESSED

contact springs, which are operated by the cam humps as the disc is rotated.

The control cam disc, with only one hump, serves the purpose of restoring to its rest position at the end of the revolution of the cam shaft, any key lever, and associated levers, which have been brought into operation.

Automatic senders have largely superseded the manually operated keyboard senders. These are controlled by a perforated paper tape on which the message to be transmitted has been perforated in the five-unit teleprinter code.

In place of the keyboard mechanism, five horizontal selector bars, similar to the combination bars on a teleprinter keyboard, are fitted and lie parallel to the cam shaft. At the right hand side of the machine is fitted a tape sensing unit which has five peckers which control the position of the five selector bars in accordance with the perforations in the tape. Thus each row of perforations in the

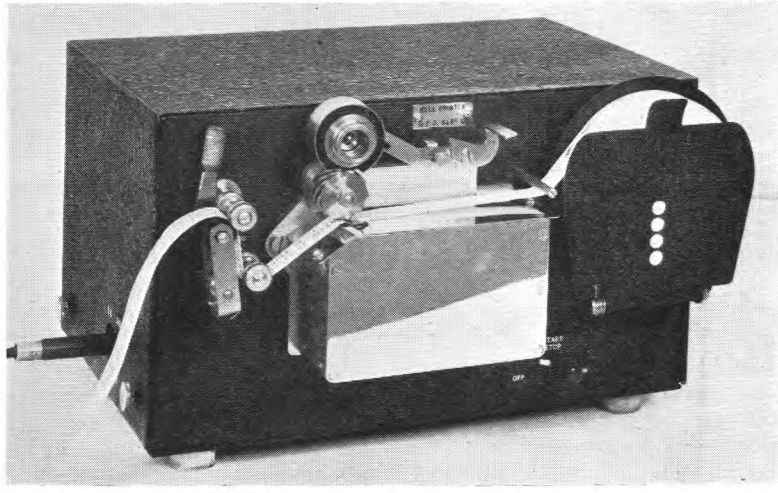


FIG. 12.38. GENERAL VIEW OF HELL PRINTER
(By courtesy of H.M. Postmaster-General)

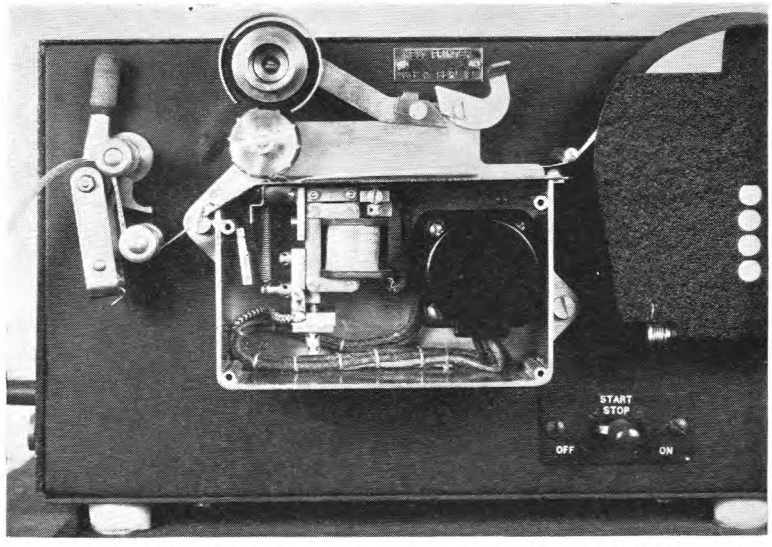


FIG. 12.39. HELL PRINTER SHOWING CLOSE-UP VIEW OF PRINTING AND TAPE FEED MECHANISM
(By courtesy of H.M. Postmaster-General)

tape, i.e. each character combination, is sensed by the peckers and a combination is set up on the selector bars which virtually take the place of the key levers on the keyboard model. According to the setting of the combination bars, the corresponding system of levers is operated and the operating arm for the character concerned is moved between the cam disc and contact springs, and transmission of the character combination in the Hell code is achieved.

A typical Hell printer is shown in Fig. 12.38. It consists of a printing mechanism, paper tape feed mechanism, driving motor with centrifugal type speed governor and an automatic starting and

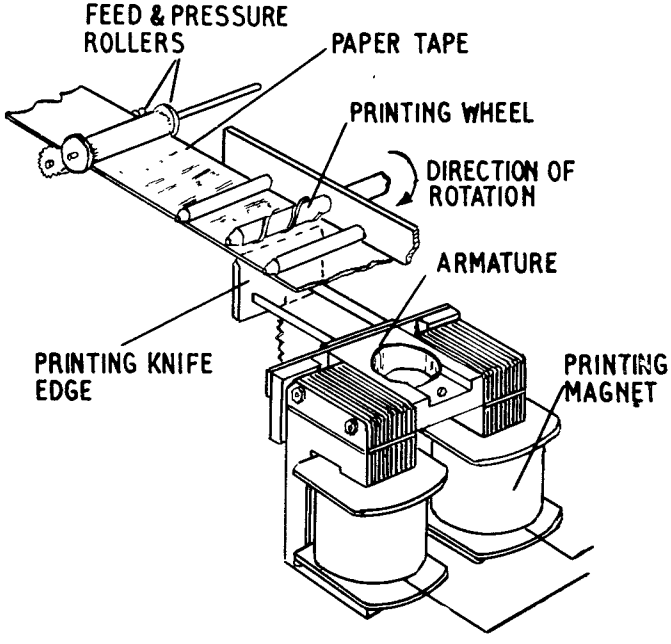


FIG. 12.40. PRINCIPLE OF HELL PRINTING MECHANISM

stopping device. Fig. 12.39 gives a close-up view of the printing and tape feed mechanisms (with cover plates removed) whilst Fig. 12.40 shows the printing mechanism schematically.

Whilst the motor is running and the pressure roller is engaged so that it presses the paper tape against the feed roller, the tape is fed forward at a speed determined by the setting of the motor governor which has an external knob by which it can be adjusted. The printing knife edge is attached to the armature of the printing electromagnet which is energized by the incoming signals. The printing wheel has a raised helical writing edge on its surface which is inked by means of an ink roller, see Fig. 12.39, situated immediately above the printing wheel.

Thus as the electromagnet is energized the printing knife edge is moved upwards and presses the paper tape against the raised helical writing edge on the printing wheel and a mark is made on the tape. The obliquity between the helical writing edge and the knife edge is such that the area of contact between the tape and the inked helix is small and the duration of the shortest signal is such that the

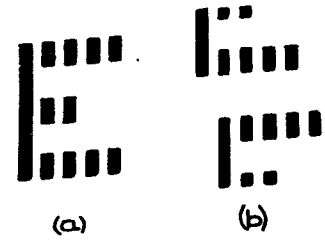


FIG. 12.41. HELL SYSTEM
(*a*) Letter E printed at correct speed
(*b*) Letter E printed at incorrect speed

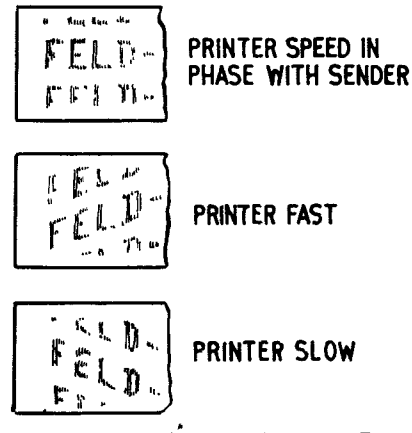


FIG. 12.42. HELL SYSTEM: TYPICAL PRINTING ILLUSTRATING EFFECT OF SPEED ERROR

corresponding mark occupies one of the 25 elements of printing area. A complete vertical line as in the letter I is formed by a signal duration of five times the shortest signal and the speed of the tape is slow relative to the peripheral speed of the helix so that the line formed is nearly, though not quite, perpendicular to the edge of the paper tape.

Fig. 12.41(*a*) shows how the letter E appears when printed. The marks forming a letter are so close together that when viewed from normal reading distance they appear as a letter rather than separate marks. The width of the paper tape is sufficient to accommodate two characters and if

the writing helix is taken twice around the printing wheel, as shown for simplicity in Fig. 12.40, the two characters will be printed one above the other. In practice a number of writing helices are provided on the printing wheel, as for example on a multi-start screw thread; this enables a lower speed of rotation of the printing wheel to be employed and gives the most satisfactory printing arrangements. The double printing is done to avoid the necessity for complicated phase synchronization between the sender and the printer. If only one line of characters were printed and the two machines were out of phase the line of characters would slant upwards (printer running fast) or downwards (printer running slow) and the characters would ultimately become split, see Fig. 12.41(*b*). With the practice of printing two characters one will always be complete and readable.

The nature of the characters printed is shown on Fig. 12.42 which also shows the effect of the printer running fast and slow.

To avoid the necessity for continuous supervision of the printer, a start-stop device is incorporated. This is an electrical circuit arrangement which provides for automatic starting-up of the motor on receipt of a half-second starting signal and for automatic stopping if no signals are received for a period of ten seconds.

In practice the Hell system is principally used for transmission over radio links, the output from the sender being used to key the radio transmitter. At the receiving end the output from the radio receiver is passed through a thermionic relay device which converts the pulses of tone from the radio receiver into single-current pulses suitable for the operation of the Hell Printer electromagnet.

CHAPTER 13

FACSIMILE AND PICTURE TELEGRAPH SYSTEMS

THE noun "facsimile" (pronounced fak-sim-il-e, with the accent on the second syllable) means an exact reproduction and the object in facsimile telegraphy is to transmit and receive telegraphically in such a way that the received copy is an exact reproduction or image of the original picture, drawing, message etc.

There is sometimes confusion in the use of terms, which seems to arise from the American practice of reserving the name "facsimile telegraphy" for the transmission of, for example, purely black and white subjects, such as written, typed or printed messages, line diagrams or charts, or sometimes for any system not using photographic reproduction: whilst using "picture telegraphy," or "photo-telegraphy," when the transmission of intermediate tones and photographic reproduction is involved. This restriction of the meaning of facsimile is at variance with the recommendations of the British Standards Institution (B.S.I.) and it is considered preferable that "facsimile" should be used as the all-embracing name of this system of telegraphy, leaving "picture telegraphy," or "photo-telegraphy," with the narrower meanings that they clearly suggest.

The description "documentary facsimile" is used in this chapter for the case of systems which merely produce a readable copy of a written, typed or printed message, or a line diagram, etc.: as distinct from "photo-telegraphy," which is the most refined form of facsimile telegraphy and in which the object is to produce a photographic copy of an original, which for all practical purposes is indistinguishable from a direct photographic copy. Documentary facsimile systems usually employ "direct-recording" receiving equipment whereby the received signals reproduce a facsimile copy of the original document by direct-recording on to a sheet of special paper,* without the need for any further processing. The special types of paper employed in the receiver, which will be described later, are sensitive to electric current and reproduction of the message is dependent either on an electrolytic or burning action.

The transmission requirements in facsimile telegraphy are more exacting than in all other systems of telegraphy, for the latter are concerned solely in transmitting messages and receiving them correctly in some convenient form. In facsimile telegraphy the form and tone of the received image must at all points be a faithful copy of the original and the only concessions made are that received copy may be larger or smaller than the original, and may be in monochrome even when the original is coloured. (Colour facsimile telegraph systems have recently been invented but are not yet in any considerable use.) In view of the stringency of these demands, it is interesting to note that inventors essayed to meet them, with some success, more than 100 years ago, showing a very clear appreciation of the problems to be solved.

The Scope for Facsimile Telegraphy. The principal uses of facsimile telegraphy are as follows—

(1) The transmission of photographs, notably for publication in the press. This is conducted on a world-wide scale using both land-line and radio transmission channels.

(2) The transmission of documents, weather maps, instructions, etc., not in the nature of ordinary telegrams. A special case is the transmission of such information in private transmission networks, e.g. in parts of America instructions to train crews are transmitted to rail-side kiosks at remote parts of the system.

(3) As an alternative to the telephone-telegram service for public telegrams on the lightly-loaded feeder routes fringing a main teleprinter network, and possibly as a competitor for some of the phonogram traffic handled by subscribers. Similar scope can be found on private telegraph networks. Developments in this type of service can be confidently expected.

(4) In wireless broadcast services, to give the subscriber (the listener) a permanent record of news, weather forecasts, etc., as a supplement to speech and television broadcasts. This type of service is making some progress in the U.S.A. where there are many privately-owned broadcast networks.

(5) The transmission of any kind of text in languages for which the teleprinter is unsuitable, either because there are too many characters in the alphabet or there is no real alphabet at all, as in Chinese. In general, also, facsimile telegraphy can be claimed to have the advantage that it avoids many of the language difficulties that can arise in the international operation of other systems of telegraphy.

* A recently-developed direct-recording system employs a percussion method of recording an inked impression on ordinary paper.

The Fundamental Technical Problems in Facsimile Telegraphy. The problems which have to be solved in facsimile telegraph systems are—

(1) How to explore systematically the picture to be transmitted, so that the picture intelligence can be translated through light energy, or otherwise, into an orderly series of recognizable electrical signals.

(2) How to transmit these electrical signals faithfully over the land-line or radio transmission channel and

(3) How to recognize the received signals synchronously and in correct phase, so that they may be used by reconversion into light energy, or by other means, to reproduce the appropriate picture tone at every point within a contour of shape similar to that of the original picture.

The principal ways of solving these problems and the various designs of facsimile equipment adopted are indicated in the following pages.

General Principles of Scanning at the Sender. The orderly exploration of the picture in the sender is known as "scanning." When we scan a page of a book in reading, our eyes follow the lines of print in sequence and always from left to right, and it is by some such orderly means that the picture in a facsimile sender must be scanned.

There are, broadly, three kinds of material to be scanned, namely—

(1) A single page, which is usually wrapped into cylindrical form on a drum. This category includes photographs.

(2) Narrow continuous paper tape.

(3) Continuous sheet paper, which may be considered as broad tape. In a special experimental high-speed system described by the R.C.A. (Bibliography No. 6) the intelligence to be transmitted is first photographed on to 35 mm cinematograph film.

Two methods of scanning are in commercial use—

(1) Optical scanning, in which a light spot projected by a lamp (or lamps) and optical system explores the photograph or copy. This method is invariably used for photo-telegraphy and is also most commonly used for documentary work.

(2) Resistance scanning, used for direct-recording documentary work in the U.S.A. in the Western Union Deskfax system.* This particular system has been introduced commercially only in recent years but the principle is a century old. The scanning is performed by a stylus touching the document and it is arranged that the characters offer more (or less) electrical resistance than the base. This is described in a later section.

* In later models of Deskfax equipment, resistance scanning has been abandoned and optical scanning is used.

In the experimental R.C.A. system already mentioned the film is scanned by a beam from a kinescope (cathode ray) tube, the beam covering the picture area in the same general way as in a television viewer. Very rapid scanning is possible, because the beam has no inertia, but systems designed for very high speeds can only have specialized application, on account of the limitations of transmission over ordinary telephone circuits.

Cylindrical Scanning in Photo-telegraph Senders. The page to be scanned is wrapped around (or less commonly, within) a cylindrical drum which rotates at a constant speed. The scanning device views only a small elemental area of chosen size at any instant. The scanning may be performed in three ways, viz.—

(1) As a continuous spiral, like a close-coiled spring or a fine pitched machine screw.

(2) As a series of discrete rings having their plane perpendicular to the axis of the drum.

(3) As a combination of the above, so that a bent trace is followed for each revolution.

Method (1) is favoured by most makers, the axial movement of the drum relative to the scanning device being produced, as in a lathe, by a nut driven by a simple lead-screw of very fine pitch (say $\frac{1}{100}$ in.) equal to that of the scanning spiral. In a type of machine designed by the B.P.O. and manufactured by G.E.C. for the use of Cables and Wireless Ltd. (and also in the Muirhead-Belin portable sender) the same result is effected without having to use a lead screw of such fine pitch.

The method in the G.E.C. equipment is to drive the drum by a hollow shaft located inside which, but free to rotate relatively, is a lead-screw having a pitch $\frac{1}{10}$ in. The drum is driven at 60 r.p.m. and the lead-screw at either 54 or 66 r.p.m. in the same direction. A nut on the lead-screw keys with a sliding fit into a slot, or keyway, inside the hollow shaft, so that the nut rotates solidly with the hollow shaft but may slide freely along inside it. The nut turns on the lead screw at $66 - 60$ (or $60 - 54$) $= 6$ r.p.m. $= \frac{1}{10}$ r.p.s. and therefore advances $\frac{1}{10} \times \frac{1}{10} = \frac{1}{100}$ in. per second.

In method (2), which is not commonly employed, it is necessary to produce the small axial movement during the brief part of each revolution when the picture is not actually being scanned, that is when the clips which hold the picture to the drum are passing the scanning device.

Method (3), adopted by Muirhead and Co., Ltd., will be found later in this chapter under a description of the Muirhead-Jarvis picture telegraph equipment.

In the usual case the optical, or light, scanning

consists of brightly illuminating the picture and collecting reflected light, using a lens system or optical head. In the majority of modern equipments the optical head is fixed and the drum both traverses and rotates. In the earlier German machines, made by Siemens-Karolus-Telefunken, and in at least one modern machine, the optical head does the traversing.

There are two methods of illuminating the drum and collecting the reflected light. In the first method a tiny area only of the picture is illuminated, determined by the fineness of scanning and being, for example, of the order of $\frac{1}{100}$ in. square when scanning at 100 lines per inch. This is achieved by projecting light through a suitably shaped mask, and focusing an image of the mask on the drum by means of a microscope objective. As much as possible of the reflected light is collected by one or more lens systems. This method is shown in Fig. 13.1.

In the second method, shown in Fig. 13.2, a larger area of the picture is illuminated, by focusing an image of the lamp filament on the drum. Light reflected from this area is collected by an objective lens, having in its focal plane a tiny aperture which passes a spot of light of the required size for the scan, of the order of $\frac{1}{100}$ in. square. This second method is usually preferred, because in the first method the shape and position of the scanning spot can be distorted by mechani-

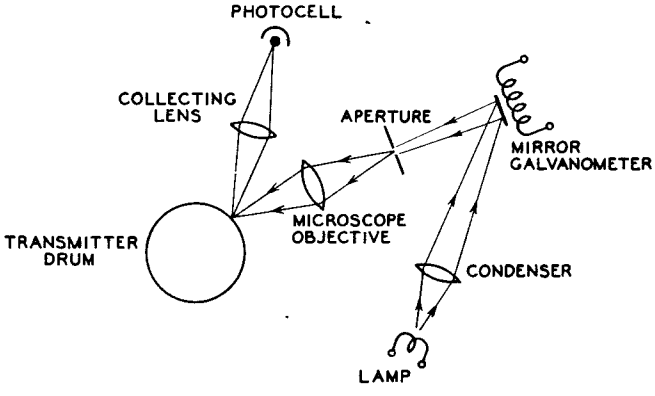


FIG. 13.1. SCHEMATIC DIAGRAM OF TYPICAL TRANSMITTER OPTICAL SYSTEM PRODUCING AN ILLUMINATED PICTURE AREA OF THE SIZE OF THE SCANNING SPOT

cal irregularities in the picture on the drum. In each case the collected light impinges on a photoelectric cell, which will be described later.

Scanning a Continuous Tape. In a tape (direct-recording) documentary system the scanning proceeds in a series of close lines across the moving tape and the illumination spot must be caused to sweep across the tape at such frequency as to produce the desired number of traces per inch of tape.

One way of causing the spot to sweep is that

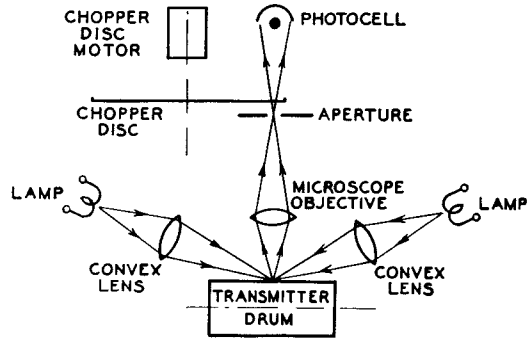


FIG. 13.2. SCHEMATIC DIAGRAM OF TYPICAL TRANSMITTER OPTICAL SYSTEM ILLUMINATING A PICTURE AREA LARGER THAN THE SCANNING SPOT

adopted by the R.C.A. illustrated in principle in Fig. 13.3. A hexagonal glass prism is rotated in the path of the scanning beam and, as the tilt of each face varies, the emergent beam is continuously deflected whilst remaining parallel to the incident beam. As each fresh face enters the incident beam, the emergent beam starts a new sweep. Cylindrical (instead of spherical) lenses are used, the first of which projects a narrow beam of light on to the prism and the second of which focuses the moving beam into a spot on the tape.

Methods of scanning a wide tape (or continuous page) have been devised, but are not yet often used on account of the practical difficulties in comparison with scanning on a drum.. The difficulties are—

(1) If the scanning sweeps are to be always in one direction, it is difficult with conventional optical scanning to avoid wasting time between the sweeps.

An experimental high speed system devised by Philips' Electrical Ltd. (Bibliography No. 11), does, however, use optical scanning of continuous sheet up to 20 cm wide, employing three optical systems rotating within a cylinder over which the paper is draped.

The difficulty would be less in the case of resistance scanning, as more than one stylus could be used.

(2) If the scanning sweeps are made alternately in opposite directions to avoid lost time, then another difficulty is introduced because of the need for a higher degree of accuracy of synchronization

between sender and receiver. With one-way scanning the effect of asynchronism is to cause all scanning lines to slope in one direction in the received copy, thus giving a skew to it, whereas with bothway scanning asynchronism causes alternate scanning lines to slope away from each other.

Photo-electricity and Light-sensitive Cells. Whatever the method of optical scanning used, reflected or transmitted light of varying intensity (and of varying colour in the case of coloured subjects) has to be converted into electrical variations. This is made possible by use of the phenomena of photo-electricity, the discovery of which must be considered among the most important advances towards practical facsimile telegraphy, equalled only by the development of thermionic valves.

The phenomena of photo-electricity can be grouped under two main headings—

(*a*) Photo-electric emission.

(*b*) Photo-conductivity.

Light is a form of energy and light falling on a body is capable of imparting some of its energy to electrons near the surface of the body, exciting them into greater activity. If the body is an electrical conductor, e.g. a metal, free electrons near the surface can be accelerated sufficiently by the light energy to leave the body and, if a neighbouring electrode is given a relatively positive potential, the free electrons will stream to it and form an electric current; this freeing of electrons by the light energy is called "photo-electric emission."

All metals are photo-emissive in varying degree. If the body is a non-conductor there are no free electrons near the surface in the absence of light but incident light can give up some of its energy in freeing some of the electrons. They will not be so accelerated as to leave the surface but only sufficiently to cause the non-conductor to behave as a conductor. This effect is "photo-conductivity." In a similar way the conductivity of a poor conductor may be increased by the effect of light.

At this point it is necessary to digress for a moment to deal with one or two points which are necessary for the further understanding of photo-electricity.

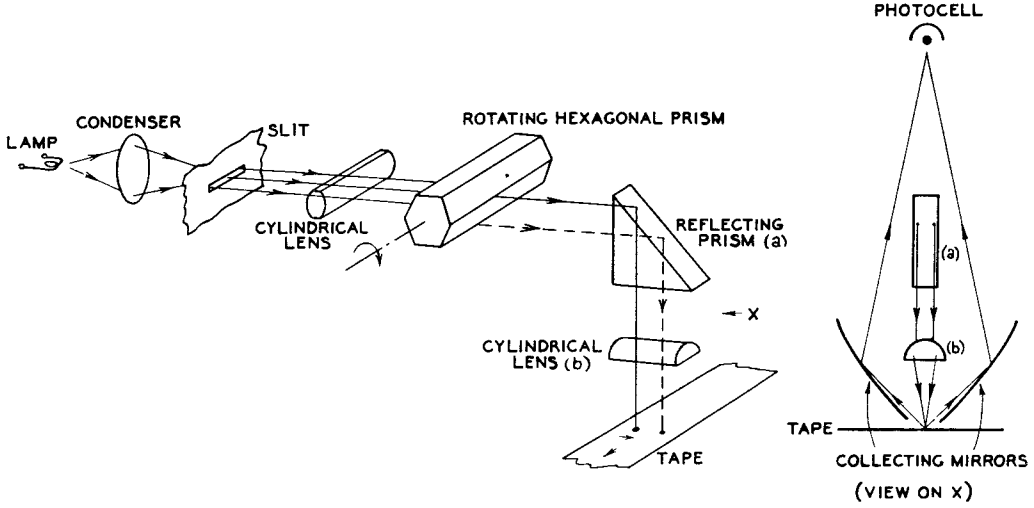


FIG. 13.3. SCHEMATIC DIAGRAM OF R.C.A. TAPE FACSIMILE SCANNER

Light is propagated as an electro-magnetic radiation, in much the same way as a radio wave, and in both cases the characteristics of the radiation vary with the wave length. Light waves have a very short wave length which is measured in Ångstrom units (abbreviated as Å). 1 centimetre $= 10^8$ Å.

Visible or white light comprises radiations of all the colours of the rainbow from red (approximately 7,000 Å) to violet (approximately 4,000 Å). However, radiations in the infra-red and ultra-violet parts of the spectrum may also provoke photo-electric effects.

Photo-emission. The photo-electric current emitted by a conductor is extremely small, measurable only in micro-amperes. The current varies for different metals and for different wave-lengths of incident light, there being, in fact, for every metal some particular maximum wave-length beyond which photo-emission is not produced. Most metals are actually unaffected by visible light and

infra-red radiation but respond to ultra-violet radiation. There are, however, a few metals namely lithium, sodium, potassium, rubidium, caesium, strontium and barium which produce appreciable photo-emission due to visible incident light.

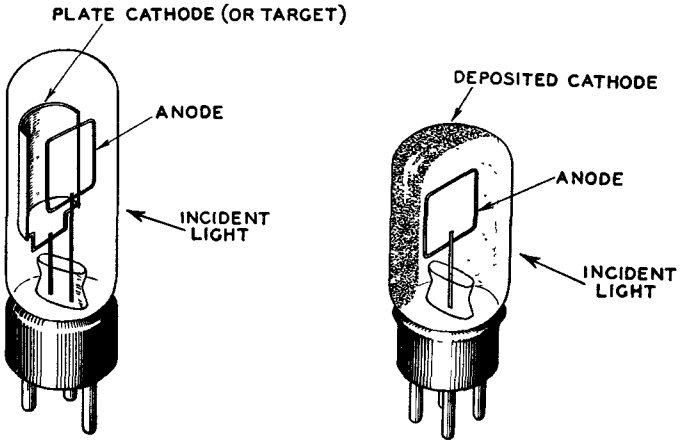


FIG. 13.4. TWO TYPES OF PHOTO-EMISSION CELLS USED IN FACSIMILE TELEGRAPHY

The photo-electric current emitted by a metal surface in a vacuum is proportional to the incident light flux (measured in lumens) and variations of the photo-electric current occur without measurable time lag, i.e. instantaneously with the light variations. If the metal is not in a perfect vacuum, but in an inert gas such as argon or helium at extremely low pressure, the electrons emitted from the metal surface produce other free electrons by collision with the gas molecules. Thus the presence of the gas causes increased sensitivity, and although the photo-electric current is increased, the proportionality between the incident light flux and the photo-electric current produced is not necessarily affected appreciably. However, a small time lag occurs in this case between a change in the incident light and the corresponding change of photo-electric current, but not such as to be objectionable at the frequencies applicable in conventional methods of facsimile telegraphy.

Photo-emission Cells. Fig. 13.4 shows two types of photo-emission cells used in facsimile telegraphy. They are about the size of ordinary radio receiving valves. Vacuum cells are usually known as "hard" cells, whilst those containing a gas at low pressure are called "soft" cells.

The target, or cathode, upon which the light is projected may be deposited on the glass of the cell wall or it may be a plate. In the commonest type of cell the base of the cathode is silver, which is first oxidized and then heated in a vapour of caesium so that a complex oxide is formed with an extremely thin surface layer of caesium. The anode may be a single wire or a wire grid. Fig. 13.5 shows the approximate shape of the response curve of a typical caesium oxide cell. It will be seen that there is a peak in the ultra-violet region and another larger peak in the red and infra-red region, whilst the response to blue is relatively poor. Overall, the caesium oxide cell gives a better response to visible light of all frequencies than any other type of cell.

In facsimile telegraphy the illumination of the photo-cell will normally come from a tungsten filament lamp which, as also shown in Fig. 13.5, will, at normal running temperatures, provide more energy in the red region than in the blue region (the actual shape of the curve varying with the temperature of the filament). This characteristic of the lamp light further exaggerates the response of the cell to light reflected from a red subject compared with a blue subject. However, so far as black and white subjects are concerned this arrangement is ideal because the maximum overall output is achieved, which is important when dealing with such small outputs.

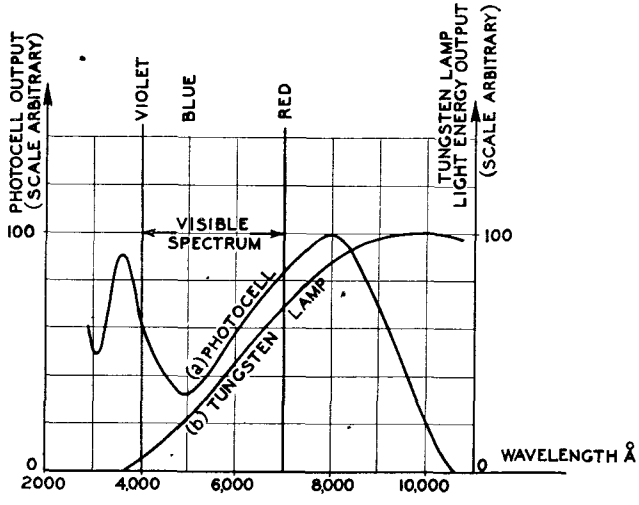


FIG. 13.5.

(*a*) Relative sensitivity of typical caesium oxide photo-cell to light of various wave-lengths
(*b*) Relative light energy output of tungsten lamp at various wave-lengths

A final point to note from the curves is that the

caesium-oxide cell gives some response well into the infra-red approaching the heat ray spectrum and therefore is liable, in the absence of incident light, to give a small output due to thermionic emission at room temperatures. This so-called "dark current" is greater in gas-filled cells than in vacuum cells and manifests itself as background noise.

In both vacuum and gas-filled cells the voltage applied between cathode and anode is important.

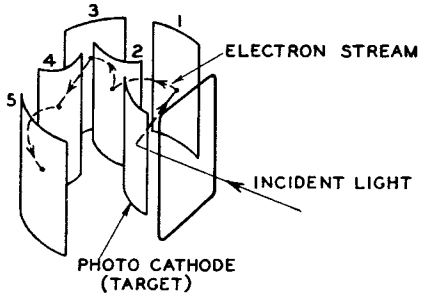


FIG. 13.6. PRINCIPLE OF ELECTRON MULTIPLIER PHOTO-CELL

In the case of the vacuum cell the electrons ejected from the cathode are the sole source of photo-electric current, and when a sufficient voltage has been applied to the anode to collect all these electrons, further increase of voltage has no effect. Thus no increase in sensitivity is achieved by increasing the applied voltage beyond about 25 V. In gas-filled cells the amplification already described, due to ionization by collision, increases rapidly with voltage until, in a typical cell, a condition arises with about 100 V applied in which a visible glow discharge occurs, which will then be maintained even if the light is cut off from the cell. The voltage required to produce glow discharge is dependent upon the intensity of illumination; the brighter the illumination the lower the voltage at which a glow discharge occurs. The glow discharge is harmful to the cell and precautions against damage are taken by the provision of a current limiting resistance in the cell circuit. Another disadvantage of working with too high an applied voltage is that the response of the cell begins to depart appreciably from a linear relationship with the intensity of illumination.

The sensitivity of typical caesium oxide cells to light from tungsten filament lamps is approximately as follows—

Vacuum cells: 15–25 micro amps per lumen.

Gas-filled cells: 60–150 micro amps per lumen.

Gas-filled cells are the more often used in photo-telegraphy.

Electron Multiplier Photo-electric Cells. The most recent development in photo-emission cells affecting their use in photo-telegraphy has been the introduction of the electron-multiplier type of cell. In this type of vacuum cell the incident light falls on a photo-cathode as already described but, instead of a single anode, a series of electrodes is provided. The electrodes are in grid form and each is at a higher (positive) potential than its neighbour nearer the photo-cathode. Starting from the photo-cathode, the first multiplier electrode is bombarded by the electron stream forming the photo-electric current, and liberates more electrons, usually known as secondary-emission electrons. This augmented electron stream similarly bombards the second multiplier electrode, and so on. Fig. 13.6 shows the arrangement diagrammatically.

The usual types of cell have from five to ten multiplying stages and the current amplification at each stage may be up to five times using an inter-stage potential of the order of 100–150 V. The principal advantages arising from the use of these cells are a simplification of the photo-cell amplifier and a higher signal-to-noise ratio in the amplifier output. The latter arises from the relatively small effect of the resistance noise that occurs in the input resistance of the amplifier.

The disadvantages of the multiplier cell, compared with a simple cell, are a much higher first cost and the greater complication and higher voltage of the power supplies to the various electrodes. Care must be taken in the use of multiplier cells that the maximum final stage output (of the order of 1–10 milliamps) recommended by the maker is not exceeded, due to the use of too great an illumination, otherwise the cell may be damaged.

Photo-conductivity. As already stated photo-conductivity is characterized by an increase in the conductivity of certain materials when light falls upon them. The materials which best typify this behaviour are the semi-conductors which are also used in the construction of dry plate rectifiers, namely selenium and cuprous oxide. Selenium cells were among the earliest discovered, but for the following reasons they are unsuitable for facsimile telegraphy. In the first place the change of conductivity is not proportional to the change of intensity of illumination, and in the second place there is an appreciable time lag in the response of the cell when the illumination is varied. Probably for these reasons also these cells have not been developed to the same extent as have photo-emission cells.

Photo-voltaic Cells. There are other types of cells than those already described which, nevertheless, depend for their action fundamentally on either photo-emission or photo-conductivity. The best known are the selenium photo-voltaic cells, the action of which is an extension of the simple photo-conductivity effect. In a typical cell a metal plate (usually iron) is coated on one side with pure selenium, over which is applied a layer of metal to form a current collector, so thin as to be transparent. The incident light pierces the transparent front electrode and impinges on the selenium. Electrons are freed from the selenium and collect on the transparent metallic covering, which may be connected through an external circuit (not including a source of e.m.f.) to the back plate, when the electrons will traverse the circuit as an electric current. The cell thus behaves, in the presence of light, as a generator of an e.m.f. and current. This is the justification for their description as photo-voltaic cells. They are also variously known as rectifier cells, because the arrangement will function as a rectifier of alternating currents, and as barrier-layer cells, because between the selenium and the transparent electrode is the seat of the rectification, a layer through which current will flow easily in one direction but which forms a barrier to reverse current.

These cells suffer from the same time lag defect as selenium photo-conductivity cells and are not, therefore, used in photo-telegraphy. They are ideal for incorporating in compact instruments such as light (or exposure) meters, indicating on a micro-ammeter a measure of the intensity of illumination of the cell. Such meters are of use in making adjustments to photo-telegraph apparatus and have the advantage of not requiring any external power supplies.

Fig. 13.7 shows a typical family of response curves for varying external load. In colour response, the selenium rectifier cell does not differ greatly from the human eye, having its maximum response at 5,500 Å.

Optical Scanning—The Scanning Spot. One of the problems of facsimile telegraphy is to secure adjustments of the sender and receiver such that the individual scanning lines are not so narrow as to fail to meet, nor yet so wide as to overlap. At the sender there are two common ways of achieving this end, whichever method of drum illumination is employed. These are—

1. The use of a rectangular scanning spot, adjusted to have a width equal to the scanning pitch, so that adjacent lines abut exactly. This method is illustrated in Fig. 13.8 and is favoured by most makers.

2. The employment of a scanning spot which is a trapezoid in shape, the average length of the unequal parallel sides being adjusted to equal the scanning pitch. In this way the lines overlap but the total light energy per unit area reflected from the parts where overlapping occurs is equal to that in the central part of each scanning line, as also explained in Fig. 13.8. This method is used in the Cables and Wireless equipment and is

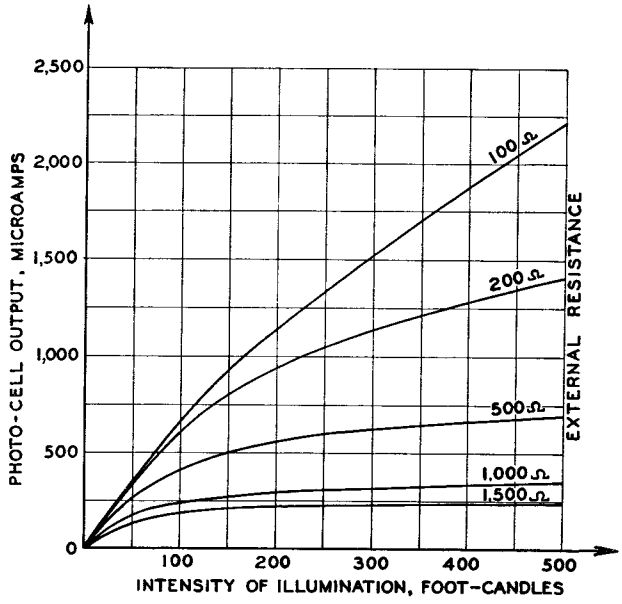


FIG. 13.7. OUTPUT OF 45 mm diameter EVANS ELECTROSELENIUM LTD. (E.E.L.) SELENIUM CELL INTO VARIOUS EXTERNAL RESISTANCES

probably to be preferred so far as ease of adjustment is concerned.

These are not the only arrangements used. For instance the high speed facsimile system developed by Philips of Holland uses a round scanning spot at the transmitter.

Maladjustment of the line width in the sender is unlikely to have noticeable consequences, as it only results in false interpretation of tone values. In the receiver, however, overlap or separation of the scanning lines makes the individual lines distinguishable due to the presence of darker or lighter fringes.

The arrangements at the receiving end have not yet been described, but the choice of the above mentioned two types of light scanning spot also applies to the receiver when photographic reproduction is employed. Other reproduction processes are available as will be shown later.

Resistance Scanning at the Sender in the Deskfax (direct-recording) Facsimile System for Documentary Transmission. The Western Union Telegraph Company of New York introduced a simple direct-recording facsimile set for documentary work a few years ago which served both as a sender and receiver. Both in transmitting and receiving, the message form is wrapped round a metal cylinder, with which it makes electrical contact, and is scanned by a tungsten stylus which makes a

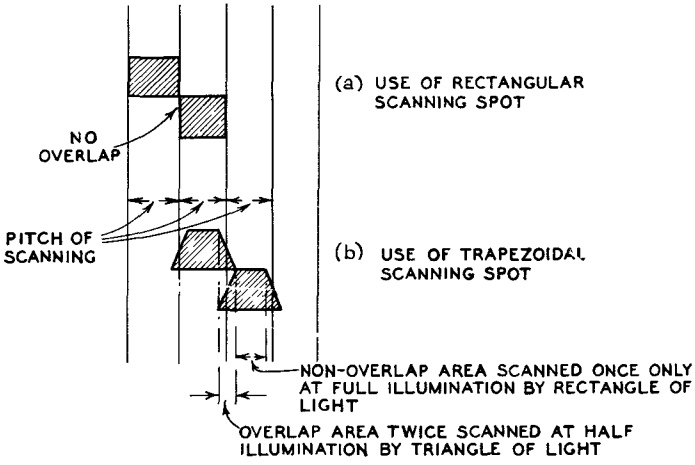


FIG. 13.8. ALTERNATIVE SHAPES OF SCANNING SPOT

second electrical contact. (*Note*: In later models of the Deskfax, resistance scanning has been abandoned and optical scanning is used.)

The copy for scanning can be in either of two forms—

1. In the first method the paper used on the drum is a special paper called Teledeltos, which is also used in reception. Teledeltos paper consists of a metallized backing which carries a black substance, like carbon black, the surface of which is coated with a very thin insulating layer which is light grey in colour. When in use, the metallized back of the paper lies in intimate contact around the surface of the drum. The message is written or typed on to a plain paper telegram form (to be kept as a local copy), beneath which is placed a special carbon paper with carbon side down and a sheet of Teledeltos paper with the metallized side down. The transferred carbon is absorbed into the thin surface of the Teledeltos paper and reduces its electrical resistance at these points relative to the surrounding areas of paper.

2. In the second method the paper used on the drum is a black carbon paper of lower resistance than Teledeltos paper. Instead of a carbon paper, a waxed paper is placed between the telegram form and the black conducting paper when writing the message. The writing is transferred cleanly to the black conducting paper as characters of white insulating wax. This method therefore provides high resistance characters on a low resistance base, i.e. the converse of the first method.

In both cases the message is scanned at 125 lines per inch and the output is an amplitude-modulated carrier of 1,800–1,900 c/s. It will be realized that the cost of materials at the sender is high, compared with the use of a simple paper form for optical scanning.

Scanning at the Receiver. Before describing how the output from the photo-electric cell is converted to a signal suitable for transmission, and what are the criteria for satisfactory transmission, it is desirable to proceed to a description of the receiving end scanning. The purely mechanical aspects of scanning at the receiver do not differ from those already described for the sender, and it is in fact usual in photo-telegraphy for similar construction to be used in the two equipments. Sometimes, however, cylindrical scanning at the sender may be combined with continuous-page scanning at the receiver. It is proposed first to describe the methods by which the scanning at the sender and receiver are made to proceed in correct relationship and then to describe some of the available reproduction processes at the receiving end.

Synchronism. The first essential in the relationship between the scanning at sender and receiver is that they shall proceed synchronously. This implies, in the usual case of machines using rotating drums, that the speed of rotation of the sending and receiving drums shall agree to a high degree of accuracy. Recommendations for this accuracy and for other features concerning international photo-telegraphy have been made by the C.C.I.T. The C.C.I.T. recommends that in comparing the speed of sender and receiver a 1,020 c/s alternating current, having a fixed relationship to the speed of the sending drum, shall be transmitted, and used at the receiver in a stroboscopic device. The speed of the receiver shall be adjusted so that the stroboscopic image does not move by more than one white plus one black sector in two minutes when the frequency of flashing of the stroboscopic device is equal to the frequency of comparison, i.e. 1,020 c/s (nominally). This means that the speed of sender and receiver are then correct to 1 part in 10^5 approximately. The explanation of this is as follows.

The nominal 1,020 c/s tone received causes a neon lamp to be flashed 1,020 times per second and to illuminate a stroboscopic disc having alternate black and white sectors, so designed that when the disc is driven at correct speed, it rotates through an angle exactly equal to one black plus one white sector between flashes (i.e. in $\frac{1}{1020}$ sec), so that the stroboscopic image appears to be stationary. In two minutes therefore, at correct speed, the disc will move by $1{,}020 \times 120$ black and by the same number of white sectors; but if in this time a speed error causes the stroboscopic image to move one more, or less, (black + white) sector, the speed error is evidently 1 in $(1{,}020 \times 120)$, i.e. 1 in 10^5 approximately. The means actually adopted at the receiver may differ in practice (as will be shown) though not in principle from that described by the C.C.I.T. It will also be shown later that a simple 1,020 c/s tone cannot always be satisfactorily employed because of the characteristics of carrier telephone circuits, the availability of which has greatly increased in recent years. This difficulty was discussed at the 1948 Brussels meeting of the C.C.I.T. A simple means of overcoming the difficulty is coming into fairly general use and is described later under the section dealing with transmission.

The effect of speed error is to give the picture a skew. Thus a straight line which should cross the scanning lines at right angles will slope up or down if the speed is incorrect, as shown in Fig. 13.9. If a picture has been inadvertently received with an objectionable but constant amount of skew and the transmission cannot be repeated it may, if a sender is available, be transmitted to a local receiver with a suitable speed error to correct the defect. There will inevitably be some loss of definition due to scanning twice in the same direction but this will be less serious than the skew and is usually undetectable in practice.

In picture telegraph systems the frequency-standard controlling the motor speed at the sender and receiver is a tuning-fork controlled oscillator or a crystal-controlled oscillator.

In some direct-recording documentary facsimile systems, e.g. the Mufax system, and the Telefax system, the synchronism depends upon running the sender and receiver motors synchronously from frequency-controlled mains.

Phase. The second essential is that the sending and receiving drums shall run in correct phase as well as in synchronism. This ensures that the received picture is correctly received and not intersected by the image of the clips holding the picture to the sender drum. The effect of incorrect phasing is also illustrated in Fig. 13.9. In practice it is only necessary to put the two drums in correct phase once for each picture transmitted, and to do this the sending station transmits a phasing signal for a short time before starting the drum traversing. The phasing signal is a pulse of tone, sent once per revolution of the transmitting drum at the instant when the paper clips on the drum pass the optical head. The C.C.I.T. recommends that either the 1,020 c/s synchronizing tone or the carrier tone for the picture signals (i.e.

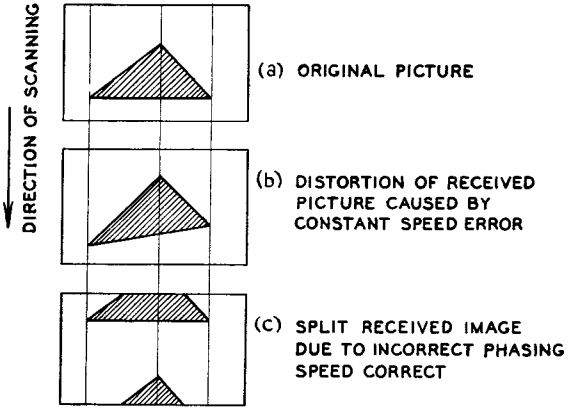


FIG. 13.9. EFFECT OF INCORRECT SPEED AND PHASE

1,300 c/s) may be used for the phasing pulse. At the receiver, the operator sets the drum rotating at correct speed and then operates a "start-drum" switch, which first arrests the drum at the correct starting position whence it is released by the next phasing pulse. Thereafter the correct phase is maintained merely by the sender and receiver keeping within the prescribed limits of relative speed.

Index of Co-operation. The third essential for correct shape in the received image is that the ratio $\frac{\text{height}}{\text{breadth}}$ of the picture space shall be the same in the original and received copy.

If D is the diameter of the sending drum.
If d is the diameter of the receiving drum.
If P is the scanning pitch at the sender.
If p is the scanning pitch at the receiver and
If n is the number of lines scanned,
then, as stated above, the following equation must apply—

$$\frac{\pi D}{nP} = \frac{\pi d}{np}$$

i.e.

$$\frac{D}{P} = \frac{d}{p}$$

This ratio $\frac{D}{P}$ is a constant of the sender and receiver known as the "index of co-operation." For instance, machines having the following constants are most frequently used in Europe—

(*a*) Drum diameter 66 mm.
Pitch $\frac{3}{16}$ mm, i.e. lines per mm (scan) $= 5\frac{1}{3}$.
(*b*) Drum diameter 88 mm.
Pitch $\frac{1}{4}$ mm, i.e. lines per mm $= 4$.

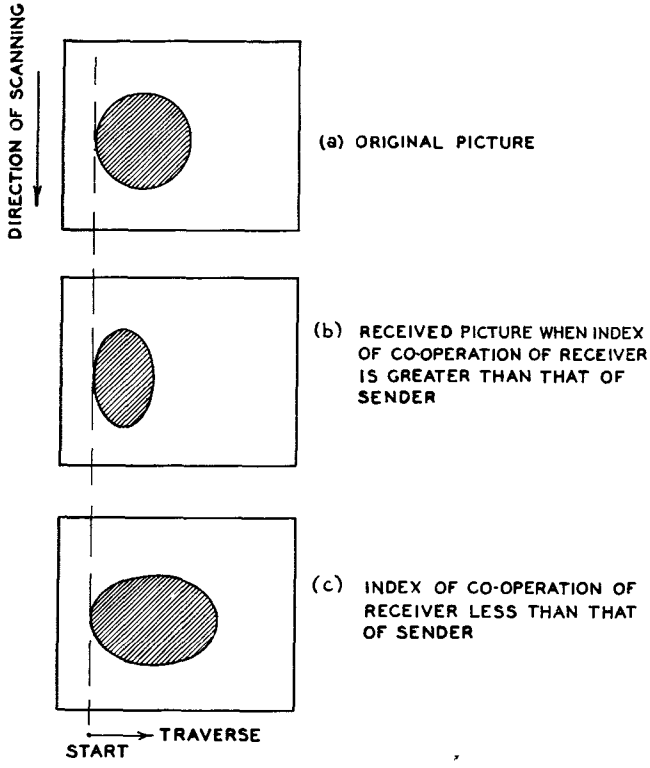


FIG. 13.10. EFFECT OF RECEPTION ON A MACHINE HAVING DIFFERENT INDEX OF CO-OPERATION FROM SENDER (EQUAL DRUM DIAMETERS ASSUMED FOR SIMPLICITY)

In each case, the index of co-operation is $\frac{D}{P} = 352$, which is merely a number and has no unit of measurement.

Some machines have the facility of operating at more than one scanning pitch and care is necessary in their use to ensure that the correct pitch is being used.

The pitch of the scan decides the degree of definition in the picture and it is important to realize that the definition possible for a given picture area is decided by the sending machine. Thus, if a given picture is transmitted from a drum (*a*) above, it will be received on (*b*) as a larger picture having poorer definition, which could be reduced photographically to the same size and definition as a picture received on a second drum (*a*). If, however, the same original is transmitted from drum (*b*) it is scanned at the lower definition given by (*b*) and, whereas (*a*) will receive it as a smaller picture of better definition, photographic enlargement of the received copy to the size of the original must inevitably reduce the definition back to that of the sending end scanning. Fig. 13.10 shows the effect of reception on a machine having the wrong index of co-operation.

Reproduction Processes. The reproduction processes used most widely at present are—

1. *Photographic reception*, either in negative form on a film, or in positive form direct on to photographic bromide paper. The photographic method is essential for the finest reception of pictures, to be suitable for high quality reproduction in newspapers, etc.

The disadvantages of high cost of the materials and the time required to perform the chemical processing (in a dark room), washing and drying, make the method prohibitive for the reception of written messages in commercial systems. However, 16 mm substandard cinematograph film is used in the experimental R.C.A. high speed system, and 45 mm film is used in the Philips experimental high speed system. The photographic method in picture telegraphy is described in some detail later in the chapter.

2. *Reception (direct-recording) on Teledeltos Paper*, developed in America by the Western Union Telegraph Co.

The type of paper used has been already described in the section dealing with resistance scanning in the Deskfax sender. The scanning is performed by a tungsten stylus which exerts a steady pressure on the paper. The inertia of the stylus is unimportant as it is not required to move at signal frequency. A voltage is applied between the drum and the stylus varying in accordance with the received signal. The voltage may be either a.c., of the frequency received from line, or it may be rectified to d.c., the voltage reaching a peak value in the neighbourhood of 500 V at the speeds normally used. Blackening of the paper is produced by burning through to the carbon backing, a slightly unpleasant smoke being given off. The great advantage is the immediate production of the image without processing. The Teledeltos paper, though less costly than photographic material, is nevertheless fairly expensive. The range of tone from full-black to full-white (actually

a light grey) is much less than that obtainable from photographic reception and the definition is not so good. Nevertheless, provided that the copy is not required for reproduction purposes it can give a fairly good image of a photographic original and a good image of a full-black and full-white original, e.g. a line drawing. This material is used for documentary work in the Western Union Telefax and Deskfax equipment.

3. *Reception (direct-recording) by electrolytic means* on a specially prepared chemically-impregnated paper which is used slightly damp. This method has been known since the very earliest days of facsimile telegraphy, when Alexander Bain used a paper impregnated with starch and potassium iodide, which produced a brownish-black stained image on the passage of a direct electric current. In modern times a similar method (although employing different chemicals) was introduced for the Hogan Fax-News system in America and is now fairly widely used in other systems, notably in the Mufax system developed by Muirhead and Co. Ltd.

The paper used in Mufax receivers is a resin-bonded sulphite pulp paper of high wet strength and great absorbency. It is impregnated with an electrolyte, a colour forming substance, and other substances which intensify the colour and limit its spread. If point contact is made with the paper by means of a recording stylus (or a writing bar and helix), the passage of an electric current causes the dissociation of the electrolyte, and one of the dissociation products reacts with the stylus to form a metallic salt. This in turn reacts with the colour-forming substance to colour the paper. The colour depends on the metal of which the stylus is made; Mufax receivers employ a stainless steel stylus, as ferric salts give rise to the most intense black coloration.

This type of paper is supplied ready for use in sealed canisters, or plastic bags, to preserve the right degree of dampness. The paper has a life, after opening the canister, which is limited by its gradual drying-out, but which is of the order of a month when the paper roll is mounted in the special chamber in the receiver.

The image has a range of tones much less than is obtainable by photographic means but fairly good definition is obtained. The image in the case of a half tone picture is seen to best advantage by light transmitted through the thin translucent paper and is good enough for low grade reproduction. The paper is moderately cheap, the voltage required is only about 40 V and no processing (and only slight drying) is necessary. The drying is apt to cause slight crinkling of the paper and some darkening of the image, the latter being no disadvantage. Other methods have been (and in some cases are still) used, which may be capable of further development. These include the following—

4. *The use of a continuous fine jet of atomized ink* which can be partly, or wholly, deflected by a moving vane controlled by the signal. This method was developed by the R.C.A. A disadvantage is the inertia, though small, of the deflecting vane.

5. *The use of the varying pressure of a moving stylus* on a carbon paper covering a sheet of ordinary paper.

In printing systems, e.g. the R.C.A. tape system, a similar result is achieved by pressing the paper against the receiving helix which is inked from an impregnated roller.

6. *The use of papers sensitive to the varying temperature of a jet of air*, being either chemically treated, e.g. with a salt of nickel, or waxed and thereby showing more or less resistance to the application of a water ink.

Transmission of Facsimile Telegraph Signals

The following description concerning the nature of the signals to be transmitted in facsimile telegraphy will be related to photo-telegraphy transmission but the same principles apply in documentary systems. In the sender, a resistor and a source of steady e.m.f. are connected in series between the cathode and anode of an emission type photocell and the picture to be transmitted is illuminated by a steady source of light. During the scanning of the picture, the photocell responds in accordance with the intensity of light reflected from the elements of picture area, and this response may be measured in terms of the photo-electric current flowing in the resistor or of the variations in P.D. produced at the terminals of the photocell. The varying P.D. across the photocell forms the input of a photo-cell amplifier, which is usually designed for linear amplification.

When scanning any surface of uniform tone density, the intensity of illumination of the photocell is constant and therefore its output is constant. Between continuous pure white and continuous full-black, however, the range of power output of the amplifier (a d.c. amplifier in this simple case) may be as much as 30 db, and intermediate picture tones produce corresponding intermediate power levels.

The rate of change of the photocell output depends upon the rate of change of tone in the picture, and is a maximum when an abrupt change occurs from pure white to full-black, or vice versa.

In the scanning of a photograph, the whole range of tones from full-black to pure white may be encountered, as well as widely varying rates of change of tone. Thus the primary picture current is, typically, a direct current varying widely both in amplitude and in rate of change of amplitude. It may be regarded as a steady direct current having a value representing a mid-grey tone with a non-periodic alternating current component superimposed. It is necessary to know the greatest

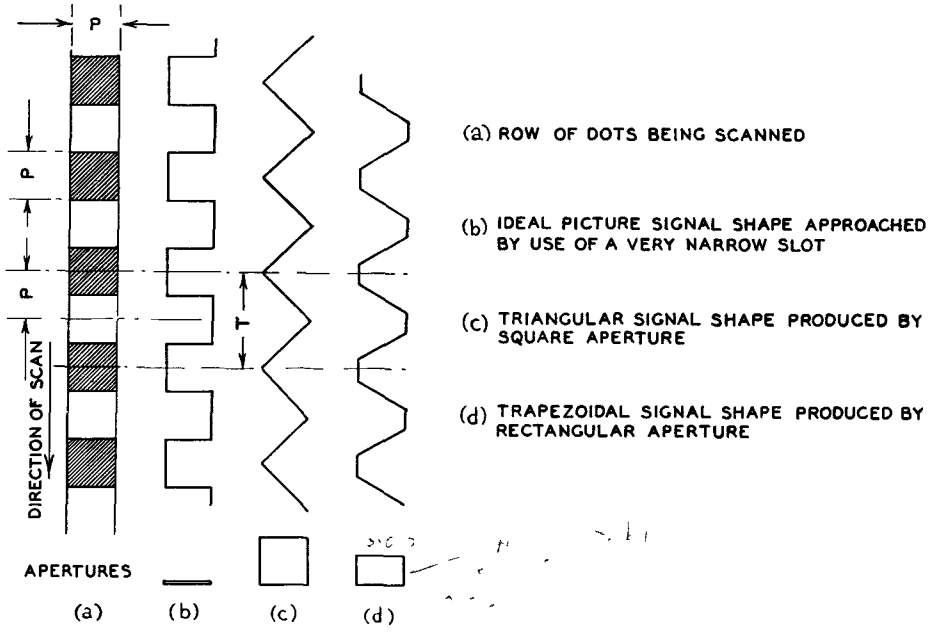


FIG. 13.11. EFFECT OF SCANNING APERTURE ON SIGNAL SHAPE

frequency of this a.c. component, because this determines the minimum frequency band-width that is required in the transmission path.

The picture definition of a boundary between black and white running in the direction of the scanning lines is decided by the pitch of scan, and it is usually assumed that the definition required in the direction at right angles to this should not be worse. This means that it should be possible, when scanning to resolve a continuous chain of alternate full black and pure white squares spaced at a distance P apart, centre to centre; where P = the pitch of the scanning spiral in mm. The ideal signal shape required is therefore a rectangular wave having a periodic time T, equal to the time taken to scan from the centre of one black square to the centre of the next black square. This is illustrated in Fig. 13.11.

If D = drum diameter (mm) and n = speed of drum in r.p.s. then, since the drum makes one revolution in $\frac{1}{n}$ sec, the periodic time of the square wave is $T = \frac{1}{n} \times \frac{2P}{\pi D}$

i.e. $T = \frac{2P}{\pi Dn}$ sec.

Hence the frequency F of the fundamental sine wave is $F = \frac{\pi Dn}{2P}$ c/s

For example—

If $D = 66$ mm

$P = \frac{3}{16}$ mm

and n = 1 r.p.s.

then $F = \frac{\pi \times 66 \times 16}{2 \times 3} = 550$ c/s

At least the third harmonic, i.e. 1,650 c/s, would need to be transmitted for the signal to bear any resemblance to a rectangular wave. See p. 127, Chapter 5. Further consideration of what takes place in practical scanning will, however, show that the a.c. component of the photocell output for the case under consideration is not a rectangular wave. Fig. 13.11 shows a row of alternate black and white squares to be scanned, the length of side of the squares being equal to the pitch of scanning P. If the size of the scanning spot were an equal square (which would be

desirable for maximum power output) it will readily be seen that the wave would only have maximum amplitude, either positive or negative, at the instant when the scanning spot exactly covered a black or white spot, and the half wave would be triangular in form.

Further consideration will show that an approximation to a rectangular wave could only be produced by the use of an extremely narrow scanning spot, but this would give rise to practical difficulties owing to the greatly reduced signal output from the photocell. In practice the width of the scanning spot is made about 0·8 P, which produces a wave of trapezoidal shape, and it is only necessary to transmit the fundamental sine wave to give a fairly accurate representation of the photo-cell output. Thus in the above example the signal to be transmitted is d.c. plus a 550 c/s a.c. component. When transmitting a normal photograph, the a.c. component of the signal will only occasionally reach a frequency as high as 550 c/s.

Line Transmission. A photocell signal having the characteristics just described would not be very convenient for valve amplification, as it contains a d.c. component, nor, if amplified, would it be suitable as a line signal because of the low frequencies involved. The signal is therefore employed, in the usual case, to amplitude-modulate a carrier which, in 1931, was fixed by the C.C.I.T. at 1,300 c/s for international photo-telegraphy. This choice of carrier frequency was made to suit lightly-loaded cable circuits.

Thus the standard C.C.I.T. system requires the transmission of a 1,300 c/s carrier with $\pm$ 550 c/s side-band frequencies. A nominal band-width of 750 to 1,850 c/s is therefore required and the margin which is necessary in practice is amply provided by a normal telephone circuit. Because the future of long distance telephony resides in the use of carrier (or coaxial) telephone circuits, having a standard pass band of 300–3,400 c/s, the C.C.I.T., in 1951, recommended an additional carrier frequency of about 1,900 c/s to make the best use of such telephone circuits.

Some of the methods used to produce the modulated carrier are described in the later section dealing with picture-telegraph equipments.

The requirements for radio transmission of phototelegraphy differ in some important respects from those for line transmission, and the latter only will first be considered. The following are the important requirements for line transmission. Where reference is made to recommendations of the C.C.I.T., it may be assumed that the C.C.I.F., which recommends the technical standards for international telephony, has also made similar recommendations. (The two committees were amalgamated in 1956 to form the C.C.I.T.T.)

(*a*) The attenuation/frequency distortion should not be excessive, otherwise the received signal wave shape will be distorted. The transmission line should therefore produce, as nearly as is practicable, the same attenuation of all signal frequencies in a band somewhat wider than the minimum necessary for the picture signals. For example, in the case we have been considering the attenuation equalization should ideally be flat from below 750 c/s to above 1,850 c/s. The C.C.I.T. actually recommends that the attenuation/frequency distortion of the complete connexion between sender and receiver should not exceed 1·0 neper (or 9 db) in the band of frequencies to be transmitted.

(*b*) The transmission equivalent of the circuit should remain as nearly as possible constant during the sending of the picture, since sudden variations of level of 0·1 neper (or 0·9 db), are observable on the picture. It is also necessary to avoid any interruptions to the circuit, however short. In practice some interruptions will unavoidably arise from line faults and power failures, but interference by working staff at repeater stations and telephone exchanges can be largely prevented. The circuits must be specially marked at all points where such interference would otherwise be likely to occur and, as far as possible, the connexion should not be routed through any telephone switchboards. The picture calls are normally booked for a specified duration, and the switching at the trunk terminal points is carried out at the repeater station test boards.

(*c*) Phase distortion must not be excessive, otherwise the received signal wave shape will be distorted. Thus the various component frequencies of the signal must arrive with, as nearly as possible, their original phase relationship, as well as their original relative amplitudes. Both these matters are more fully explained in Chapter 5. On long circuits phase equalization, as well as attenuation equalization, may have to be carried out in order that satisfactory pictures may be transmitted. The C.C.I.T. Recommendations include curves of group delay as a function of frequency for typical telephone channels. From these an estimate can be made of the bandwidth suitable for use. It would appear on purely theoretical grounds that the group delay variations should not exceed about a third of the duration of the picture element time, but in practice satisfactory transmission seems to be obtained with variations up to the duration of the picture element.

(*d*) Echo signals can ruin a picture by the production of "ghost" images. Therefore a long two-wire circuit is unsuitable for photo-telegraphy, since it provides loop paths for the circulation of echo signals. If a normal four-wire circuit with short two-wire ends is used transmission may not proceed in both directions simultaneously, and for unidirectional transmission echo suppressors should be used on the four-wire portion. To allow simultaneous transmission in both directions, the normal four-wire terminations are omitted and the circuit is extended right to the photo-telegraph stations on a four-wire basis: echo suppressors must then, of course, be omitted. In practice a faint ghost image may not be readily detectable as such, and may only appear to cause general degradation of the picture. This, however, cannot be counted upon, and for first-class work the above circuit arrangements are essential.

(*e*) Unwanted modulation of the picture carrier must be avoided. This may arise from crosstalk from other telephone circuits, noise from power supplies, interference from telegraph circuits, overloading of amplifiers, etc. The C.C.I.T. recommends a signal-to-noise ratio of at least 4 nepers (35 db). The C.C.I.T. also states that the stability of the circuit should be at least 2 N (17 db), but if echo suppressors are used in four-wire circuits a stability of 0·5 N (4·3 db) is sufficient.

(*f*) An important practical consideration is that, notwithstanding the above conditions, some of them stringent, a commercially successful service can only be achieved if the circuits used are to be found among the normal telephone circuits on the various routes, so that they may carry a reasonable volume of traffic. It is possible that eventually there may be available sufficiently extensive networks of music type circuits, having a much wider frequency band, which will allow of the standardization, for use when required, of higher definition or greater scanning speeds or both. Even now, using the rather low 1,300 c/s carrier and an index of co-operation 352, it is often possible to transmit pictures successfully at drum speeds of two revs/sec (which causes a theoretical band spread of 200 to 2,400 c/s) without appreciable degradation at abrupt black to white boundaries due to clipping of the lower side-band.

(*g*) When using carrier or coaxial circuits an important point arises in the synchronization of the sender and receiver. The 1,020 c/s master tone sent from one station may be received with a frequency error at the other station because of a discrepancy between modulation and de-modulation frequencies in the carrier equipment. When the carrier equipment is functioning correctly, the

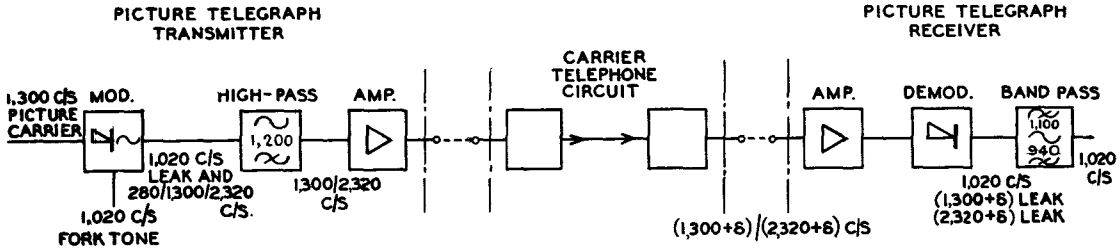


FIG. 13.12. TRANSMISSION OF SYNCHRONIZING (FORK) TONE WHEN USING CARRIER TELEPHONE CIRCUIT

error may be up to $\pm$ 2 c/s, which is too much for satisfactory synchronization.

This defect is overcome by the following method. Instead of transmitting a simple 1,020 c/s tone, for synchronizing, the standard 1,020 c/s tone is caused to modulate the 1,300 c/s picture carrier tone, and the 1,300 c/s and the upper side frequency 2,320 c/s are then transmitted; the original 1,020 c/s and, incidentally, the lower side frequency 280 c/s are cut off by a high-pass filter. At the receiving end, rectification and the use of a 1,020 c/s band pass filter enable the true 1,020 c/s difference frequency to be extracted, regardless of what frequency changes are suffered in transmission. Fig. 13.12 shows a typical arrangement in block schematic form. The frequency error introduced in the carrier circuit is shown as δ.

Radio Transmission. The special problems of radio transmission will now be considered. The types of transmission, that might be used, fall into the following four classes depending upon the radio frequency employed; the older system of denoting these groups by wave length is also shown in brackets.

(*a*) Low frequency (Long wave).
(*b*) Medium frequency (Medium wave).
(*c*) High frequency (Short wave).
(*d*) Very high frequency (Ultra short wave).

Low frequency transmitters are little used for telephony circuits because, although they give

stable reception conditions over long distances (apart from severe noise at times), high powered expensive transmitters are required.

Medium frequency and very high frequency transmissions are not of much interest as they are only suitable for relatively short distances, for which they give stable conditions and would probably present no special problems in picture telegraphy.

High frequency transmissions also give stable conditions over short (approximately optical) distances, but the principal interest in them lies in that transmission to very great distances is possible, using transmitters of only a few kW power, by virtue of the refraction of the sky waves by the ionized layers of the upper atmosphere. Such transmissions are of great economic attraction but present many problems, notably the following—

1. Severe fading to a depth of as much as 40 db is experienced due to multi-path transmission. The signals received over different paths beat together and sometimes cancel each other. As well as general fading there may be selective fading, in which at any instant a certain narrow band of frequencies only may suffer extreme fading. The selective fades usually sweep through the complete audio spectrum at widely varying rates, causing different narrow bands in succession to be severely attenuated and possibly lost.

2. The circuits may be noisy and, particularly in the troughs of the fades, the signal-to-noise ratio may fall very low.

3. The multi-path transmission results in effects similar to echo in land lines. True echoes also result from waves that have completely encircled the world or have travelled round the world in the opposite direction to the main wave.

Whilst A.G.C. in the radio receiver provides a marked degree of compensation for general fading, it does not reduce the selective fading or improve the signal-to-noise ratio. The use of space-diversity reception is frequently adopted to minimize the effects of fading. In this method, two or three antennae are spaced in the order of 1,000 yards apart, each having a separate radio receiver, and the best signal at any instant is automatically selected to the exclusion of the others. Although the use of diversity reception and A.G.C. result in satisfactory reception of telephony and two-tone or F.M. telegraphy, picture telegraphy is not practicable when using an amplitude-modulated carrier (as in line transmission) principally because normal methods of A.G.C. are inapplicable.

The methods which were first tried to overcome this defect, adopted the general working principle of the half-tone print.

In one method, the varying picture tone at the sender was used to control the frequency of a multi-vibrator. For each cycle of the multi-vibrator the radio transmitter sent a dot signal at constant power and of constant duration. At the receiver a series of identical dots were printed, regardless of the varying level of the signals, their closeness (and hence the apparent density of the received picture) depending upon the frequency of the multi-vibrator, i.e. the picture density at the sender. In a second system, which became well-known as the "Constant-frequency variable-dot" system, the frequency of sending dots remained constant but the duration of the dots varied according to the density of the picture at the sender. In the dark tones the black dots were long and almost touched each other, whilst in the light tones the black dots were very short and left large white spaces between them.

Both of these systems are now of only historical interest as at present the system in general use is the sub-carrier frequency-modulation system.

Sub-carrier Frequency-modulation (S.C.F.M.). In this system an audio-frequency carrier is frequency-modulated by the picture signal. The following are two examples of typical conditions used, (*b*) having been recommended by the C.C.I.T. and the C.C.I.R.—

(*a*)	Pure white 2,000 c/s Full-black 1,600 c/s	Sub-carrier	1,800 c/s
(*b*)	Pure white 1,500 c/s Full-black 2,300 c/s	Sub-carrier	1,900 c/s

The picture telegraph sender and receiver used are commonly the standard amplitude-modulation sets working, for instance, to the C.C.I.T. recommendations for land-line work. In using such sets on a circuit consisting typically of a radio channel extended at each end by a landline, an AM/FM converter and an FM/AM converter are necessary. These converters may be employed in immediate connexion with the picture sender and receiver, or alternatively at the radio transmitter and receiver where the landlines terminate. It will be clear that in the former case the landlines have to transmit a frequency-modulated carrier, and in the latter case, shown in Fig. 13.13, an amplitude-modulated carrier. The former is probably the more convenient arrangement from the point of view of flexibility of operation, but the latter may be desirable if the landlines are carrier telephone circuits with a not very good frequency stability, or older audio lines with a limited frequency response.

A potential difficulty in the use of S.C.F.M. on landlines arises from the use on certain telephone

trunk circuits of single-frequency supervisory and dialling signals. For example, the C.C.I.F. recommendations concerning the standards to be employed in international telephony, allow the use of a single frequency signalling system using 2,280 c/s. With S.C.F.M. transmission of picture signals it would be quite possible for a particular sustained picture tone to produce a steady signal of 2,280 c/s for long enough to cause the telephone signalling receivers to operate and interrupt the circuit. If the signalling receivers cannot be

Drum speed 60 r.p.m.

Maximum modulating frequency 550 c/s (fundamental).

Band spread in A.M. sections of the circuit 1,300 c/s $\pm$ 550 c/s (i.e. 750 c/s to 1,850 c/s.)

Audio-frequency sub-carrier 1,800 c/s.

Frequency deviation 200 c/s.

Pure white signal frequency 2,000 c/s.

Full-black signal frequency 1,600 c/s.

Approximate band-spread in S.C.F.M. sections of the circuit 2,000 + 550 c/s to 1,600 — 550 c/s.

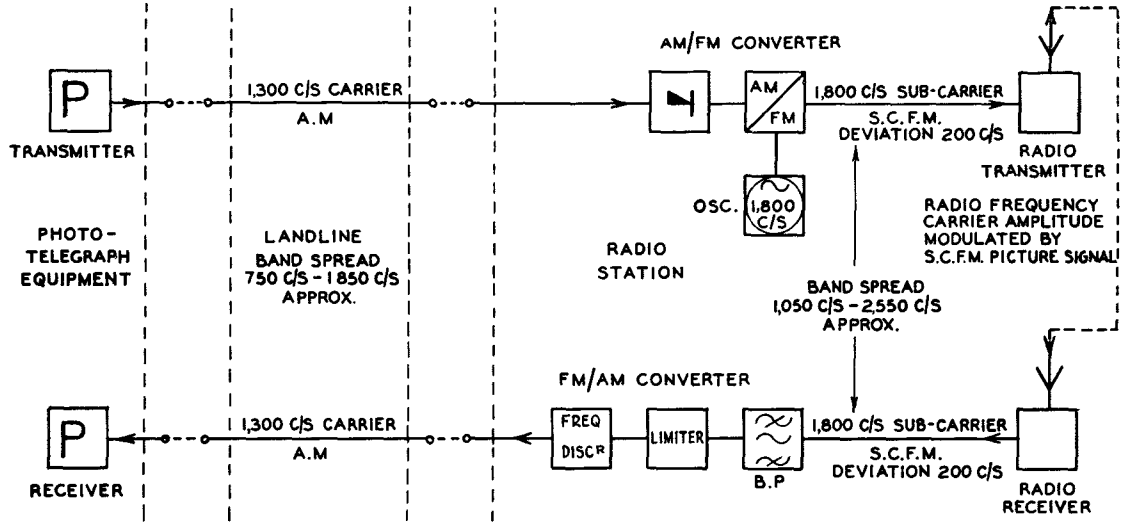


FIG. 13.13. TYPICAL ARRANGEMENT OF A COMBINED RADIO AND LANDLINE CIRCUIT

excluded from the circuit, it may be possible to transmit a low level blocking signal simultaneously with the facsimile signal, but well separated from it in frequency.

Telephone circuits employing the alternative double-frequency system, also recommended by the C.C.I.F., would appear to be preferable for picture-telegraph transmission on a S.C.F.M. basis, as the picture signal would never produce 2,040 c/s and 2,400 c/s simultaneously to operate the signalling receivers.

The frequency-modulated sub-carrier is used to amplitude-modulate the radio-frequency carrier. In view of the high frequency stability demanded for picture telegraphy, which is not as yet readily attainable in commercial F.M. radio receivers, the foregoing method is at present preferred to direct frequency-modulation of the radio-frequency carrier.

The following may be considered a typical system—

Index of co-operation of photo-telegraph sets 352, carrier frequency 1,300 c/s.

(i.e. 2,550 c/s to 1,050 c/s) since side frequencies beyond the first are negligible.

It should be understood that, for a series of constant intermediate tones between pure white and full-black, the sub-carrier is deviated from 1,600 c/s by lesser amounts than 200 c/s, usually in accordance with an approximately linear law. Also the band spread depends, as in the A.M. case, upon the rate of change of tone, the fundamental modulating frequency lying anywhere above 0 c/s and up to 550 c/s.

At the sending end, see Fig. 13.13, the A.M./F.M. converter consists of a rectifier of the A.M. signal, an 1,800 c/s beat-frequency oscillator and a frequency modulator. Following the radio receiver (see Fig. 13.13) a band-pass filter selects the required band of frequencies and rejects any harmonics of the sub-carrier generated in the radio path. The signal is then passed to an amplitude limiter, which removes any amplitude modulation of the required signal that has been acquired in the radio transmission. Finally a frequency discriminator restores the amplitude-modulated

carrier which passes to the photo-telegraph receiver.

Photographic Reception. The essential requirement for photographic reception is a beam of light modulated in intensity by the received signal. Three widely-differing types of equipment are commonly used for this purpose—

(*a*) The Duddell mirror oscillograph.
(*b*) The "crater" gas lamp.
(*c*) Nicol prisms and a Kerr cell.

The Oscillograph Method. The demodulated picture signal is fed to a Duddell oscillograph, in which it passes round a tensioned loop of fine wire, forming a bifilar suspension in a strong magnetic field. A very small mirror of the order 0·03 in. × 0·06 in. is mounted on the loop. Current in the loop causes it to turn by "motor" action against its own natural mechanical restraint, so that the mirror is deflected through a small angle. The inertia of the loop and mirror system is very small and, with suitable oil damping, the oscillograph will faithfully follow current variations at picture signal frequency. Light from a lamp with a compact filament, fed from a stabilized and smoothed d.c. power supply, is focused by an aperture and lens system as a constant beam on to the oscillograph mirror. The reflected beam, which is diverging, is intercepted at a point where it has spread to convenient dimensions by a mask with a cutout aperture.

Assuming that minimum signal represents black and that positive reception straight on to photographic paper is required, then this minimum signal must correspond to maximum light in the receiver. Therefore with the oscillograph carrying the minimum (black) current it is arranged that the aperture in the mask is fully illuminated, whilst maximum (white) current deflects the mirror so that the light beam just completely misses the aperture. (Actually the oscillograph is also supplied with a biasing current). This is illustrated in Fig. 13.14 (*a*), from which it will be realized that if the aperture were rectangular the light transmitted would vary linearly with the mirror deflexion for the small angles of deflexion used.

If negative reception on film had been required, it would have been necessary to arrange that the aperture was fully lighted with maximum (white) current and fully darkened (or nearly so) for minimum (black) current Fig. 13.14 (*b*).

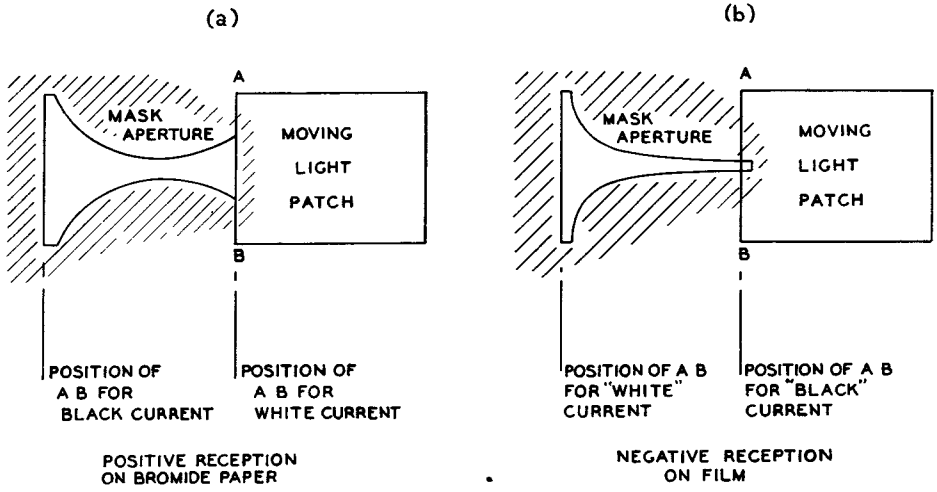


FIG. 13.14. OSCILLOGRAPH RECEPTION: USE OF COMPENSATING LIGHT APERTURES

Whether negative reception on film is used, or positive reception on bromide paper, the photographing emulsion is actually of a type in which the density of image (after development) bears approximately a logarithmic, not a linear, relationship to the light exposure. This is illustrated in Fig. 13.15. This requirement can be partly met by shaping the mask aperture as shown in Fig. 13.14 so that with linearly increasing mirror deflexion the lighted area of the mask aperture grows at an ever increasing rate.

The characteristic curve for bromide paper has, in general, a shorter straight portion and a shorter toe than that for film, so that the required aperture shapes differ. The best shape for the mask aperture is found, in practice, by experiment for each particular grade of sensitive photographic material to be used. The mask cannot be made to give all the correction (or non-linearity) required because its width would have to increase to impracticable

dimensions. For this reason the electronic part of the receiver is designed to give further correction at the end of the tone range corresponding to the wide part of the aperture by causing the rate of change of oscillograph deflexion to increase progressively. When receiving a purely black and white image, without half tones, a simple rectangular aperture may be used.

The light transmitted by the mask is brought to

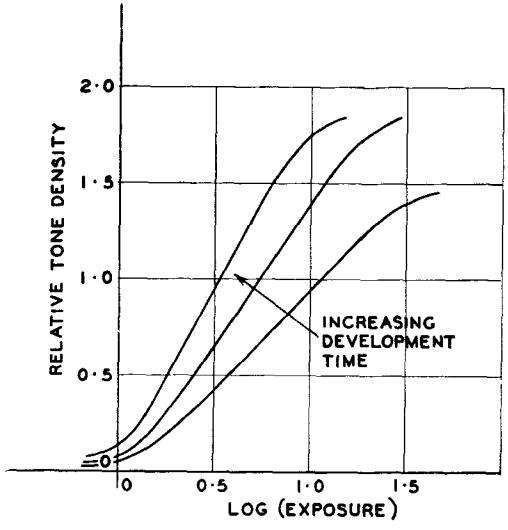


FIG. 13.15. TYPICAL FAMILY OF CURVES FOR DIFFERENT DEVELOPMENT TIMES, SHOWING RELATIVE TONE DENSITY AS A FUNCTION OF LOG (LIGHT EXPOSURE)

focus at an aperture of the required shape and size for the scanning spot; an image of this illuminated aperture is focused on the receiving drum. This arrangement is used in the Muirhead-Jarvis equipment and is illustrated in the block-schematic for that equipment, Fig. 13.25.

The Crater Lamp Method. The crater lamp, (known also by various other names) which is used in several types of receiver, is a special type of glow lamp containing neon, argon or helium. As the name implies the lamp produces a brilliant glowing crater of light, the intensity of illumination from which bears an approximately linear relationship to the applied voltage. It will be seen that this provides a very simple source of modulated light, by merely supplying the lamp from the picture signal suitably amplified. The only ready means of matching the varying lamp output to the needs of the photographic material is by providing all the correction required in the non-linear amplifier.

The crater lamp is not capable of responding to the maximum possible range of picture signal, say 30 db, obtainable from some photographic originals. Its range is more nearly 15 db, so that it cannot reproduce the full range of tones in a long-range original. However its range is adequate for all ordinary purposes. Close examination of a picture produced by crater lamp illumination shows it to be composed of brick-like elements caused by the flashing of the lamp on the a.c. supply. This is quite distinct from the appearance of a picture produced by the oscillograph method, in which the silver deposit on the print is quite uniform over any area of unvarying tone density.

The Kerr Cell Method. The third method of producing modulated light for exposing the photographic material is becoming obsolete, but is still to be found in some of the Siemens-Karolus-Telefunken (German) sets and possibly in others. This method employs a Kerr cell, which consists of a small two-plate capacitor immersed in nitrobenzene (chemical formula $C_6H_5NO_2$) and which can be made to behave as a light valve when used in conjunction with two Nicol prisms. A Nicol prism is made from a specially shaped crystal of calcite (Iceland Spar) cut diagonally into two parts, which are then cemented together with Canada balsam, a slow-drying transparent cement used in lens making. The function of the Nicol prism is to produce plane polarized light from ordinary light. In ordinary light the electrostatic vectors lie in all the possible positions of a plane rotated on the axis of propagation of the wave. Plane polarized light, on the other hand, is confined to wave trains in one position of the plane. The ordinary light incident in a certain direction on the Nicol prism is not passed on as such, i.e. with vibrations in all directions, but is refracted by the calcite into two separate waves with vibrations mutually at right angles. One of the two rays is internally reflected at the balsam film, whilst the other ray penetrates the balsam and emerges from the calcite as a plane polarized ray.

The plane polarized ray is passed to the Kerr cell, which has the property of turning the plane of polarization through an angle depending upon the voltage applied to the capacitor plates in the cell. When there is no voltage applied to the cell the plane of the polarized light is not changed and it will be transmitted through a second Nicol prism positioned similarly to the first prism. As the voltage on the cell is increased, and the plane of the light emerging from it is gradually turned, the second Nicol prism transmits a gradually weakening light, since the component of the electrostatic vector in the only possible plane of transmission

gets smaller. In practice the second Nicol prism is usually placed so that it cuts off the light with no voltage on the Kerr cell. The combination of prisms and cell is thus behaving as a continuously variable light valve. The turning effect of the Kerr cell is not linear throughout the effective range of applied voltage but varies approximately as shown in Fig. 13.16.

Positive and Negative Photographic Reception. If only one copy of a picture is necessary positive reception will generally be used, because extra time is required to produce prints from a negative. Speed in processing, finishing and delivery are usually of first importance, and all unnecessary steps have to be omitted. For this reason direct positive reception is much the more frequently used. According to the type of equipment used, it may be necessary for the sender to know whether the receiver intends to receive a positive or a negative.

Two points arise—

(*a*) In printing from a negative, the face of the negative bearing the silver image is placed in close contact with the sensitized side of the photographic paper. The picture on the print is, therefore, a mirror image of the (negative) picture seen when viewing the right side of the negative. With sender and receiver drums revolving in the same direction past the optical heads, the necessary allowance is made by scanning in opposite directions at sender and receiver. If the sending drum is moving from left to right in front of the optical head, then the receiving drum must conversely move from right to left.

(*b*) If maximum line signal represents white on the sender drum, then for positive reception maximum signal must produce minimum light, but for negative reception maximum signal must produce maximum light.

Other points to be considered in the choice between negative and positive reception are—

(*c*) Negative material is obtainable with the greater sensitivity, which allows lower receiver lamp power, and probably longer life. This may be of some consequence in view of the time required to set up a new lamp accurately.

(*d*) Negative reception allows much more control in the matter of re-touching, choice of paper, shading, etc., during printing, enabling the best to be made of a picture that may have been received with defects, notably in radio transmission.

Photographic Processing and Technique. Detailed description of photographic processing is beyond the scope of this book. A few points, however, may be of interest. The problem is to secure first-class results with a minimum expenditure of time. The secret of success lies in working out, after repeated experiments, a routine found to give the required compromise and then to adhere to it rigidly.

1. Composition, strength, time and temperature of development must be standardized. It must be realized that any developer oxidizes rapidly and that uniform results cannot be achieved by using old developer.

2. Fixation should be no longer than is essential,

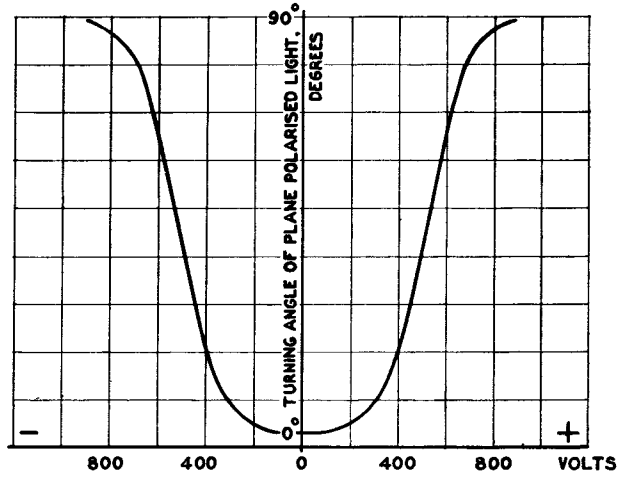


FIG. 13.16. ROTATION OF PLANE POLARIZED LIGHT BEAM WITH VARIATION OF VOLTAGE APPLIED TO A KERR CELL

and the use of modern high speed fixing solutions can be considered with profit.

3. Film should be hardened during fixing, so that after rapid washing it may be dried quickly by a jet of hot air (or otherwise) without damage.

4. Printing methods must be standardized. The Press require perfectly glazed prints on glossy surfaced paper, and scrupulous cleanliness and adherence to method is necessary to achieve uniformly good results using heated glazing surfaces.

5. A high standard of workmanship must be set and maintained by a frequent searching and unbiased examination of results. It is a mistake to think that because reception conditions are not always perfect anything less than the best is adequate in processing.

6. The examination of results for defects in photographic processing technique will, at the same time, disclose any deterioration in the adjustments of the machine. Some of these adjustments, notably in the optical system, require meticulous care, and it is too late to think about making them when a picture call is waiting.

Characteristics of various Photo-telegraph Equipments

The following are some of the well-known equipments that are at present in use in Great Britain, and Table 13.1 gives their principal technical characteristics.

BRITISH

1. *Muirhead & Co., Ltd., Beckenham, Kent.*
Muirhead-Jarvis fixed station sender and receiver.
Muirhead-Belin portable sender.

2. *The General Electric Co., Ltd., London.*
Fixed station sender/receiver for radio work, manufactured to a B.P.O. design.
A transportable sender and receiver or sender/receiver (this equipment was previously manufactured by the Unit Telephoto Co., Ltd., Glasgow).

FRENCH

1. *Établissements Edouard Belin.*
Fixed station sender and receiver.
Portable sender similar to the British Muirhead-Belin version.

GERMAN

1. *Siemens Karolus Telefunken.*
Fixed station, sender and receiver.

AMERICAN (U.S.A.)

1. *Times Facsimile Corporation.*
Times Telephoto transportable sender/receiver.

2. *Acme Newspapers Incorp.*
Portable and Transportable sender/receivers.

It is not the purpose of this chapter to give an exhaustive list and full descriptions of most of the common systems in use in the world but references are given to assist the reader who requires further information. The following sections only give such descriptions of typical systems of phototelegraphy as are necessary to illustrate principles.

TABLE 13.1

Maker	Type	Drum Diameter mm	Approx. Maximum Picture Size cm	Drum Speed r.p.m.	Scanning Lines per mm	Index of Co-operation	
						No.	Standard
Muirhead	Fixed, Press	89·5	26·6 × 25·4	60; 120*	3·9, 5·9	352; 528	352 C.C.I.T.
Muirhead	Fixed, B.P.O.	66	18 × 25	60; 120	5·33	352	C.C.I.T.
Muirhead and Belin	Portable	66	18 × 13	60; 120	5·33	352	C.C.I.T.
Belin and Siemens	Fixed	66	18 × 13	60; 120†	5·33	352	C.C.I.T.
Karolus	Fixed	88	26·5 × 17·5	60; 120†	4	352	C.C.I.T.
General Electric Co.	Fixed	88	26·5 × 22·5	60	4	352	C.C.I.T.
General Electric Co.	Transportable	88	26·5 × 20·4	60; 120	4	352	C.C.I.T.
Times Facsimile Corporation	Transportable	70	21 × 18	90	3·78	264	C.C.I.T. for radio
Acme Newspaper Incorporated	Transportable	73·8	21·5 × 18	100	3·94	290	—

* 90 r.p.m. also on some models.

† Siemens, 60 r.p.m. only.

The Muirhead-Jarvis Photo-telegraph Equipment. This high grade modern equipment was designed primarily for the Press for amplitude-modulation landline work. It is also used by the B.P.O., London, and by some other official installations. By the addition of a separate AM/FM converter it can be adapted for S.C.F.M. radio work and is used in this way in the B.P.O. Cable and Wireless Service.

Some of the characteristics of the Press and B.P.O. equipments are shown in the first two lines of Table 13.1. The Press prefer the larger diameter drum to allow the use of the popular 10 in. × 8 in. film or paper.

A general view of the sender, receiver and associated equipment racks, formerly in the Central

Telegraph Office, B.P.O., London, and now installed in Electra House, is shown in Fig. 13.17 and a close view of the sender in Fig. 13.18. The whole of the equipment is operated direct from a.c. mains.

The Sender. A block schematic of the essentials of the sending equipment is shown in Fig. 13.19, while Fig. 13.20 shows the mechanism. The whole of the mechanism shown forms a movable carriage, sliding on machined guides and driven by the lead screw engaging in a nut secured to the main frame of the machine. The optical equipment is secured to the main frame behind the carriage.

The basis of the drum drive is a 1,020 c/s fork-controlled oscillator, comprising two resistance-capacity coupled pentodes, one pair of fork coils being included in the control grid circuit of the first valve and the second pair of coils, which maintain the fork vibration, taking power from the cathode circuit of the second valve. This general type of valve-maintained tuning fork, shown schematically in Fig. 13.21, has been well-known for many years. A third valve provided is a power amplifier supplying two output circuits, one for the drum motor drive and the other for use in synchronizing. The constancy of frequency of the output depends wholly on the tuning fork, which is made from steel having a very low coefficient of frequency of from one to three parts in 10^6 per °C. No provision is made for temperature control, but the fork is contained in, and in contact with, a thick brass cylinder the mass of which smooths out the effect of any rapid changes of temperature. The fork is accurately set, in manufacture, to be as near as possible to its nominal frequency, but a small rotatable magnet is provided near the tip of the fork allowing of adjustment over a complete range of 300 parts in 10^6.

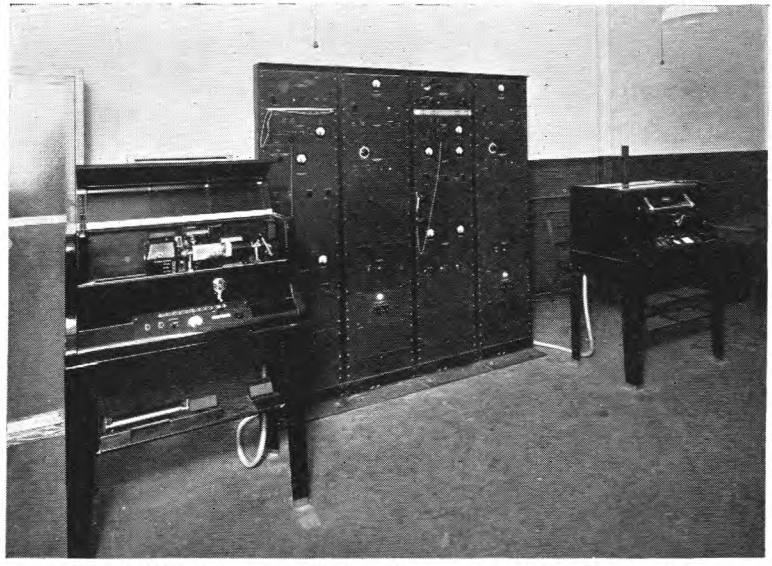


FIG. 13.17. MUIRHEAD-JARVIS PHOTO-TELEGRAPH EQUIPMENT
(By courtesy of H.M. Postmaster-General)

The supply from the tuning-fork oscillator to the motor circuit goes by way of an electronic frequency-halver, which may be switched in or out of circuit, thereby enabling the supply to the motor to be either 510 c/s or 1,020 c/s, corresponding to drum speeds of 1 r.p.s. and 2 r.p.s. respectively.



FIG. 13.18. MUIRHEAD-JARVIS PHOTO-TELEGRAPH EQUIPMENT: A CLOSE VIEW OF THE SENDER
(By courtesy of H.M. Postmaster-General)

The frequency-halver is followed by a power amplifier which has an output of 60 watts to drive the motor, a type of synchronous motor known as a phonic motor. The rotor of the phonic motor is laminated, has 51 teeth and carries no windings. The stator is also laminated and has six poles having teeth cut in the pole faces, with similar pitch to the teeth on the rotor. Fig. 13.22 shows the parts of the phonic motor. The 1,020 or 510 c/s a.c. is fed to the windings encircling the stator teeth and a polarizing d.c. is fed to the stator field windings. The motor is not self-starting and, for starting, is belt driven above synchronous speed through a free-wheel drive by an auxiliary 24 V d.c. motor, which latter is then switched off. On slowing down the phonic motor synchronizes, as can be verified stroboscopically, with its rotor advancing one tooth in each cycle of the oscillator supply. Thus at 1,020 c/s supply the motor runs at 20 r.p.s., and at 510 c/s supply the motor speed is 10 r.p.s.

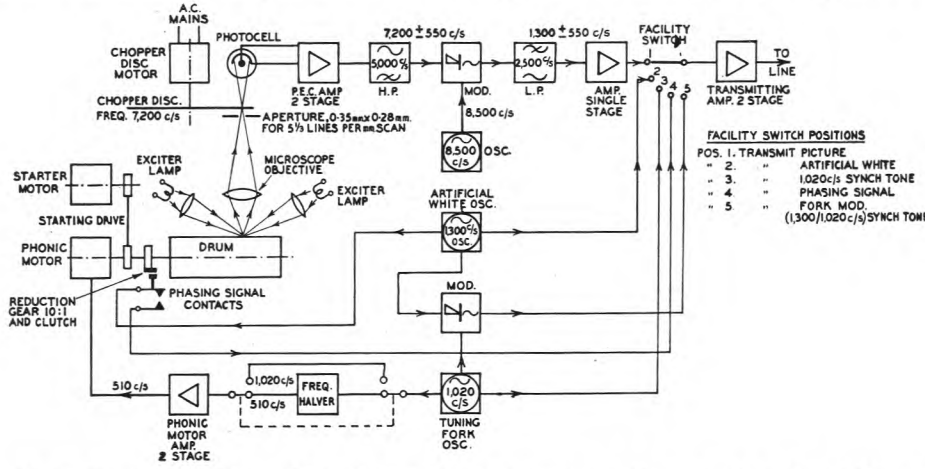


Fig. 13.19. Simplified Block Schematic of Muirhead-Jarvis Photo-telegraph Transmitter.

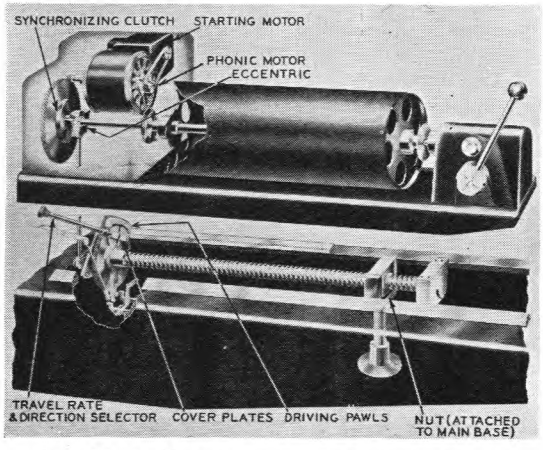


Fig. 13.20. Mechanism of Muirhead-Jarvis Photo-telegraph Transmitter

(By courtesy of Muirhead & Co., Ltd.)

at 20 r.p.s., and at 510 c/s supply the motor speed is 10 r.p.s.

The phonic motor drives the main shaft through a 10 to 1 reduction gear, to give the required drum speeds, and through a pawl clutch which is electromagnetically controlled when the operator presses the "start-drum" button.

Electrical contacts controlling the transmission of the 30 mS, 1,300 c/s tone phasing signal impulses are operated by a cam on the large gear wheel once per revolution. It is therefore necessary to arrange that the longitudinal paper clips on the sender drum bear a fixed angular relationship to this gear wheel. This is arranged as follows. When the start-drum button is pressed, this allows the clutch to engage in one position only, since there is only a single pawl to drive into a single slot.

Next, the main (driven) shaft carries a driving dog fixed relative to the clutch pawl, and this dog drives another on the drum, fixed relative to the paper clips. The phasing signal is thus arranged to be transmitted under the control of the operator when the clips are passing the optical head.

The drum is supported freely between centres and at its tailstock end it carries a second dog, which drives a friction device to prevent the drum from oscillating. An eccentric is fitted to the main shaft to operate a rocking lever carrying two pawls, which, in turn, drive a gear wheel mounted on the carriage-traversing lead screw. The direction of drive, and the number of teeth advanced for each

throw of the eccentric, depend upon the position of two sector plates which hold the pawls out of engagement. This small angular movement of the lead screw for a complete revolution of the drum allows the lead screw to have a coarse pitch of the order of half-an-inch.

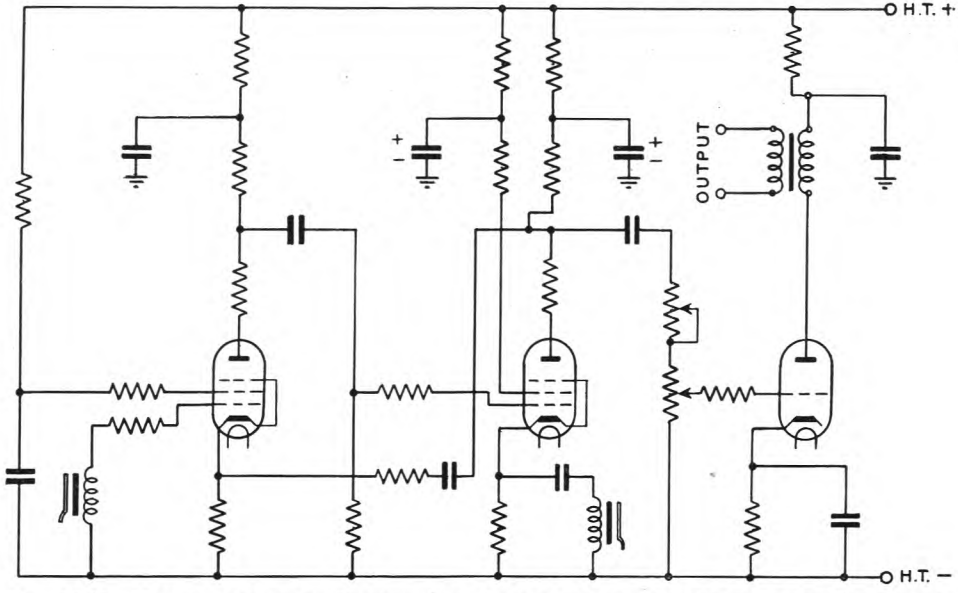


FIG. 13.21. VALVE-MAINTAINED TUNING-FORK OSCILLATOR OF MUIRHEAD-JARVIS TELEGRAPH EQUIPMENT

The carriage can be manually traversed by means of a handle mounted on the front of the console, whilst the motor-driven traversing is engaged by the operation of a lever located between the gear box and the drum. An indicator on the front of the console shows the operator the position of the drum when the console lid is closed.

The drum is illuminated by two exciter lamps, and it is arranged that an image of each filament is focused on the drum to form together a cross of light. To ensure constancy of illumination the lamps are supplied from a heavily smoothed rectified supply, the rectifier being fed from a constant-voltage stabilizing transformer. Each lamp takes approximately 4 amps at 6 V. Light reflected from the drum is focused by the microscope objective at a point just beyond the scanning aperture, which is 0·35 mm × 0·28 mm for $5\frac{1}{3}$ lines/mm scanning.

Beyond the aperture, and before the photo-electric cell, the now-diverging beam passes through the teeth of a chopper disc, the purpose of which is to provide the carrier frequency. As the speed of the chopper disc need not be very accurate it is driven by a mains-supplied induction motor. The chopping action provides a carrier frequency of approximately 7,200 c/s, which is deliberately high compared with the maximum fundamental modulating frequency of 550 c/s. There is thus no difficulty in separating the modulating frequency, which it is not desired to transmit directly, from the carrier and side-bands which have to be transmitted by the use of a high-pass filter cutting off at 5,000 c/s.

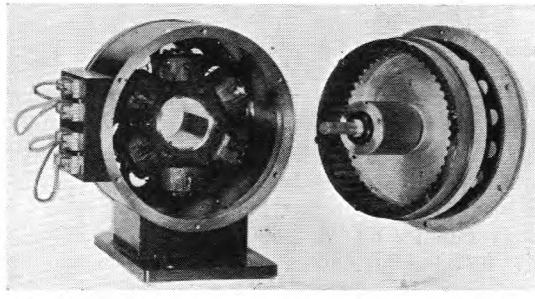


FIG. 13.22. PHONIC MOTOR OF MUIRHEAD-JARVIS PHOTO-TELEGRAPH EQUIPMENT
(By courtesy of Muirhead & Co., Ltd.)

Any irregularities in the chopper disc, or in its action, are liable to produce unwanted modulations of the carrier. For this reason the disc runs within a sealed cover, so that dust will not lodge in the

teeth. Also, a fixed aperture near the chopper disc reduces the cross-section of the beam to less than the size of the holes in the disc, so that small irregularities in the disc have no effect.

Fig. 13.23 shows the circuit of the photo-electric cell amplifier. It will be seen that the photo-cell is connected in series with a resistor across the smoothed anode supply and produces voltage variations at the control grid of the first-stage amplifier valve. As the photo-electric cell current

The sender console is provided with a light-tight lid (in the same way as the receiver), but this need not necessarily be closed when sending as the brilliance of the light spot makes the general room illumination relatively negligible.

The Receiver. The receiver console (Fig. 13.17 and 13.24) has the same general appearance and construction as the sender console. The drums are charged with film or bromide paper in the dark-room and loaded into individual light-tight

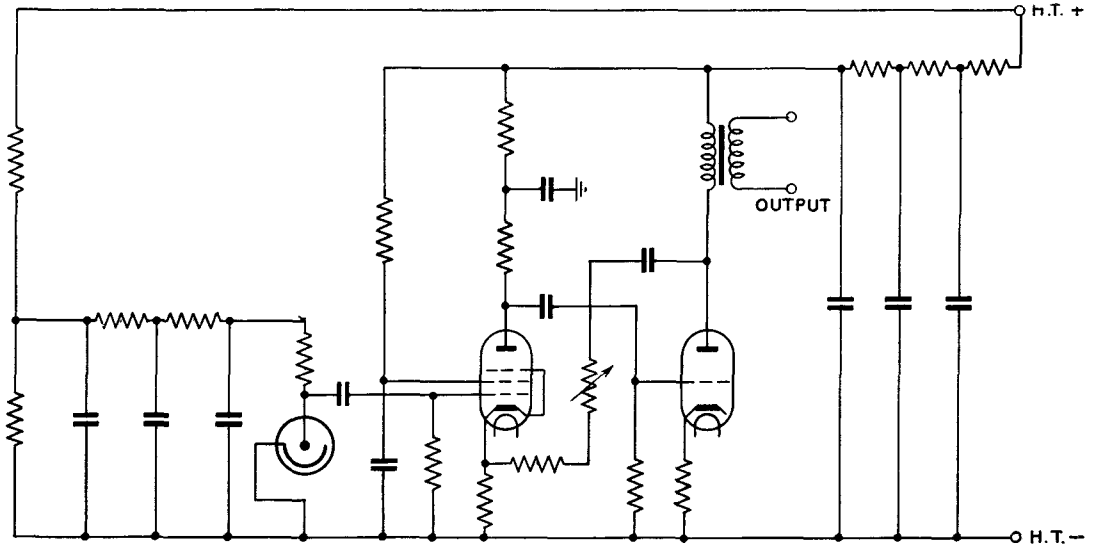


FIG. 13.23. PHOTO-CELL AMPLIFIER, MUIRHEAD-JARVIS PHOTO-TELEGRAPH EQUIPMENT

is very small, and therefore highly sensitive to noise interference, the amplifier is mounted as close as possible to the photo-cell in the rear of the sender console, and not on the associated equipment rack.

The standard C.C.I.T. carrier frequency of 1,300 c/s is derived by taking the modulated 7,200 c/s carrier to a frequency-changer (or modulator) supplied from an 8,500 c/s oscillator. The frequency-changer is followed by a low-pass filter cutting off at 2,500 c/s, which allows only the 1,300 c/s derived carrier and its side-bands to pass, and after further amplification this constitutes the transmitted signal.

An auxiliary 1,300 c/s oscillator is provided to supply the following requirements used in setting up the equipment—

(*a*) "Artificial white" signal.

(*b*) "Artificial black" signal, which is approximately 30 db below artificial white.

(*c*) Phasing impulses.

(*d*) Modulated tone 1,020/1,300 c/s for frequency checking over carrier telephone circuits.

boxes (or cassettes) having a longitudinal slit covered by a shutter. The loaded cassettes are stored ready for use on a tray beneath the console. In use, the cassette slides into the gap between the headstock and tailstock and the drum is lifted on to centres as in the sender. When the light-tight lid of the console is closed and locked, the locking action also opens the shutter in the cassette so that the film may be exposed to the scanning spot projected from the optical head mounted on the back frame of the console. A handle is provided on the front of the console for traversing the drum, together with an indicator, as on the sender.

A simplified block schematic diagram of the receiving equipment is shown in Fig. 13.25. The fork-oscillator, frequency-halver, phonic motor amplifier, phonic motor and starting motor are similar to those provided on the sender. The general arrangement of the drum-driving and traversing mechanism is also similar in sender and receiver but the clutches differ. In the receiver clutch the single pawl on the driven member,

which bears a fixed angular relationship to the drum-driving dog (as in the sender), is allowed to engage with the nearest of 100 teeth on the driving member at the instant of reception of a phasing pulse. The paper clips on the sending and receiving drums are thus always phased within 3·6°.

The line is connected to a variable attenuator and amplifier when receiving picture tone, and through a fork-tone demodulator unit direct to the amplifier when synchronizing over a carrier telephone circuit. To the output side of the amplifier are connected first the equipment required in setting up and monitoring the reception and second, the further equipment required to adapt the received picture signal to the needs of the Duddell oscillograph.

The auxiliary equipment just mentioned consists of—

(*a*) A monitoring amplifier-loud speaker unit which may be usefully left in circuit throughout a picture call.

(*b*) A cathode ray oscillograph unit, used principally for synchronizing the receiver tuning-fork oscillator to the fork-tone transmitted by the sender, before starting the receiving drum. This equipment is actually combined with the loud-speaker unit (*a*). The C.R.O. tube produces a trace which in use is an incomplete circle. When the fork-oscillators in the sender and receiver are in exact synchronism the trace is stationary, and it rotates in one direction or the other when the receiver fork-oscillator is adjusted for higher or lower frequency than the received tone. This result is achieved by using the local fork-tone to produce a full circular trace on the C.R.O., by connecting the two pairs of electrostatic deflecting plates in a resistive and capacitative circuit respectively. The received synchronizing signal is then applied to the control grid of the C.R.O. to suppress part of the trace.

(*c*) An anode-bend detector for the 1,300 c/s phase signal pulses. These pulses after detection operate a high speed relay with its contact in the electromagnetic release circuit of the pawl in the clutch already described. Signals are fed to this detector under control of a relay, operated by pressing the "phase" button.

In the main signal path the amplifier is followed by a diode compensator which may be switched out of circuit at will. Its use is necessary, however, when receiving ordinary photographs having half-tones, in order to modify the range of received signal power to one which when aided by the shape of the light mask already described produces a range of picture density matching the original. The compensator consists of a combined resistive and diode load on the amplifier. At low signal inputs only the resistive load is effective, but as the signal voltage increases, the diode load impedance falls progressively, thus producing an output which is non-linear.

The compensator is followed by a final amplifier, demodulator and low-pass filter, cutting off at 1,000 c/s to eradicate any unwanted frequencies arising in the demodulation.

The optical arrangements are illustrated in Fig. 13.25. The image of one coil of the 6 V, 48 W receiver lamp is focused on the oscillograph mirror. For uniformity of results in reception, the voltage of the lamp must be accurately set to a predetermined value and for this purpose a voltmeter and control are provided.



FIG. 13.24. RECEIVER CONSOLE OF MUIRHEAD-JARVIS PHOTO-TELEGRAPH EQUIPMENT
(*By courtesy of H.M. Postmaster-General*)

The AM/FM Converter. The AM/FM converter consists of a series of panels which can be added to the standard AM-type Muirhead-Jarvis sender and receiver racks to enable transmission and reception to be conducted on a S.C.F.M. basis.

Transmission. Fig. 13.26 shows the essentials of the sending terminal in block schematic form.

The chopper disc, photocell, photocell amplifier, high-pass filter and "set-black" attenuator are those of the normal AM transmitter and these are oscillator, a fixed frequency oscillator and a modulator. The two oscillators each have a frequency of the order of 100,000 c/s and operate with the

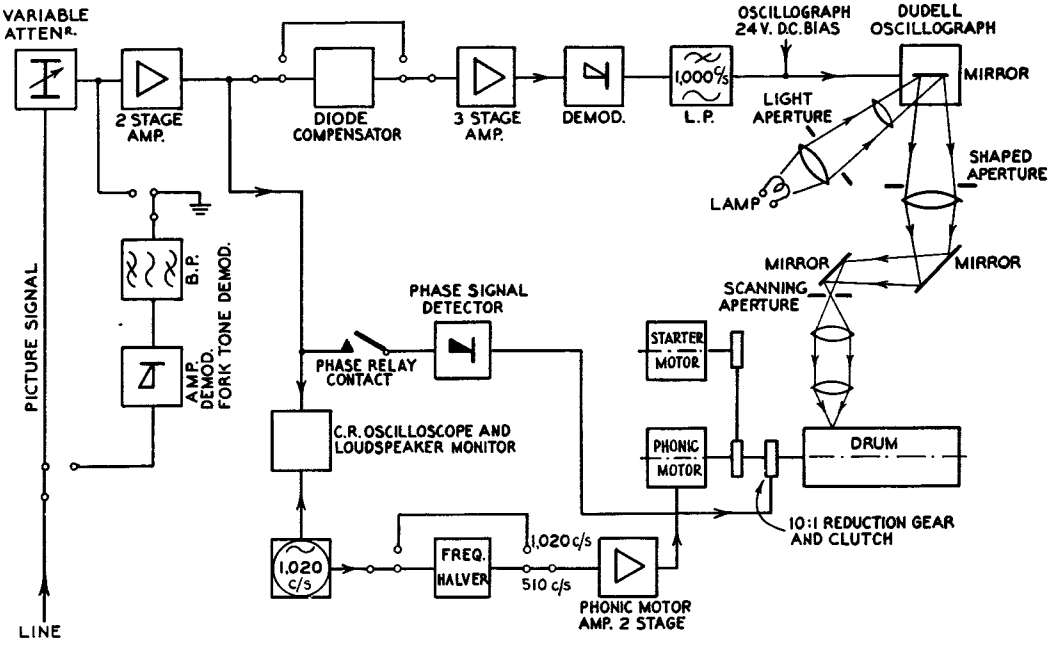


FIG. 13.25. SIMPLIFIED BLOCK SCHEMATIC OF MUIRHEAD-JARVIS PHOTO-TELEGRAPH RECEIVER

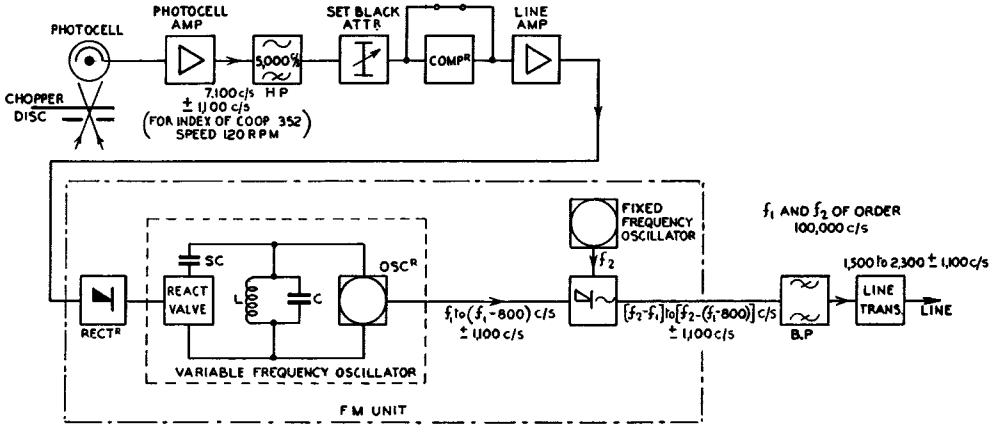


FIG. 13.26. MUIRHEAD-JARVIS TRANSMITTER ADAPTED TO SUB-CARRIER FREQUENCY MODULATION (S.C.F.M.) TRANSMISSION

connected to the compensation amplifier (if required), line amplifier, the FM unit and thence to line via a band-pass filter. The compensation amplifier is not usually required at the transmitter.

The FM unit comprises an amplifier and full wave rectifier of the AM input, a variable frequency modulator and L.P. filter as a beat-frequency oscillator.

The rectified AM signal is applied to the grid of a reactor valve in the variable-frequency oscillator, to vary the conductance of the valve and, thereby, the capacitance in the oscillatory circuit. This

produces a change of frequency of 800 c/s from steady black to steady white. The difference frequency of the fixed and variable frequency oscillators, derived from the modulator and isolated by the band-pass filter, varies from 1,500 c/s (steady black) to 2,300 c/s (steady white). This is the S.C.F.M. line signal, which contains side frequencies up to 1,100 c/s (at index of co-operation 352, drum speed 120 r.p.m.) according to the rate of change of tone in the picture.

Receiver. Fig. 13.29 shows a monitor set designed by Muirhead & Co., Ltd., for mounting on the receiver rack of the Muirhead-Jarvis picture telegraph equipment. The monitor operates on the Mufax principle using a continuous roll of a slightly damp electrolytic paper, the recording electrodes being a revolving wire helix and a stainless steel writing edge. The principle was described earlier in this chapter.

The monitor is the equivalent of a receiver with

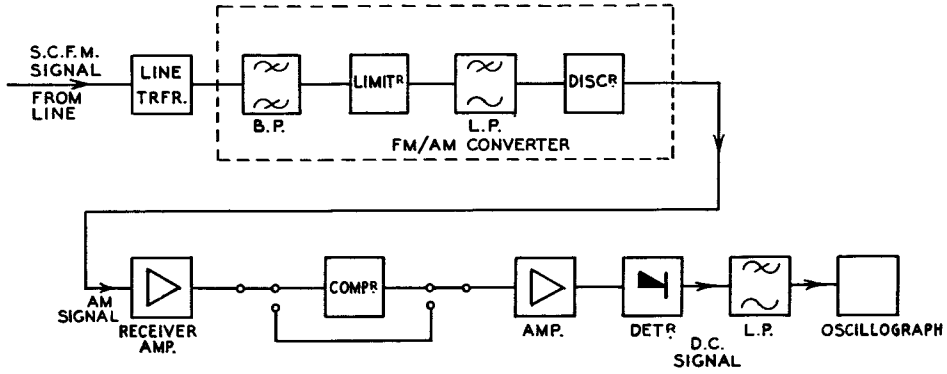


FIG. 13.27. MUIRHEAD-JARVIS RECEIVER ADAPTED TO S.C.F.M. RECEPTION

Reception. Fig. 13.27 shows the receiver in block schematic form.

The line signal is connected to a band-pass filter which rejects all circuit noise that falls outside the required signal frequency band. This noise arises mainly from atmospherics in the radio path. The filter is followed by a limiter (which is also an amplifier) the purpose of which is to derive a signal of approximately constant amplitude. This is necessary because severe fading in the radio frequency signal received is only partially corrected in the radio receiver, and further correction must be applied in the particular frequency band passed by the filter. If not corrected, this spurious amplitude-modulation would distort the final amplitude-modulated signal extracted for operating the Duddell oscillograph.

The limiting action at the same time squares the signal wave-form, and this is partially remedied by a low-pass filter following the limiter.

The output from the low-pass filter is taken to the discriminator (or frequency detector) which interprets frequency change in the input signal as an amplitude change in the output, the output range being 35 db for 1,500 c/s to 2,300 c/s input. The discriminator consists essentially of a resistance-capacity bridge as shown in Fig. 13.28. The rest of the circuit is the same as for AM reception.

The Mufax Direct-recording Monitors and a 66 mm diameter drum. Its use enables the technical operators to see whether the picture which is being recorded on the main photographic receiver will be satisfactory, without having to wait for the photographic development to be completed. This is of especial benefit when operating on a poor radio circuit. A similar, but larger, monitor equivalent to a receiver having an 88 mm diameter drum, is also made for use remote from the receiver, to enable the Art Editor of a periodical to see what pictures are being received, without waiting for the photographic copies.

Muirhead & Co. Ltd. have demonstrated that Mufax prints can be reproduced in newsprint halftone with sufficient detail for most purposes and they have therefore introduced a self-contained Mufax picture receiver, equivalent to an 88 mm diameter drum machine and being very similar in general appearance to the monitor. This set is intended for use when the full quality of photographic reception is not warranted, in view of the greater expense of the latter and of the time required for photographic processing.

The Muirhead-Belin Portable Transmitter. This equipment is adapted to the needs of the Press, since it can be readily transported in its two cases to the vicinity of a news event and set up in the nearest telephone exchange having the necessary grade of circuit for the transmission.

The equipment is a sender only, so that no question of operating it in a darkroom arises, but the Press photographer may need to provide temporary darkroom facilities for processing the pictures to be transmitted. The sender has the standard index of co-operation 352, to enable it to work to a Muirhead-Jarvis (or any other C.C.I.T. standard) fixed-station receiver.

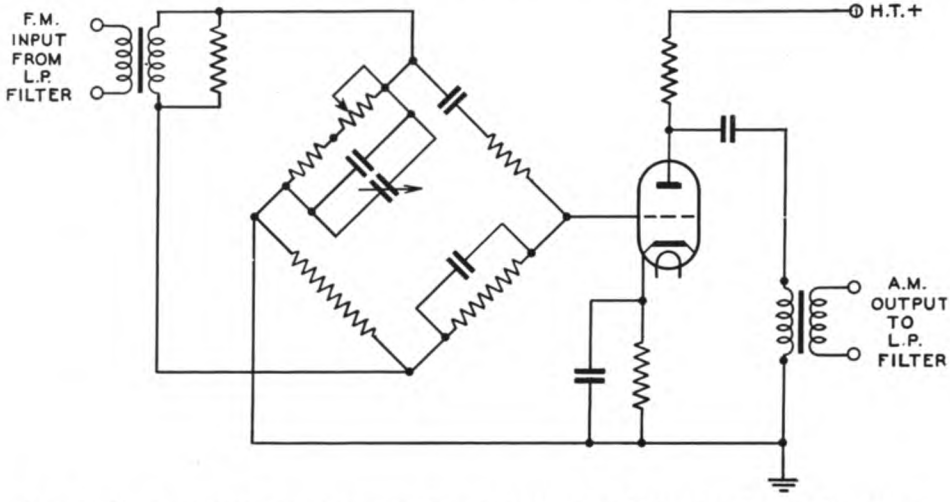


FIG. 13.28. SIMPLIFIED SCHEMATIC OF DISCRIMINATOR OF MUIRHEAD-JARVIS RECEIVER



FIG. 13.29. A MUFAX MONITOR SET
(By courtesy of Muirhead & Co., Ltd.)

Some of these portable equipments are designed to work from a.c. or d.c. mains or from an 8 V supply from a car battery, and include a motor generator from which the various power supplies are taken; others are suitable for a.c. supplies only. The appearance of the equipment is shown in Fig. 13.30 and the block schematic arrangement in Fig. 13.31.

The optical arrangements are generally similar to those of the Muirhead-Jarvis equipment. The 66 mm diameter drum, however, is carried on a differential lead screw of resultant pitch $\frac{3}{16}$ mm ($5\frac{1}{3}$ lines per mm scanning) which is driven through a gear box by a d.c. series motor. A manually operated clutch allows alternative gears to be engaged to give drum speeds of 60 and 120 r.p.m.

The speed of the d.c. motor is maintained near synchronism, when once set up, by the application of a variable controlling load in the following manner. The motor drives a small alternator, the output of which, together with that from a high-stability 1,020 c/s valve-maintained tuning fork, is taken to a synchronizing or mixing unit. As the motor and alternator change speed, the alternator voltage changes phase with respect to the tuning-fork oscillator voltage. The mixer unit utilizes the changing phase to produce a d.c. voltage varying in amplitude, which is applied to the grid of a valve. The anode supply to this valve is taken from a small d.c. generator, also driven by the motor, so that variation of the valve grid voltage changes the load on both generator and motor, thus keeping their speed within the close limits required. A stroboscopic device on the shaft indicates when synchronism between the tuning fork and motor has been achieved on first setting up the sender, a speed control being provided for making the necessary adjustments.

The onus of synchronizing and phasing the sender and receiver rests with the receiver. The sender can transmit 1,020 c/s fork-tone for synchronizing, as well as a phasing signal derived by

contacts interrupting either the 1,020 c/s fork-tone or the 1,300 c/s picture-white tone. An additional unit can be provided to enable 1,300/1,020 c/s modulated tone to be sent when synchronizing

Approximate frequency band of AM signal at 120 r.p.m., 3,700–5,900 c/s.

High-pass filter 3,000 c/s.

Local oscillator, 6,100 c/s.

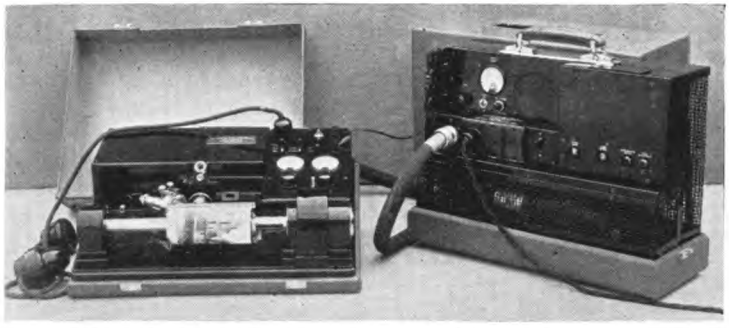


FIG. 13.30. MUIRHEAD-BELIN PORTABLE TRANSMITTER

(By courtesy of Muirhead & Co., Ltd.)

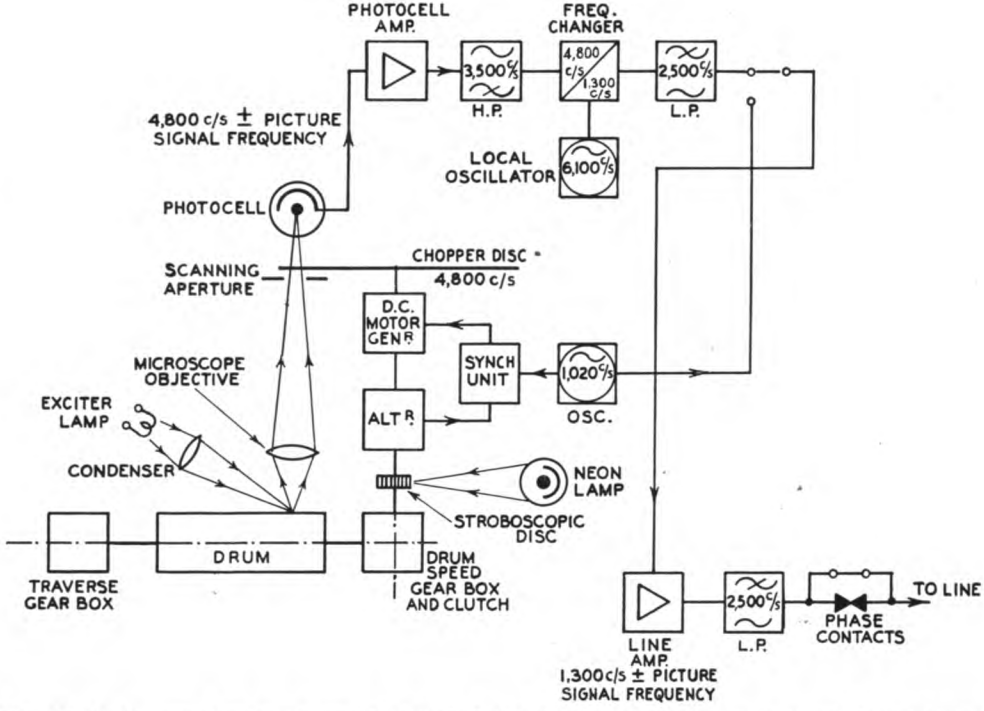


FIG. 13.31. BLOCK SCHEMATIC OF MUIRHEAD-BELIN PORTABLE PHOTO-TELEGRAPH TRANSMITTER

over carrier circuits. The 1,300 c/s AM carrier is produced in a manner similar to that adopted in the Muirhead-Jarvis equipment, although different intermediate frequencies are used as follows—

Chopper frequency 4,800 c/s.

Approximate maximum picture-signal frequency at 120 r.p.m., 1,100 c/s.

Final carrier at output of frequency-changer 1,300 c/s.

Approximate transmitter frequency band at 120 r.p.m., 200–2,400 c/s.

Low-pass filter 2,500 c/s which cuts off unwanted upper frequencies in the output from the frequency-changer.

After the line amplifier a further L.P. filter is provided, having approximately the characteristics of a normal line. When the transmitter is working direct into a short unloaded line, the filter cuts off any high frequencies which the line would otherwise be capable of transmitting but which might spoil the received picture on account of excessive amplitude distortion.

The smoothing of the 4 V d.c. power supply to the exciter lamp is assisted by the use of a small dry-type accumulator floated across the supply.



FIG. 13.32. GENERAL ELECTRIC CO. PHOTOTELEGRAPH SENDER AND RECEIVER CONSOLE EQUIPMENT

(By courtesy of H.M. Postmaster-General)

The drum, which takes a picture of maximum size 204 mm × 127 mm (8 in. × 5 in.), can be declutched from the lead screw so that it can be slid into the correct starting position relative to the optical head.

One of the two carrying cases accommodates the power equipment necessary to provide all power supplies to the transmitter, as well as the tuning fork and synchronizing units. The other carrying case accommodates the transmitter proper.

Some Interesting Points of Difference in Other Phototelegraph Equipments

1. *The General Electric Co. Sender-Receiver.* Fig. 13.32 shows a single-drum sender/receiver for S.C.F.M. radio transmission, built as a self-contained console. This set was designed by the B.P.O. and manufactured by The General Electric Co., for use by Cables and Wireless (Bibliography No. 14).

The system of mechanical transmission using a lead screw in a hollow shaft has already been described.

The method of modulating the light beam in the sender condition is an alternative to the use of a chopper disc. The method is to reflect the scanning light beam from the mirror of the Duddell oscillograph which is also used in reception and to drive the oscillograph at the sub-carrier frequency. Thus the deflection of the light beam across the scanning aperture modulates its intensity at the carrier frequency of 1,800 c/s. This is illustrated in Fig. 13.1.

The frequency standard is a 108 kc/s crystal-oscillator instead of a valve-maintained tuning fork. This primary frequency is sub-divided in two stages to 10·8 kc/s and to 1,800 c/s, the latter being used for the phonic motor drive as well as for the oscillograph drive in the receiver. In receiving, the 10·8 kc/s frequency is used to change the carrier frequency of the S.C.F.M. signal from 1,800 c/s to 12·6 kc/s after the limiting stage and before the discriminating stage. This higher carrier frequency facilitates the design of the linear frequency-discriminator. The frequency deviation of the sub-carrier is 200 c/s, giving 1,600 c/s for steady black and 2,000 c/s for steady white.

2. *The Times Telephoto Sender-Receiver.* An interesting point about the Times telephoto equipment is the use of a special photocell in a capacitance bridge circuit, for directly amplitude-modulating an 1,800 c/s fork-oscillator tone applied to the bridge. This arrangement is an alternative to the use of light beam modulation for producing the carrier frequency. The circuit is shown schematically in Fig. 13.33.

The photocell has two anodes, one the normal photo-current anode and the second a photo-electrically inactive auxiliary anode, which approximately balances the capacitance to cathode of the former. These two anode-cathode capacitances form two arms of the bridge, which is completed by the resistance arms shown connected to the photocell anodes. The bridge is balanced for either black or white by adjustment of the variable resistor $R1$, and this decides whether positive or negative transmission will result. Modulation of the light falling on the photocell unbalances the bridge and produces a correspondingly amplitude-modulated 1,800 c/s carrier current in the load resistor $R2$. The full output range is of the order of 12 db from black to white. (There are still

further alternative means of producing an amplitude-modulated carrier which are probably not much used. For a description of these methods the reader is referred to No. 1 in the bibliography.)

Like the G.E.C. equipment, the Times Telephoto set is also a self-contained single-drum sender/receiver, but built for table mounting instead of in console form; it has the further interesting feature that, in at least some models, both photographic and Teledeltos reception are available.

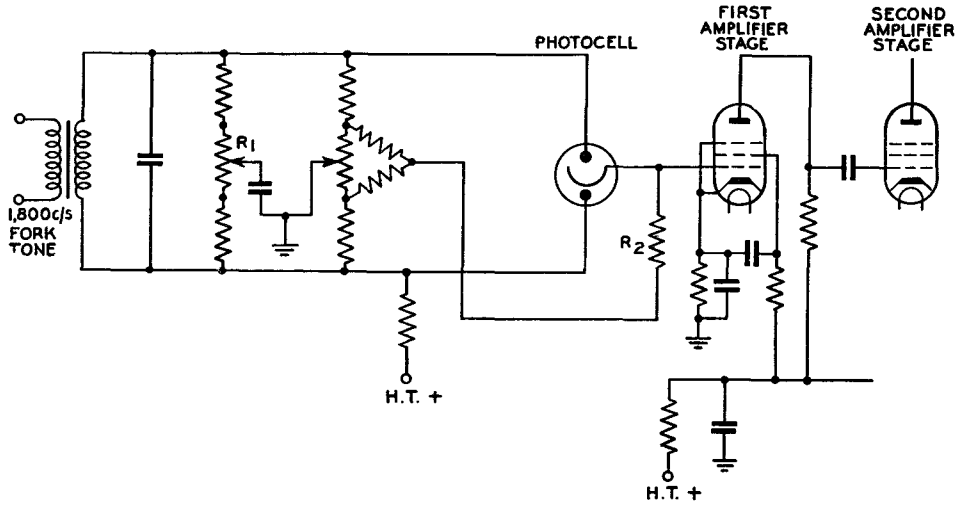


FIG. 13.33. TIMES TELEPHOTO PHOTO-TELEGRAPH EQUIPMENT: PHOTO-CELL MODULATOR AMPLIFIER

Facsimile Systems for Documentary Transmission

In recent years a great deal of attention has been devoted to the development of facsimile systems for the transmission of documentary matter, e.g. written, typed or printed messages, line diagrams and charts. Systems of this type are designed with a view to eliminating the need for skilled operators and to produce facsimile copies of original documents which can be taken straight off the receiving machine ready for use. Direct recording methods are therefore used and the document is reproduced in the receiving machine either on Teledeltos or electrolytic papers (see footnote, p. 550). The document to be transmitted is scanned in the sender by photo-electric or resistance methods, the former usually being preferred.

The principles used in the scanning at the sender and the reproduction in the receiver have already been described earlier in this chapter.

Several commercial types of equipment are available for use and reference is given in the bibliography (Nos. 2, 3 and 4) to the Western Union Telegraph Co., Ltd., Telefax systems as representative of the systems most widely used in the U.S.A. In the U.K. Muirhead & Co., Ltd., have developed the MUFAX system (see bibliography No. 13) and Creed & Co., Ltd., now manufacture the Western Union types of optical Telefax equipments.

A detailed description of these equipments is beyond the scope of this book and the reader is referred to the bibliography for fuller information.

The following are the more important factors which have to be considered in the design of a documentary system and serve to show ways in which the requirements differ from those for photo-telegraph systems. Some of the requirements are mutually contradictory and the best compromise must be sought in practical systems.

1. The operation of the equipment must be as simple as possible, particularly at the out-station terminal, and it should not be necessary for the operators to give undivided attention to the circuit. Thus—

(*a*) Loading and unloading of the message should be easy and foolproof.

(*b*) Synchronizing and phasing should preferably be automatic. This has led to the use of frequency-controlled a.c. mains as the basis of synchronism in some systems, including the Telefax, and Mufax systems.

(*c*) Supervisory functions should as far as possible be automatic, and sending and receiving operators should as far as possible be independent of immediate co-operation between each other.

2. Notwithstanding the inevitable complications arising from 1(*c*), the equipment should be as simple and cheap as possible to maintain, and should also be designed for reasonable first cost. The minimum of routine adjustment and maintenance should be the aim. In particular, the operators should only be required to perform the simplest and most infrequent adjustments.

3. The consumable materials, notably the paper used at both sender and receiver, should be cheap. The paper should be clean to handle.

4. There should be the minimum of after-work to perform on the received copy. (This, as well as the cost, precludes the use of photographic reception.)

5. Transmission time must be short. Therefore—

(*a*) The scanning should be no finer than is essential for accuracy.

(*b*) Unnecessary space on the telegram form, or other copy, should be avoided.

(*c*) The maximum advantage should be taken of the usable frequency spectrum of the transmission path.

6. The equipment should be compact, light in weight and moderate in power consumption.

7. The sender should preferably handle the following types of original and with the same adjustment throughout—

(*a*) Documents hand-written in ordinary writing ink or pencil.

(*b*) Typewritten documents.

(*c*) Teleprinter tape stuck on a form.

(*d*) Printed matter.

Documentary systems are of particular interest to Telegraph Administrations and private operating agencies concerned with the transmission of telegrams. The over-riding consideration, however, which will in almost every case determine the scope of future use of systems of this type, is an economic one.

To transmit a telegram in a reasonable time, i.e. a few minutes, requires a frequency band-width comparable to that of a telephone circuit, as against a band-width of only 120 c/s for teleprinter transmission. For short distances, e.g. up to 30 miles, this is no disadvantage, because up to this distance teleprinter circuits are also provided on individual physical circuits. Beyond this distance it usually becomes economic to provide channelling equipment which permits up to 18 or 24 individual teleprinter circuits to be operated over one telephone circuit. In so far as facsimile equipment enables operator savings to be made, these can be set against the increased line costs involved in facsimile working. Account has however also to be taken of the relatively high costs of the special facsimile papers which have to be employed.*

As a result it seems likely, on present costs, that the most profitable exploitation of facsimile telegraphy for the transmission of telegrams will be found on short distance circuits, e.g. between head offices and small sub-offices in the telegraph service and between private subscribers and public telegraph offices. For these cases there is the prospect, provided the first costs and annual charges for the facsimile equipments are reasonable, that savings can be made in telegram acceptance and delivery costs apart from the advantages which should be obtained, as compared with telephone or hand delivery methods, in speeding up the transmission and delivery of the messages.

For specialized applications, e.g. the transmission of weather maps for meteorological purposes, documentary facsimile systems have indisputable advantages over other methods and will undoubtedly be employed more and more in the future on land line and radio transmission circuits.

* A recently-developed direct-recording system employs a percussion method of recording an inked impression on ordinary paper, thus eliminating the necessity for a specialized facsimile paper.

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CHAPTER 14

POWER PLANT

THIS chapter gives practical information on the provision of power supplies for the various types of modern telegraph equipment. It will be realized that practical power plants vary greatly in detail but those described in this chapter are representative of modern practice and are typical of those employed in B.P.O. telegraph services.

General. The types of telegraph transmission and terminal equipment in use in the B.P.O. have changed basically since about the year 1928. This has caused a complete revision of the standards of provision of power supplies. Prior to this standardization of telegraph systems, direct current signalling was almost exclusively used for telegraph transmission. The circuits were usually provided on overhead wires or on wires in special telegraph cables and various types of telegraph instruments were used. In the larger offices line signalling power supplies were provided at ± 40 V, ± 80 V and ± 120 V and a local supply at ± 24 V; this was the "universal battery plant," operated on a charge-discharge basis. The appropriate line voltage was chosen according to the length or resistance of each circuit. At very small offices the equipment worked to the larger offices on a "central-battery" basis or used primary battery supplies.

Standardization of Paper Supplies. There are advantages from the points of view of design, provision and maintenance to be derived from the use of only a few standard power supplies and it is convenient for the equipment designer to know exactly the characteristics of the power supplies available. However, important equipment developments do from time to time demand fresh power supplies or changes in the characteristics of existing supplies. Absolute standardization cannot be wisely enforced on a long term basis. An example of such a development is the growing use of indirectly heated valves.

The following are the present standard power supplies employed in B.P.O. telegraph services. Not all equipment in service conforms to these standards, as for example phonogram equipment, much of which uses 22–24 V or other telephone exchange voltages.

(*a*) Signalling and Teleprinter and other Motors. ± 80 V d.c.

(*b*) Teleprinter Automatic Switching, Phonogram and T.T. equipment — 50 V d.c.

(*c*) M.C.V.F. Type 3 equipment—

Filaments: — 21·5 V d.c.
Anodes: + 130 V d.c.

(*d*) M.C.V.F. Type 4 equipment—

Valve heaters: 6·3 V a.c.
Anodes: + 220 V d.c.

(*e*) Teleprinter Switchboard Lamps: 6 V a.c. or d.c.

The characteristics of these various supplies are described later.

Stability of Telegraph Power Supplies. Compared with telephony, telegraphy—particularly machine telegraphy—is relatively much more vulnerable to brief interruptions of power supply. In telephony the major part of the occupied time of a circuit is spent in speech and during speech a brief interruption is not likely to cause inconvenience and may even pass unnoticed. In machine telegraphy the circuit, during most of its occupied time, is liable to show the effects of discontinuities in the power supply as errors in the telegraph messages. For this reason the operation of machine telegraphy demands that precautions should be taken to safeguard the continuity of power supplies to all but the smallest installations, for which the cost cannot be justified. The continuity of telegraph services which operate over telephone type circuits, e.g. M.C.V.F. telegraph systems, are equally dependent upon the power supplies at telephone repeater stations on the route of the circuits.

Power Requirements of Various Telegraph Equipments

The following are the requirements to be met by power supplies for the various telegraph equipment in service.

(*a*) **Teleprinters.** A teleprinter requires a supply for its motor and, except in the case of 1,500 c/s single-tone V.F. installations, a double-current signalling supply.

The signalling load per teleprinter is usually about 20 mA (or about 40 mA if a local circuit is also to be supplied) taken from a ± 80 V power supply. The mean signalling voltage is not usually very critical but the positive and negative voltages should not differ by more than 4 V, otherwise

signal bias due to unbalanced voltages will begin to appear.

The ± 80 V supply is also the standard source for the teleprinter motor power, the average load being about 0·4 A per teleprinter when supplied from the positive and negative leads, i.e. at 160 V.

1. *Teleprinters No.* 3 are fitted with a shunt type d.c. motor made in four nominal voltage ranges, namely 100/110 V, 150/170 V, 200/220 V and 230/250 V. The second of these types has an absolute range for satisfactory operation of 150 to 172 V and this has been one limiting factor in the design of ± 80 V floating battery plants for instrument rooms.

The 100/110 V motor is used with a unit rectifier (principally B.P.O. types 22 C and 43 A, both of which are now obsolescent).

The 200/220 V and 230/250 V type motors are for use on d.c. mains which remain in service in the U.K. to a small extent.

2. *Teleprinters No.* 7B, which are used for private-wire and Telex services, are fitted with a two-range series type d.c. motor. The two nominal voltage ranges are 100/110 V and 160/250 V; the latter, covering an absolute range of 150 to 265 V, has allowed ± 80 V floating battery plants for renters' installations to have wider voltage limits than are permissible for teleprinters No. 3.

3. *Teleprinters No.* 11 use two-range series type d.c. motors. The motors on Teleprinters No. 11A have the same characteristics as those on Teleprinters No. 7B. The motors on the Teleprinters No. 11B have absolute voltage ranges of 160 ± 24 V and 220 ± 33 V. The former is suitable for any existing ± 80 V floating battery supply.

(*b*) **Teleprinter Station Equipment.** The various auxiliary units which can be associated with a teleprinter to form a station equipment are designed to take power supplies either at ± 80 V d.c. or at mains voltage.

Thus, for example, most auxiliary units at teleprinter stations using d.c. signalling take their power from the ± 80 V supply. V.F. converters for 1,500 c/s operation are made in two types, for a.c. mains and for d.c. mains, the latter being also suitable for use on a ± 80 V battery supply.

Calling lamps and bells, such as the teleprinter No. 7 bell signal may be operated either from ± 80 V, or a.c. mains using a 6 V transformer, or from dry cells when the mains supply is d.c.

Local supplies for relayed circuits at offices with d.c. mains are sometimes derived from the mains.

(*c*) **Teleprinter Switchboards.** These equipments use the standard ± 80 V supply with voltage stability requirements no more stringent than those of teleprinter motors and signalling, i.e. a range of about 150 to 184 V and balance of the positive and negative supplies within four volts.

Most of these equipments also require a 6-V supply for the switchboard lamps, suitable voltage limits being five to seven volts. Below 5 V there is a risk of insufficient illumination and above 7 V the life of the lamps is seriously shortened.

(*d*) **Teleprinter Automatic Switching Equipment.** This equipment requires a standard automatic telephone exchange type of − 50 V supply and the standard ± 80 V supply. It also requires a 6·3 V a.c. supply for the heaters of valves in the service signal generation and distribution equipment, which can be allowed to vary in voltage by about ± 10 per cent.

(*e*) **Phonogram and T.T. Equipment.** Most of the equipment in use is suitable for operation from battery supplies at 22 − 24 V, 40 V, 50 V or 60 V, i.e. the various telephone exchange supplies.

The following are the approximate power loads at 24 V.

Equipment	Max. Demand amps.	Daily Load A-hr
Separate Panel, per position .	0·3	3·0
Continuous panel, per position .	1·0	10·0
Position amplifiers, per position	0·1	0·5

Note—the amplifiers also require an anode supply which can be taken from any available battery of ± 80 V to 150 V. More recently, phonogram equipment has been introduced which provides the facility of automatic call queueing and distribution, and this equipment requires a supply typical of automatic telephone exchange practice, i.e. a − 50 V battery supply having limits of 46 V and 52 V. This will be the standard phonogram power supply for the future.

(*f*) **Multi-circuit V.F. Telegraph Equipment (Type 3).**

1. The four-circuit outstation equipment takes all its supplies from a.c. mains at 100/125 V or 200/250 V, 50 c/s. The voltage may vary by ± 10 per cent and the frequency by ± 5 per cent, the load being approximately 0·5kVA.

2. The standard voltage limits for the power supplies to 18-circuit equipment are—

L.T. or filament supply − 21·5 V ± 0·25 V.

H.T. or anode supply + 130 V ± 1·3 V.

± 80 V supply, each side 75 to 92 V to earth, with positive and negative supplies balanced within four volts. The upper and lower voltage

limits are set by the motor of the 160 V multi-frequency generator which runs from the combined supplies.

The following are the power loadings—

L.T. Supply. The equivalent of 0·125 A per circuit (each amplifier-detector actually takes 0·25 A but the filaments of two circuits are connected in series across the supply). Each multi-frequency generator field, 0·75 A.

1,020 c/s oscillator, 0·25 A.

T.D.M.S. oscillator, 0·5 A.

Valve Control Governor Panel, 1·25 A.

H.T. Supply. About 17 mA per circuit (average), including the relay bias supply.

1,020 c/s oscillator and T.D.M.S. oscillator, 80 mA.

± 80 V *Supply.* Signalling, 20 mA per circuit.

Relay biasing, 4 mA per circuit.

Each multi-frequency generator, 0·35 A.

T.D.M.S. motor, 0·35 A.

Test Teleprinter, 0·4 A.

All supplies for Type 3, 18-circuit equipment are normally floating battery supplies, but equipments installed in mobile terminals have been successfully run from rectifiers without batteries, but with considerable smoothing provided.

(*g*) **Multi-circuit V.F. Telegraph Equipment (Type 4).** This equipment, which incorporates individual circuit oscillators, can be arranged to take its valve heater and anode supplies wholly from a.c. mains at 200/250 V regulated externally to ± 1 per cent in voltage. The permissible frequency range is 50 to 60 c/s ± 10 per cent. The load is about 17 W per circuit. Alternatively at larger stations the anode supplies may be taken from a centralized rectifier equipment delivering + 220 V regulated to ± 1 per cent. The 220 V load is about 25 mA per circuit and the a.c. load for the heaters only is reduced to about 10 W per circuit. In these larger stations the carrier supplies may be taken from a 160 V multi-frequency generator instead of from individual circuit oscillators and the generator field supply is provided by a special 24 V rectifier. This makes a further small reduction in the circuit heater and anode power consumption. In all cases the ± 80 V signalling requirements, about 20 mA per circuit, and the 160 V supply to the multi-frequency generator when required, are taken from an external supply. This will also supply the motors of test teleprinters and miscellaneous alarms, etc.

(*h*) **Photo-telegraph Equipment.** Modern photo-telegraph equipments are designed to derive all their power requirements direct from a.c. mains, the necessary voltage stabilizing devices being provided in the equipment itself.

The Basis of Provision of Standby Supplies and Equipment

In a small M.C.V.F. telegraph terminal or telegraph instrument room it may be possible to tolerate a complete failure of the mains supply until a mobile standby engine-generator can be brought to the site, and at such stations there may be no centralized power equipment which, if faulty, could cause the whole station to be closed down.

At larger centres, however, the effects of a complete failure of the mains supply, or of centralized power plant, can cause far-reaching dislocation of the telegraph system. Particularly is this the case at a zone centre M.C.V.F. terminal or teleprinter switching centre carrying heavy through-traffic. At all important centres, therefore, it becomes necessary to design the power plant to safeguard the continuity of power supplies to the equipment.

The rules to be applied in deciding what precautions to take must necessarily be arbitrary and some cases are bound to be marginal. Some rules are necessary, however, for general guidance in planning and provision, and the following have been adopted by the B.P.O.

(*a*) **Precautions against Mains Failure.** Where there are less than eight working teleprinter circuits, power supplies are provided on a unit basis without standby arrangements.

1. *Teleprinter Offices.* Eight or more working circuits justify the provision of a floating battery power plant for the ± 80 V supply. If there is no permanent standby engine generator to replace the mains supply, the batteries provide 24 hours reserve for half the teleprinters. If there is a permanent standby engine-generator, the batteries provide not less than six hours reserve for half the teleprinters.

Where there is a teleprinter manual switchboard a ± 80 V battery supply and a standby 6-V supply are required to carry the load for 24 or six hours as above.

The phonograms service is one which intimately affects the public and, therefore, a battery supply is always provided; usually the full 24 hours reserve has been provided in the past, but six hours reserve is permissible where there is a permanent engine-generator.

2. *Public Service Teleprinter Automatic Switching Centres.* In all cases the 50 V supply and the 6·3 V a.c. supply must be provided to carry the full load with 6 or 24 hours reserve according to whether there is, or is not, a standby engine-generator.

3. *Public Service M.C.V.F. Telegraph Terminals.* The all-mains four-circuit equipments are rarely installed to provide a total of more than eight

circuits at one centre and no precautions are taken to safeguard continuity of supply.

The Type 3, 18- or 12-circuit equipment is designed to operate from battery supplies which provide 6 or 24 hours reserve for all circuits according to whether a standby engine-generator is, or is not, provided.

At terminals with Type 4 equipment, no standby provision is made for a single 6- or 12-circuit system. Where there are two 12- or 18-circuit (or in the future, sometimes 24-circuit) systems, the a.c. mains supply is replaced by a standby supply after a few seconds break and the $\pm$ 80 V supply is continuous. Where there are three or more systems the a.c. supply and the $\pm$ 80 V supply are maintained without break.

The periods of standby supply provision are the same as for Type 3 equipment and the methods of replacing the a.c. supply mains will be briefly described later in this chapter.

4. *Rented Teleprinters and Teleprinter Switchboards.* The primary responsibility for continuity of a power supply with mains characteristics rests with the renter. Nevertheless a $\pm$ 80 V battery supply is provided on the merits of each individual case, and wherever there is a multiple type switchboard both the $\pm$ 80 V supply and the 6 V supply are provided with standby. The standby provided is often for as short a period as two hours.

It will be appreciated that the great majority of renters' installations consist of only a few teleprinters, and no standby supply is installed unless the service provided is of some particular importance.

5. *Renters' M.C.V.F. Telegraph Terminals.* The same general rules are followed as for renters' teleprinters, i.e. the importance of each installation is judged individually and standby power arrangements are made available when desirable.

(*b*) **Precautions against Failure of Power Equipment.** Where teleprinters are supplied on a unit basis, each with its own individual rectifiers (or other power equipment) no reserve equipment is provided.

In the larger renters' installations provided with centralized $\pm$ 80 V rectifiers, but not with batteries, it is arranged that no rectifier supplies more than ten teleprinters and no reserve rectifiers are provided.

In all cases where floating battery supplies are provided a spare rectifier or motor-generator for each supply is provided. Apart from its function as a standby against breakdown, the reserve rectifier or motor-generator is usually essential for maintenance of the plant as will be explained later. In the case of rectifier plants the reserve rectifier may be of a simplified type, i.e. without the automatic voltage regulation features.

Rectifiers

The principles of rectification have been described in Chapter 3. The increasing use of rectifiers for the provision of d.c. power supplies has been a notable feature of the last 25 years. The B.P.O. have not used mercury-arc rectifiers for providing telegraph power supplies but have employed them to a small extent for other purposes.

Metal rectifiers, however, are extensively used in providing telegraph power supplies and now perform many of the duties for which motor-generators were formerly used. The principal advantage of metal rectifiers in comparison with motor-generators is the reduced time and money spent on maintenance. As will be seen later, however, there is still a good case for the use of motor-generators in some of the larger power plants.

The two types of metal rectifier widely used for providing power supplies are the copper oxide and selenium types. Copper oxide rectifiers were the first to come into general use in the U.K. and many of them are still in use in telegraph rectifier equipments. In 1938 the B.P.O. began to use selenium rectifiers for telegraph power plants and later they were standardized. The advantages of selenium rectifiers compared with copper oxide rectifiers are—

1. They give better voltage regulation as will be illustrated later.

2. They can be safely operated at a higher temperature, viz. copper oxide disc temperature about 55°C maximum, selenium discs about 75°C maximum.

3. They can be operated at a higher reverse voltage per disc.

Viz. copper oxide about 7 V (R.M.S.) and selenium about 14 to 18 V (R.M.S.) for standard discs.

Special discs are made for operation at higher reverse voltages.

These advantages combine to make the selenium rectifier smaller and lighter in weight than the equivalent copper oxide rectifier.

Simple Rectifier Circuits. (*a*) *Single-phase, half-wave rectifier.* Fig. 14.1 shows the simplest form of rectifier circuit. The transformer is required to provide the designed a.c. voltage to the rectifier circuit. A resistive load is shown. The arrangement is called a half-wave circuit because the rectifier will only pass a load current during alternate half-cycles of the a.c. voltage when transformer terminal 1 is positive with respect to

terminal 2. During the other half-cycles the rectifier, if it is perfect, will pass no current.

Fig. 14.2 shows the form of the rectified voltage and current in the idealized case namely when—

1. The a.c. voltage is sinusoidal.
2. The load is resistive.
3. The rectifier is perfect i.e. has negligible forward resistance and infinitely great backward resistance, so that the d.c. voltage and current

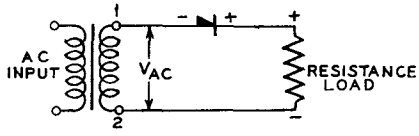


FIG. 14.1 PRINCIPLE OF SINGLE-PHASE HALF-WAVE RECTIFIER

half-waves have the same shape as the a.c. voltage half-waves.

It will be realized that, due to the intermittent nature of the rectified current, this rectifier is not useful for telegraph supplies as the latter are required to be reasonably smooth.

(*b*) *Single-phase full-wave rectifiers.* The obvious first step to be taken to produce a smoother d.c. output from a single phase rectifier is to arrange

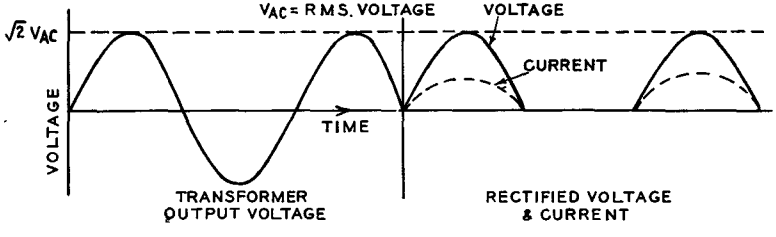


FIG. 14.2. RECTIFIED VOLTAGE AND CURRENT OF SINGLE-PHASE HALF-WAVE RECTIFIER

for both positive and negative half-waves of the a.c. input to contribute to the d.c. output. There are three simple circuits which are commonly used namely—

1. The Bridge circuit.
2. Push-pull circuit.
3. Voltage-Doubler circuit.

Bridge rectifier circuit. Fig 14.3 shows a simple full-wave bridge circuit which is greatly used. It forms the basis of all the unit rectifiers used for supplying d.c. teleprinter motors in the B.P.O. Both positive and negative half-waves of the alternating voltage find a low impedance path through the bridge and the load resistor R_L to pass a useful current. Thus when AC terminal 1 is positive with respect to 2, rectifiers B and C conduct in series with R_L. When terminal 2 is positive with respect to 1, rectifiers D and A conduct. It will be seen that in both cases the polarity of V_L, i.e. the potential applied to the load, is the same.

When B and C are conducting, both A and D have to withstand a voltage equal to the difference between the applied a.c. voltage and the voltage drop in B or C due to the load current. The voltage drop in B or C is relatively small, so that A and D each withstands almost the full a.c. voltage. During the alternate half cycles B and C withstand almost the full a.c. voltage.

If v = instantaneous a.c. voltage.
V_M = peak a.c. voltage.
$V_{\text{a.c.}}$ = R.M.S. a.c. voltage.
$V_{\text{d.c.}}$ = theoretical average rectified voltage.
V_L = average d.c. load voltage.
I_L = average d.c. load current.
R_F = rectifier forward resistance.

then the relationship between $V_{\text{a.c.}}$ and $V_{\text{d.c.}}$ is obtained as follows. Assuming a sinusoidal a.c. voltage and linear rectification, then the rectified d.c. voltage will be a series of sinusoidal half-waves.

The law of the a.c. voltage can be stated as

$$v = V_M \sin \theta.$$

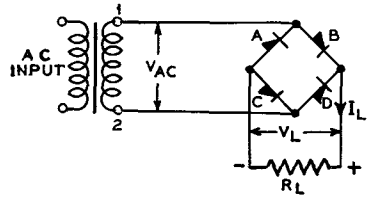


FIG. 14.3. SINGLE-PHASE FULL-WAVE BRIDGE RECTIFIER CIRCUIT

To find the R.M.S. (root mean square) voltage $V_{\text{a.c.}}$, it is necessary to—

(*a*) Integrate $v^2 = V_M^2 \sin^2 \theta$ with respect to θ from o to π (i.e. over a half-wave).

(*b*) Divide by the base π to obtain the average or mean value of v^2.

(*c*) Take the square root of the result.

Thus

$$V_{\text{a.c.}} = \sqrt{\frac{1}{\pi}\int_0^{\pi} V_M^2 \sin^2 \theta d\theta}.$$

$$= V_M \sqrt{\frac{1}{\pi}\int_0^{\pi} \sin^2 \theta d\theta}.$$

$$= V_M \sqrt{\frac{1}{2\pi}\int_0^{\pi} (1 - \cos 2\theta)\, d\theta}.$$

$$= V_M \sqrt{\frac{1}{2\pi}\left[\theta - \frac{\sin 2\theta}{2}\right]_0^{\pi}}$$

$$= V_M \sqrt{\frac{1}{2\pi}[\pi]} = \frac{V_M}{\sqrt{2}}.$$

To find the theoretical average value of the a.c. rectifier circuit is shown in Fig. 14.5. It requires only two rectifier arms but has the slight disadvantage of using a centre-tapped transformer secondary winding. The transformer design is somewhat inefficient as only one half of the secondary winding is used at any instant, and each half must produce the same voltage as the complete

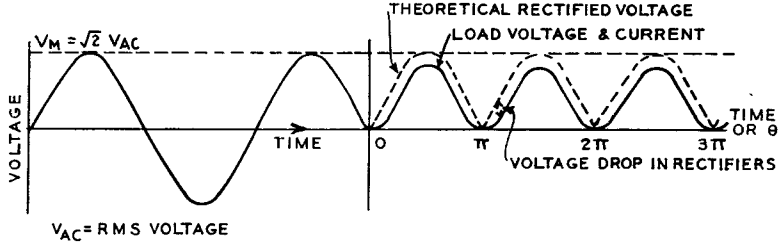


FIG. 14.4. RECTIFIED VOLTAGE AND CURRENT OF SINGLE-PHASE FULL-WAVE BRIDGE RECTIFIER

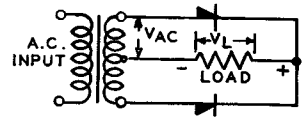


FIG. 14.5. SINGLE-PHASE PUSH-PULL RECTIFIER CIRCUIT

half-wave $V_{d.c.}$ (which is equal to $V_L + R_F \cdot I_L$) it is necessary to—

(*a*) Integrate $v = V_M \sin\theta$ with respect to θ from *o* to π.

(*b*) Divide by the base π.

Thus

$$V_{d.c.} = \frac{1}{\pi}\int_0^{\pi} V_M \sin\theta d\theta.$$

$$= -\frac{V_M}{\pi}\left[\cos\theta\right]_0^{\pi}$$

$$= -\frac{V_M}{\pi}[-1-1] = \frac{2V_M}{\pi}$$

Thus

$$\frac{V_{a.c}}{V_{d.c.}} = \frac{\frac{V_M}{\sqrt{2}}}{\frac{2V_M}{\pi}} = \frac{\pi}{2\sqrt{2}} = 1{\cdot}11.$$

All these are well-known relationships. Thus starting with known values of V_L and I_L, the approximate R.M.S. voltage required can be estimated by adding to V_L the voltage drop in the rectifier (in effect adding the forward resistance of two bridge arms in series to that of the load) and multiplying by 1·11. This allows the transformer to be designed.

In practice the rectification is not quite linear and the multiplying factor is not exactly 1·11. This arises because, as can be seen from Fig. 14.4, the forward resistance is not constant with varying load current. The resistance decreases as the load increases, giving a toe to the rectified voltage half-wave, as shown in Fig. 14.4.

Push-pull Circuit. The single-phase push-pull winding of the bridge rectifier transformer. The efficiency of use of the rectifiers is the same in the two cases, as it will be seen that each arm of the push-pull rectifier has to be designed to withstand a reverse voltage equal to almost 2 $V_{a.c.}$ and is thus equivalent in this respect to two arms of the bridge rectifier. This circuit is not used in any of the B.P.O. telegraph rectifiers.

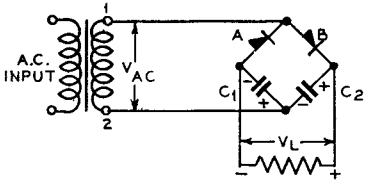


FIG. 14.6. SINGLE-PHASE VOLTAGE-DOUBLER RECTIFIER CIRCUIT

Voltage-doubler Circuit. This is an interesting circuit (Fig. 14.6) in which, by the use of capacitors, the rectified voltage $V_{d.c.}$ is about twice the transformer voltage $V_{a.c.}$. During one half cycle when transformer terminal 1 is positive, rectifier *B* conducts and charges capacitor C_2 to about the peak voltage of the a.c. wave; similarly during alternate half-cycles rectifier *A* conducts and charges capacitor C_1. The polarity of the capacitor charges is indicated in Fig. 14.6 and it will be seen that they are in series-aiding across the load. During the half-cycle when either capacitor is not being charged its voltage falls rapidly, and the P.D. developed across the load depends upon the capacitance of the capacitors and the resistance of the load. It will be clear that this type of rectifier has a high internal impedance and is only suitable for small load currents. It has often been used for

supplying signalling current to a single teleprinter circuit.

(*c*) *Three-phase Rectifiers.* Fig. 14.7 shows a three-phase full-wave rectifier circuit such as is used for the larger capacity telegraph power plants. The operation can best be understood by

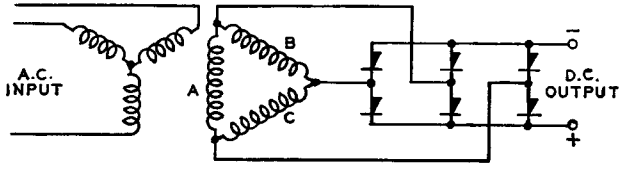


FIG. 14.7. THREE-PHASE FULL-WAVE RECTIFIER CIRCUIT

drawing three a.c. voltage waves in their correct phase relationship, i.e. $\frac{2}{3}\pi$ radians apart.

The particular pair of rectifier arms to which, at any instant, the greatest forward voltage is applied, decide the value of the rectified voltage at that instant. Neglecting transformer reactance the shape of the d.c. voltage is as shown in Fig. 14.8. This is a much smoother output than is obtainable from a full-wave single-phase rectifier and the voltage fluctuations in the output occur at three times the frequency.

The relationship $\frac{V_{\text{a.c.}}}{V_{\text{d.c.}}}$ can be readily calculated for the idealized case as follows—

The d.c. wave shape is seen to repeat every $\frac{\pi}{3}$

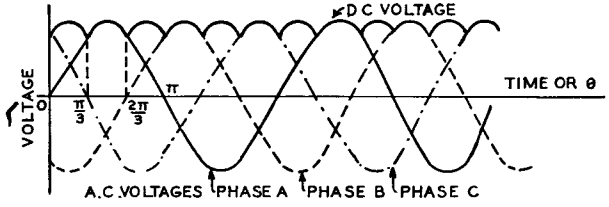


FIG. 14.8. RECTIFIED VOLTAGE AND CURRENT OF 3-PHASE FULL-WAVE RECTIFIER

radians and the average d.c. voltage can be found by integrating $V_M \sin\theta$ between $\frac{\pi}{3}$ and $\frac{2\pi}{3}$ and dividing by the base $\frac{\pi}{3}$.

Thus

$$V_{\text{d.c.}} = \frac{1}{\frac{\pi}{3}} \int_{\frac{\pi}{3}}^{\frac{2\pi}{3}} V_M \sin\theta \, d\theta$$

$$= -\frac{3V_M}{\pi}\left[\cos\theta\right]_{\frac{\pi}{3}}^{\frac{2\pi}{3}}$$

$$= -\frac{3V_M}{\pi}\left[-\tfrac{1}{2} - \tfrac{1}{2}\right] = \frac{3}{\pi}.\ V_M$$

$V_{\text{a.c.}}$, as in the calculation for the single-phase rectifier, is equal to $\frac{V_M}{\sqrt{2}}$

Therefore

$$\frac{V_{\text{a.c.}}}{V_{\text{d.c.}}} = \frac{\frac{V_M}{\sqrt{2}}}{\frac{3V_M}{\pi}} = \frac{\pi}{3\sqrt{2}} = 0{\cdot}74.$$

It will be seen that, when not conducting, each bridge arm has to resist almost the full a.c. voltage, as in the case of the single-phase bridge rectifier.

It is, of course, possible to use a three-phase half-wave rectifier but, having incurred the expense of a three-phase power supply and transformer, it is not economical to employ half-wave rectifiers and so lose the advantage of the higher and

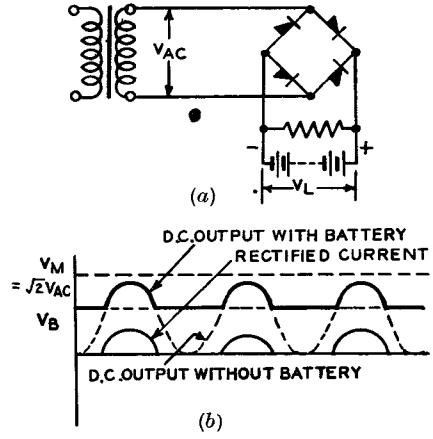


FIG. 14.9. SINGLE-PHASE FULL-WAVE BRIDGE RECTIFIER WITH BATTERY CONNECTED TO OUTPUT

smoother output to be obtained from full-wave rectification. It can be shown that with half-wave rectification $\frac{V_{\text{a.c.}}}{V_{\text{d.c.}}} = 0{\cdot}855$ and the frequency of the voltage fluctuations is half that with full-wave rectification.

Effect of Load Characteristics on Output Voltage. When a secondary battery is connected across the d.c. terminals of a rectifier set it applies a P.D. which the rectified voltage must exceed before a current can flow. The battery cannot oppose the rectifier with a voltage greater than its e.m.f. as the voltage of a battery on discharge immediately falls to this value or lower. Fig. 14.9 (*b*) shows that

in the case of a single-phase rectifier the effect is to reduce the current flow to a series of pulses and at the same time to smooth the rectified voltage and raise its average value. As the battery becomes more fully charged its voltage V_B rises, and the pulses of current become shorter and their magnitude smaller. Thus a simple single-phase rectifier supplying a battery produces a decreasing current as the charge in the battery increases and so is, at least to some extent, self-regulating. This is known as taper charging.

A similar effect is produced if a capacitor of sufficient capacitance is connected across the load terminals. The capacitor becomes charged to a mean voltage which depends upon its capacitance and which, in the absence of any other load on the rectifier, approaches the peak value of the rectified voltage.

It will be clear from Fig. 14.8 that, in the case of a three-phase full-wave rectifier, the rectified voltage is so much smoother than that produced by a single-phase rectifier that the effect of connecting a battery or capacitor is much less marked.

A d.c. motor connected to the output of a rectifier produces a back e.m.f. and so behaves as a combined resistive and capacitative load.

Voltage Regulation of Rectifiers. The d.c. output voltage of a simple rectifier equipment varies with the a.c. input voltage and with the load. A.c. input voltage variations cause approximately proportional d.c. output voltage variations. Increasing load causes a falling d.c. output voltage as illustrated in Fig. 14.10; this effect is caused partly by the impedance of the transformer and any chokes employed, but more by the resistance of the rectifier elements themselves. In this respect selenium elements are superior to copper oxide elements and Fig. 14.10 illustrates this fact. The voltage regulation curves shown are those of two very similar 110 V rectifiers used for supplying a single teleprinter motor. It will be observed that on starting the motor, the output voltage of the selenium rectifier falls much less than that of the copper oxide rectifier; the motor therefore accelerates more quickly, which is an advantage in the case of teleprinters which are not kept running continuously.

In most cases in which a rectifier is used to float a battery whilst supplying a load, it is necessary to control the output voltage of the rectifier within close limits, usually $\pm$ 2 per cent, whilst the load and the mains voltage vary within specified limits. The load range to be covered is usually full load to about $\frac{1}{10}$ full load but the lower limit may be more, or less, according to the nature of the load. The mains voltage range to be covered is usually $\pm$ 10 per cent from the declared voltage. Whilst it is possible to manually regulate a rectifier with floating batteries when the load and mains voltage variations are slow, the attention required may be excessive. Therefore, except in some very small plants, it is now the rule to employ automatic voltage regulation.

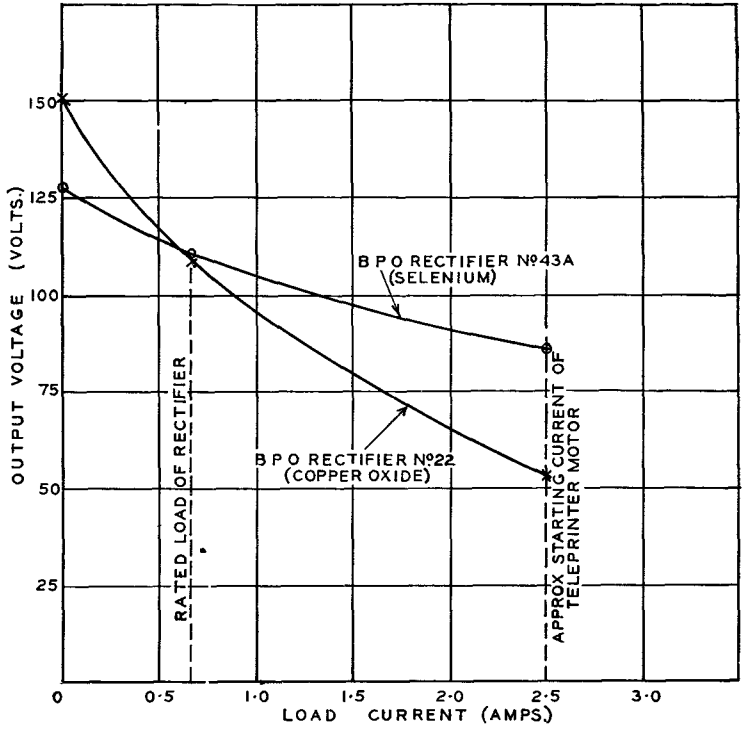


FIG. 14.10. COMPARISON OF LOAD CHARACTERISTICS OF TYPICAL SINGLE-PHASE FULL-WAVE BRIDGE RECTIFIERS OF COPPER OXIDE AND SELENIUM TYPES

Automatic Voltage Regulation

There are many ways in which automatic voltage control can be applied to rectifiers and the following are important examples.

Static Voltage Regulators including the Westat Constant-Voltage Rectifier. Regulating devices which are wholly static in operation are attractive because they are likely to require little or no

maintenance. Circuits including thermionic valves are most suitable for providing very close voltage regulation at small loads, e.g. in laboratory test sets, and are not in general applicable to large rectifiers. Their maintenance is not negligible as valve replacements have to be made and they are only used for telegraph equipments in a few special cases.

Another class of static regulator depends for its action on the change of inductance, and hence of voltage drop, of a choke coil (or inductor) with change of flux density in its magnetic core. These are often called saturated choke regulators. They usually require two separate regulating circuits to correct for load and mains voltage variations respectively and have a low power efficiency. They are not used in any of the B.P.O. telegraph rectifiers.

The Westat (and Noregg) rectifier is also wholly static in operation and is dependent upon change of inductance, in this case of a transformer, for its compensation. It uses this effect, however, in a quite different way from the more common saturated choke regulators mentioned above and has a good power efficiency. The Westat rectifier is based upon a special circuit of Westinghouse Brake & Signal Co., Ltd., and is used in 300 W and 600 W units in several B.P.O. telegraph rectifiers.

It has been shown that a three-phase a.c. voltage of R.M.S. value $V_{a.c.}$ per phase will produce from a three-phase full-wave rectifier a rectified voltage equal to $\frac{V_{a.c.}}{0{\cdot}74}$ at no load. At full load the d.c. voltage will have fallen to about $V_{a.c.}$. An equal single-phase a.c. voltage, $V_{a.c.}$, applied to a single-phase full-wave rectifier has also been shown to produce a no-load rectified voltage equal to $\frac{V_{a.c.}}{1{\cdot}11}$; at full load this would fall to about $\frac{V_{a.c.}}{1{\cdot}4}$.

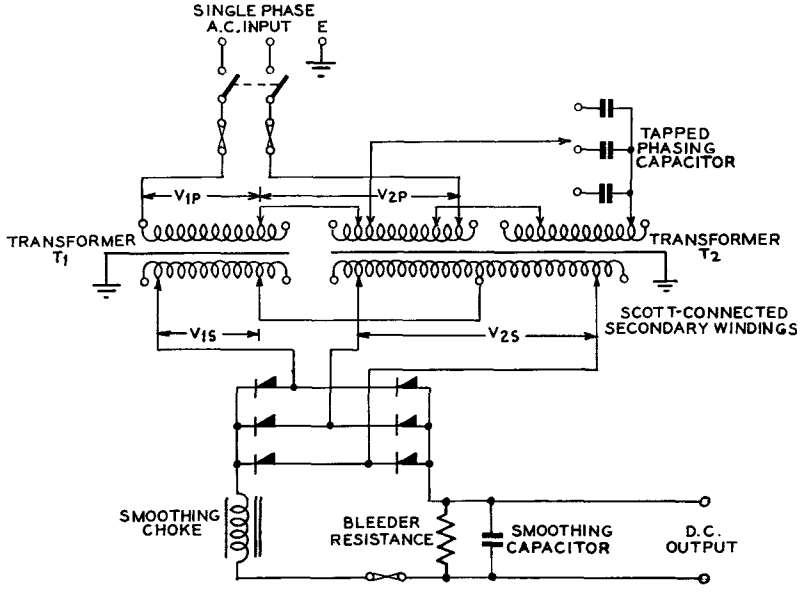


FIG. 14.11. SCHEMATIC DIAGRAM OF A WESTAT RECTIFIER

It will be noticed that the three-phase rectifier is producing at full load a rectified voltage rather higher than that given by the single-phase rectifier on no-load. Thus, if it could be arranged that a three-phase rectifier unit had a three-phase a.c. supply connected to it at full load, but only one phase of the same a.c. supply at no-load, a measure of voltage regulation would have been achieved. The Westat rectifier applies this principle, being designed to effect a gradual change from single-phase to three-phase operation between no-load and full load.

Fig. 14.11 is a schematic diagram of a typical Westat rectifier. The primary windings of two transformers T_1 and T_2 are connected in series across the single-phase a.c. supply. T_2 is a transformer with a normal core and having its secondary winding centre-tapped; its primary winding is shunted by a capacitor of such value that the combination tends to exhibit capacitative reactance.

Transformer T_1 has an air-gap in its magnetic core to accentuate its inductive reactance and cause it to behave as a choke in its primary circuit. It is arranged that at full load the mains voltage (or the primary current which is almost in phase) leads the voltage V_{2P} by about 45° and lags behind voltage V_{1P} by about 45°. Thus V_{1P} and V_{2P} are about 90° out of phase and so also are the secondary voltages V_{1S} and V_{2S} of transformers T_1 and T_2 respectively, so that a two-phase secondary supply has been produced. The centre-tap in the secondary of T_2 allows the two transformers secondary windings to be Scott-connected to a three-phase rectifier unit. The Scott-connexion derives a three-phase output from a two-phase supply, so that the required conditions at full load are achieved. As the load falls, then voltage V_{1P} falls with it due to the changing inductance of T_1, but V_{2P} changes little and the two voltages tend to come into phase.

The result is that at very light loads only transformer T_2 is effective, so that the rectifier unit input is no longer three-phase but single-phase, as required.

An increase in the load beyond full load causes the voltages V_{1P} and V_{2P} to become more than 90° out of phase, which again results in a tendency towards the single-phase condition and a drop in output voltage. The fall in voltage does not usually become very great until well beyond full load, but it does provide some protection against a heavy overload. A change in the mains voltage causes V_{1P} to change more in magnitude than V_{2P}. Since the mains voltage is the vectorial sum of V_{1P} and V_{2P} it follows that the phase relationship must also change. The net effect is therefore a much smaller

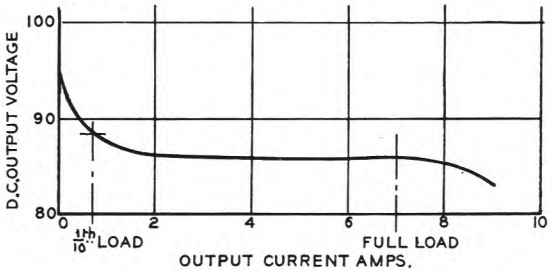


Fig. 14.12. Regulation Curve of Westat Rectifier

change in the rectified voltage than in the mains voltage. Fig. 14.12 shows the sort of regulation curve which can be obtained with varying load from a Westat rectifier adjusted for battery floating. Simultaneous mains voltage variations within the usual range of ± 6 per cent make very little difference to the curve.

The efficiency of a 600 W Westat rectifier at full-load is about 69 per cent and its power factor about 0·95. Changes of mains frequency affect the output voltage of the Westat rectifier; thus 1 per

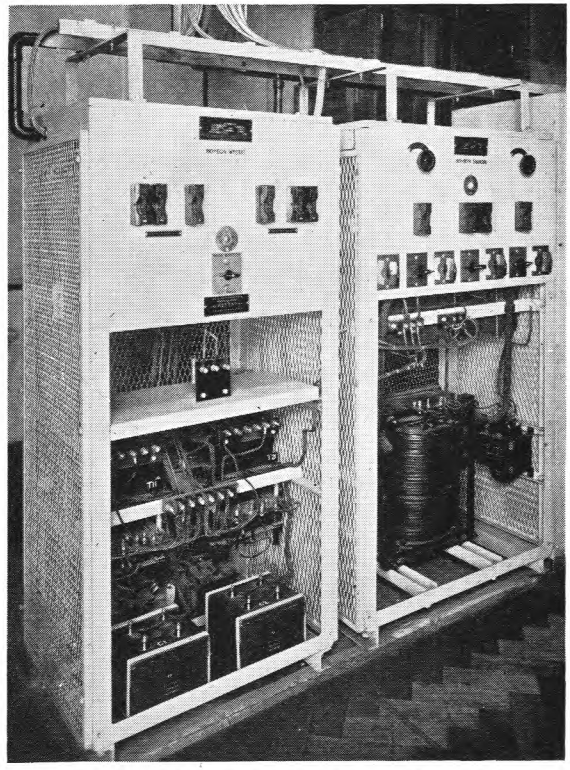


Fig. 14.13. British Post Office Rectifiers No. 56A and 57A for 80 + 80 V Battery Floating

(By courtesy of H.M. Postmaster-General)

cent change of frequency is likely to cause 1·5 per cent to 2 per cent change of rectified voltage in the same sense.

The response of the voltage regulation to changes of load and mains voltage is very rapid. However, Noregg rectifiers, which are intended for use without batteries, are provided with a choke or filter of relatively long time-constant to smooth out the rapid transients. Westat rectifiers are for use with floating batteries.

Further information about the smoothing of the d.c. output of both rectifiers and generators is given on page 573.

The output voltage curve of the Westat and Noregg rectifiers can be adjusted, both in its slope and in its general level, by numerous tappings on the transformers and capacitor. The left hand rectifier cubicle in Fig. 14.13, which is a

B.P.O. rectifier No. 56A comprising two 600 W Westat rectifiers for 80 + 80 V battery floating, shows the tapped transformers and phasing capacitors.

The Moving Coil Induction Regulator. Fig. 14.14 shows a rectifier cubicle which includes a three-phase moving coil induction regulator made by Ferranti Ltd. Fig. 14.15 (*c*) shows the regulator diagrammatically.

This is not a quick-acting regulator and it is not therefore very suitable for a rapidly varying load such as a ± 80 V load to a group of teleprinters. It finds its use in L.T. and H.T. power plants for M.C.V.F. telegraph loads and in 50 V power plants for switching and phonogram equipments.

The principle can be understood from a description of a single-phase regulator, as a three-phase regulator comprises three such units but with only one control and drive unit. The regulator Fig. 14.15 (*a*) and (*b*) is a transformer having its cylindrical windings all on one limb of a long core. There are two primary windings "*a*" and "*b*" wound in opposite directions and positioned towards the two ends of the core. There are two similarly placed and wound secondary windings "*c*" and "*d*". The moving coil "*s*" is wound on a separate tubular former which can be driven over the other coils by a lead-screw geared to a reversible split-phase disc type a.c. induction motor.

Primary coils "*a*" and "*b*" are connected in series to the a.c. supply, whilst secondary coils "*c*" and "*d*" are connected in series to the rectifier unit. The moving coil is short-circuited and its function is to create a high reluctance in the magnetic circuit. It will be realized that the a.c. supply voltage divides between primary coils "*a*" and "*b*" in a ratio which depends upon the position of the moving coil "*s*". Thus when "*s*" is right at the end of the core where coil "*a*" is situated, almost the whole of the supply voltage appears across coil "*b*". If the ratio of primary to secondary turns $\frac{a}{c}$ were equal to $\frac{b}{d}$, then the total secondary voltage across coils "*c*" and "*d*" in series would be sensibly constant whatever the position of coil "*s*". If, however, the turns ratios $\frac{a}{c}$ and $\frac{b}{d}$ are unequal, then, as coil "*s*" moves over the length of the limb a smoothly varying voltage will be obtained from the secondary windings. The number of turns on coils "*a*" and "*b*" are chosen to suit the supply voltage, and by a suitable choice of the turns ratios $\frac{a}{c}$ and $\frac{b}{d}$ any desired practical range of secondary output voltage can be obtained.

Conversely, if the mains voltage varies, the moving coil can be suitably moved to keep the secondary output voltage constant.

The following simple numerical examples of two hypothetical cases, in which it is assumed that voltage ratios are equal to turns ratios, will make the operation clear.

TABLE 14.1

Constant Input Voltage

Output Voltage Varied by the Position of the Moving Coil

Moving Coil Position	Primary Voltages			Design No. 1 Turns Ratios $\frac{a}{c}=5$ $\frac{b}{d}=2$ Secondary Voltages			Design No. 2 Turns Ratios $\frac{a}{c}=1$ $\frac{b}{d}=2$ Secondary Voltages		
	Supply	V_a	V_b	V_c	V_d	Output	V_c	V_d	Output
1	230	30	200	6	100	106	30	100	130
2	230	50	180	10	90	100	50	90	140
3	230	100	130	20	65	85	100	65	165
4	230	150	80	30	40	70	150	40	190
5	230	200	30	40	15	55	200	15	215

TABLE 14.2

Input Voltage Variations of ± 10 per cent

Output Voltage kept Constant by Adjustment of the Moving Coil Position

Moving Coil Position	Primary Voltages			Design No. 1 Turns Ratios $\frac{a}{c}=5$ $\frac{b}{d}=2$ Secondary Voltages		
	Supply	V_a	V_b	V_c	V_d	Output
3 −	207	61·5	145·5	12·3	72·7	85
3	230	100	130	20	65	85
3 +	253	138·5	114·5	27·7	57·3	85

The motor could be controlled by any type of voltage-sensitive relay, but the regulators in use

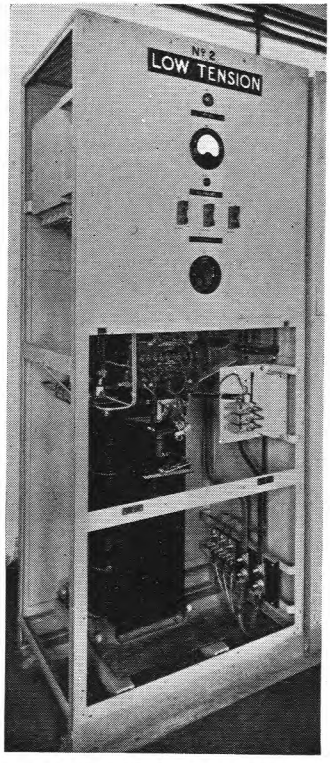
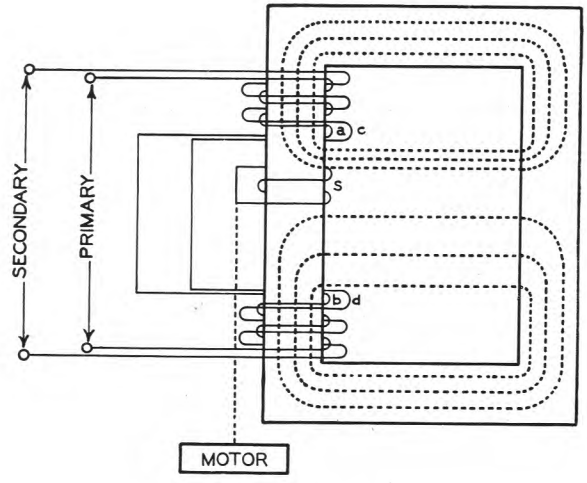
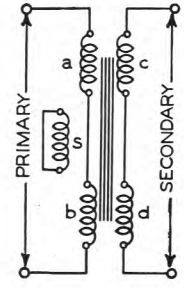


FIG. 14.14. 100 A, 28 V RECTIFIER CUBICLE SHOWING A FERRANTI 3-PHASE MOVING-COIL REGULATOR AND A.C. ASTATIC RELAY

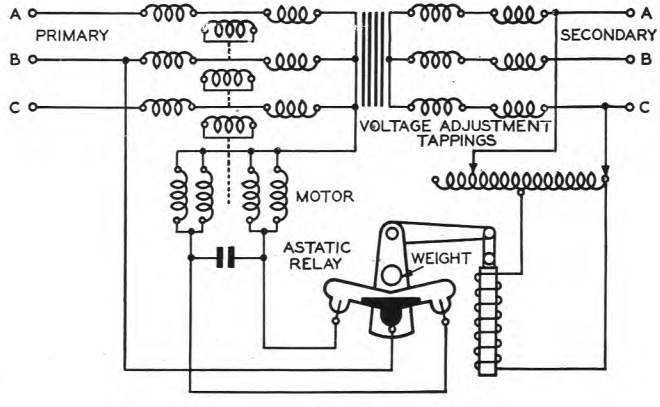
(By courtesy of H.M. Postmaster-General)



(a)



(b)



(c)

FIG. 14.15. MOVING-COIL INDUCTION REGULATOR

(*a*) Arrangement of primary and secondary windings and moving-coil
(*b*) Principle of operation
(*c*) Schematic diagram of regulator

in the B.P.O. actually employ a relay made by Ferranti Ltd. which they call an "astatic" relay. The essential parts are a solenoid with gravity controlled plunger and a tilting mercury tube assembly having three contacts for inclusion in the circuit of the reversible motor.

There are two types of astatic relay available, one for a.c. operation and the other for d.c. operation. Fig. 14.14 shows an a.c. relay mounted in front of the regulator in a L.T. cubicle, whilst Fig. 14.15 (*c*) shows that the solenoid is responsive to the voltage variations of one phase of the regulated a.c. output. The a.c. relay cannot automatically take account of variations of the voltage drop in the rectifier elements caused by varying load. It is therefore only suitable for sensibly constant (e.g. L.T. and H.T.) loads. The solenoid is fed from a tapped transformer which can be adjusted for any chosen value of regulated voltage and which also allows re-adjustments to be made to cover load changes. The adjustment of the taps is made on the wander-plug panel above the astatic relay.

For loads which vary widely throughout the day such as the 50 V load of automatic switching equipment, it is necessary to employ the d.c. astatic relay so that there may be automatic compensation for the varying voltage drop in the rectifier elements.

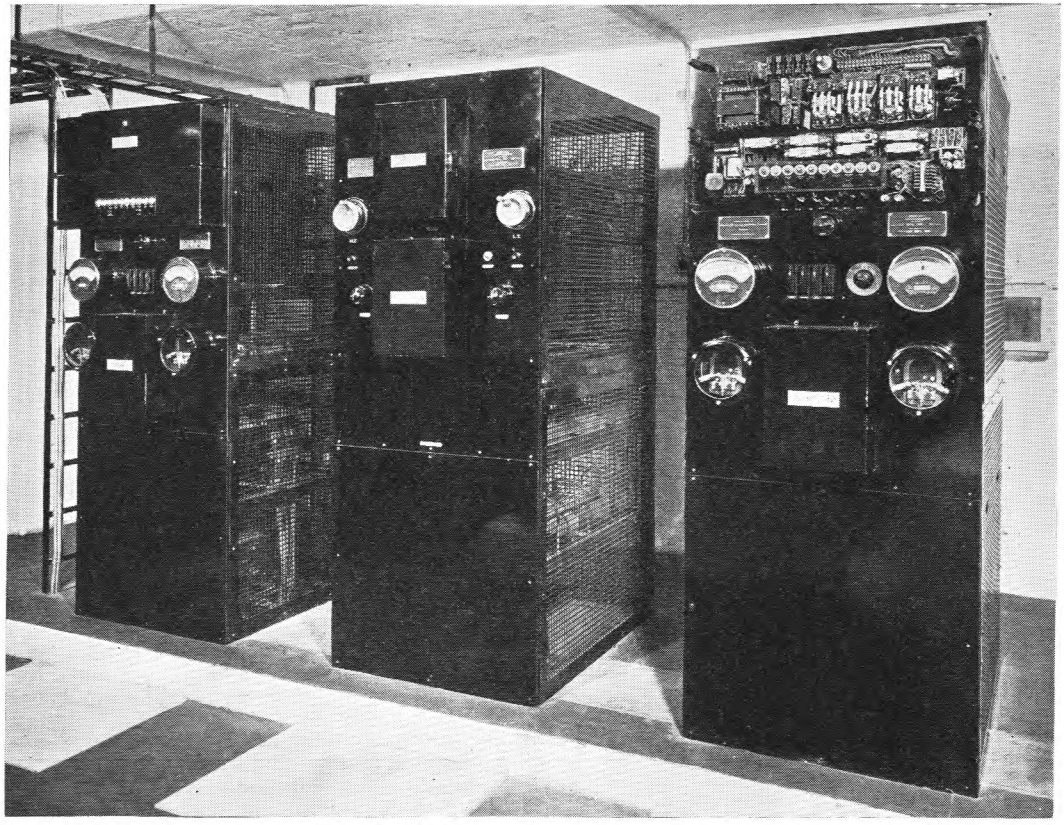


FIG. 14.16. L.T./H.T. SINGLE BATTERY FLOATING RECTIFIER POWER PLANT EMPLOYING TAP-CHANGING TRANSFORMERS

(By courtesy of H.M. Postmaster-General)

The rectifier cubicle shown in Fig. 14.14 is rated at 100 amps, 28 V and it has a full-load efficiency of 71 per cent and a full-load power factor of 0·68. The output voltage is automatically regulated within $\pm$ 2 per cent for mains voltage variations of $\pm$ 10 per cent.

Tap-changing Transformer Regulators. Figs. 14.16 and 14.17 show front and rear views respectively of a set of selenium rectifier cubicles used for single battery float operation. One of the outer cubicles contains a 110 amp, 28 V L.T.

rectifier, and the other a 15 amp, 153 V H.T. rectifier, each being provided with a tap-changing transformer to give automatic control of the output voltage. The output voltage is maintained within $\pm$ 2 per cent of the nominal value for mains voltage variations of $\pm$ 10 per cent and simultaneous load variations of 32 to 110 amp (L.T.) and 3 to 15 amp (H.T.). The d.c. voltage at the output of each cubicle is measured by a moving coil contact voltmeter (one of the lower meters in the front view), which thus takes account of the changes of voltage drop in the rectifier elements and smoothing chokes with varying load current. When the contact-voltmeter moves to its upper or lower contact it operates a telephone type relay, which in turn operates a contactor (or heavy-current slave relay). The high and low contactors control the motor which drives the tap-changing gear of the transformer. The transformer with the motor and clutch mounted upon it can be seen at the top of the nearest (H.T.) cubicle in the rear view.

The three-phase transformer made by Foster Transformers and Switchgear Ltd. is enclosed in a steel tank with the core and windings immersed in petroleum jelly to give greater cooling. An extensive range of taps on the star-connected primary windings are connected to the segments of the three flat-faced commutators above the level of the petroleum jelly. Three sets of carbon brushes are driven over these commutators by a small motor through gears and a clutch. The motor is of the split-phase reversing type. The clutch consists of a driven member, a thin flexible steel gear wheel which can be deflected out of engagement with the driving pinion by an electromagnet.

The power plant shown in the photographs, manufactured by Standard Telephones and Cables Ltd., was designed for semi-automatic operation and provides automatic current control as well as voltage control.

When a mains failure occurs the rectifier is disconnected automatically from the battery and load, and it is automatically reconnected when the power supply is restored. In order that the partially discharged battery may not take an excessive charging current on reconnexion, the transformer brushes are first driven automatically to the lowest taps before the a.c. power is connected to the transformer and then raised under the control of the current relay, which is a contact meter of similar construction to the voltage relay.

Considering the case of the L.T. rectifier, the 110 amps output is apportioned 30 amps to battery re-charging and up to 80 amps to load. The purpose of the current control is to enable the battery to be re-charged as quickly as possible by gradually raising the transformer taps so as to keep the rectifier output current near its maximum value. When, in this way, the battery voltage has been raised within the regulating range of the voltage relay the control of the transformer taps is transferred from the current relay to the voltage relay.

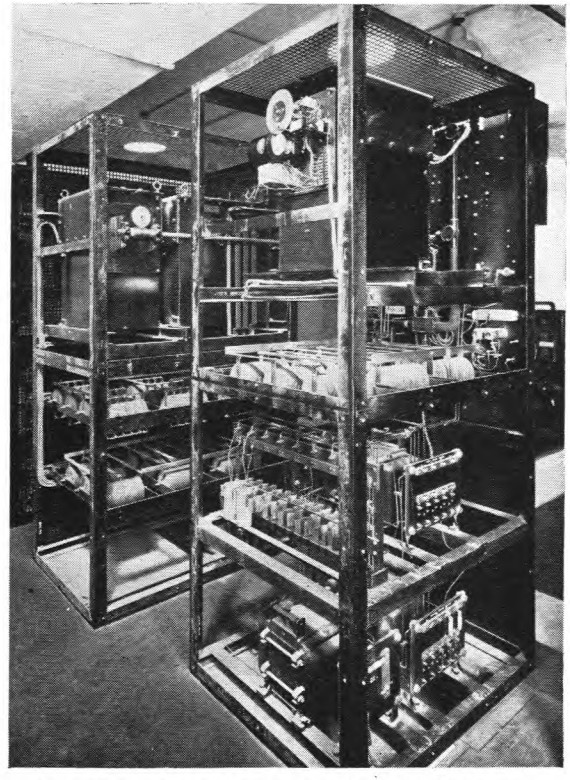


FIG. 14.17. REAR VIEW OF L.T./H.T. RECTIFIER POWER PLANT EMPLOYING TAP-CHANGING TRANSFORMERS

(By courtesy of H.M. Postmaster-General)

A description of the full circuit of this semi-automatic rectifier equipment is beyond the scope of this book but Fig. 14.18 shows simply the type of circuit necessary for automatic voltage control only.

JV is the contact voltmeter which responds to voltage changes in the rectifier output. In the case of a 28 V L.T. rectifier, floating a 13 cell battery, the coil circuit and contacts of *JV* are adjusted so that the "low" contact makes at 27·5 V and the "high" contact at 28·5 V.

When the low contact is made, relay *LV* operates. *LV*1 opens the circuit of relay *HV*. *LV*2 operates contactor *LR*. *LV*3 operates the

clutch electromagnet CL. $LV4$ inserts resistance in the coil circuit of JV so that the rectifier output must rise slightly higher than 27·5 V before the "low" contact is broken. This prevents chattering of the JV relay contacts. $LR1$ applies power to the "raise" winding of the motor, which, through clutch CL operated, drives the transformer brushes to higher taps to raise the rectifier voltage.

the simplified diagram) to prevent the motor from attempting to drive the brushes beyond the highest and lowest taps.

Motor-generator Equipments for Providing d.c. Supplies. The commercial development of metal rectifiers has occurred during the period from about 1930 and in that time they have superseded motor-generators for many purposes.

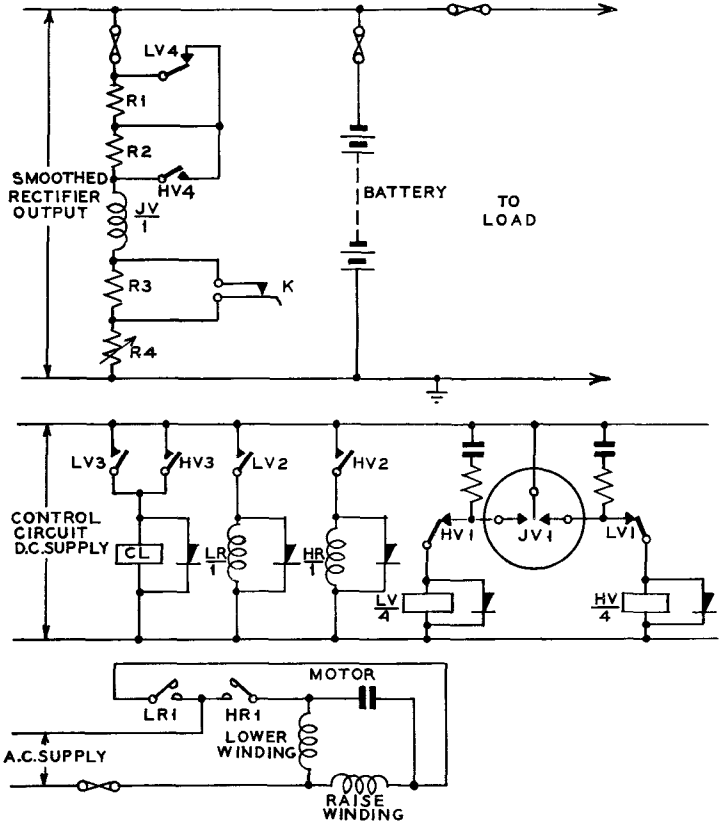


FIG. 14.18. SCHEMATIC DIAGRAM OF AUTOMATIC VOLTAGE CONTROL CIRCUIT FOR TAP-CHANGING TRANSFORMER REGULATOR

When JV leaves the "low" contact, power is disconnected from the motor and the clutch electromagnet releases, applying a brake to the clutch disc to stop it immediately.

The general operation is similar for high voltage conditions, power in this case being connected to the "lower" winding of the motor and $HV4$ reducing the resistance in the coil circuit of JV to provide the anti-chatter condition.

The operation of key K puts resistor $R3$ into the coil circuit of JV so that its mean contact position corresponds to 30 V, thus giving the facility of floating the battery at 2·3 V per cell when necessary.

It is necessary to provide facilities (not shown on

In the telegraph service of the B.P.O. motor-generators or dynamotors were at one time used for all battery-charging for which d.c. mains could not be used directly. In present-day practice, however, rectifiers are generally used for the smaller power plants and motor-generators for the larger ones.

The following are some of the general advantages and disadvantages of motor-generators—

Advantages.

1. The d.c. generator is a low-impedance source which is well suited for supplying many individually fluctuating loads without causing interference between them.

2. The ripple in the d.c. output of a generator is

at a fairly high frequency. This simplifies smoothing and for some telegraph applications smoothing is not necessary at all.

3. The control gear is fairly simple and well standardized.

4. There is complete isolation of the output supply from the mains input supply.

Disadvantages.

1. Motor-generators require more maintenance attention than rectifiers and cost more for maintenance spares.

2. The noise from motor-generators may sometimes be a disadvantage.

3. Motor-generators with their associated starters and power switchboards tend to occupy more space than the equivalent rectifiers.

Capital Cost. No general rules can be stated regarding the relative capital cost of rectifiers and motor-generators, as this depends upon so many factors that vary with time.

It seems to be often the case that the cost of rectifier equipments rises more steeply with increasing rating (i.e. output) than does that of equivalent motor-generators. The following is an illustration of this tendency, based upon the relative costs at a particular time of complete 80 + 80 V divided battery float installations having automatic voltage control and providing 24 hours reserve capacity in the batteries.

(*a*) For a 14 amp, 80 + 80 V plant—

Cost of rectifier installation = 0·82 (Cost of motor-generator installation).

(*b*) For a 24 amp, 80 + 80 V plant—

Cost of rectifier installation = 1·13 (Cost of motor-generator installation).

The B.P.O. actually uses rectifiers for 7 amp and 14 amp 80 + 80 V plants, and motor-generators for 24 amp and larger plants.

Efficiency and Power Factor. The fractional efficiency of a motor-generator is the product of the individual fractional efficiencies of the motor and the generator. It is therefore clear that it is difficult to achieve a very high value.

The following figures show a comparison between many measurements of full load efficiencies of 80 + 80 V rectifiers and motor-generators of similar rating in the B.P.O. telegraph service. The measured power factors are also shown.

	Westat Rectifiers	Motor-generators	
	7 Amp	6 Amp	12 Amp
Full-load efficiency	69 per cent	48 to 60 per cent	58 to 65 per cent
Full-load power factor	0 95	0·78 to 0·86	0·8 to 0·87

At half-load the rectifier still shows a better efficiency and power factor than the motor generators.

Construction of Motor-generators. Much of the information required by manufacturers of motor generators and associated control gear is contained in B.S.I. specifications, so that the purchaser has only to specify the particular requirements, ratings etc., referring to the equipments in question.

The following paragraphs indicate the general type of motor-generator equipment used for the telegraph services of the B.P.O.

The modern types of motor-generator in use are principally 80 + 80 V and L.T./H.T. machines. (Rectifiers are being standardized for 50 V plants in the ratings required for telegraph purposes.)

A typical motor-generator comprises a three-phase a.c. induction motor mounted between and directly coupled to two d.c. shunt-wound generators on a common bedplate.

For generator ratings up to about 4 + 4 kW (e.g. a 4 kW negative 80 V generator plus a 4 kW positive 80 V generator) the motor is of the squirrel-cage rotor type with star-delta switch starting from the three-phase supply. In this way $\frac{1}{\sqrt{3}}$ of the normal voltage is applied to the stator windings when starting the motor, thus reducing the starting current and torque.

In larger machines the induction motor has a wound rotor and is started by an oil-immersed resistance rotor starter. This gives a higher ratio of starting torque to starting current than is possible with star-delta starting of squirrel-cage motors, as well as a smoother start. In order to meet the requirements of supply authorities on the limitation of starting current, wound rotors are essential in these larger machines.

The machines are of the protected end-shield type, usually having ball and roller bearings up to the 4 + 4 kW size and oil-ring lubricated sleeve bearings in the larger sizes. Flexible couplings are used between the motor and the two generators, and coupling guards are provided to avoid the risk of accidents from entanglements of clothing.

To keep the machines as quiet as possible, ventilating fans are not used and this sometimes causes the machine frame size to be larger than that of the equivalent industrial machine. Further, the machine bedplate is not bolted to the concrete mounting pier, but simply rests upon anti-vibration pads, giving favourable conditions for silent running. Machines with ratings up to 4 + 4 kW usually run at about 1,500 r.p.m. and larger machines at about 1,000 r.p.m. Most of the constructional features mentioned above can be seen

in Fig. 14.19, which shows two 80 + 80 V motor-generators of 2 + 2 kW rating having squirrel-cage motors. This photograph also shows automatic voltage regulators mounted on the ends of the motor generators; these are described later in this chapter.

Motor Starters. The motor-starter is associated with a fuse-switch on a floor-mounting or wall-mounting framework. The principal function of the fuse-switch is to serve as an isolating point as the starter itself includes a delayed over-current release and an under-voltage release.

In standard plants the starter is manually operated. Fig. 14.19 shows manually operated star-delta switches and associated fuse-switches arranged for wall-mounting. The delay in the operation of the over-current protective devices is usually achieved by the provision of oil-dashpots (a piston operating in an oil-filled cylinder).

The over-current release responds to a prolonged over-load but the delay feature prevents a momentary current over-load (e.g. that which occurs on starting) from causing shut-down. The under-voltage release ensures that a break in the power supply, or very low voltage, causes the starter to release, so that restoration of the supply will not produce heavy over-loads through the starter being still in the running position. The starter is provided with a stop button which affords instantaneous release.

In some applications a motor-generator is required to start as soon as the mains is connected or when some starting condition is applied from the control or switchgear. An automatic starter is then required in which manual switching is replaced by the operation of power-operated contactors, and in which the timing between switching operations is controlled by timing relays instead of by human judgment. Fig. 14.20 shows an example of an automatic three-phase starter of this type.

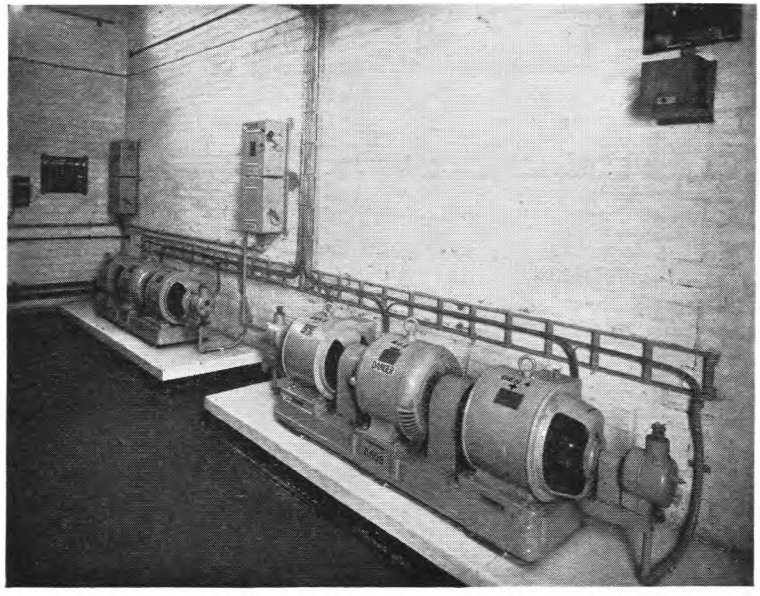


FIG. 14.19. 80 + 80 V MOTOR GENERATORS WITH MANUAL STARTERS AND ISENTHAL AUTOMATIC VOLTAGE REGULATORS

(By courtesy of H.M. Postmaster-General)

The three contactors on the left are "main," "star" and "delta," the last two being mechanically interlocked so that only one at a time can be operated. On starting, the "main" and "star" contactors close which causes the motor stator windings to be star-connected to the three-phase a.c. supply.

The timing relay, seen in the top right corner, begins to close and when it is fully operated, after, say, 10 seconds, it causes the "star" contactor to release and the "delta" contactor to close, reconnecting the motor windings to the supply in delta formation. The under-voltage and over-current releases can be seen at the bottom, with the oil dashpots protruding below the casing.

Voltage Regulation of d.c. Generators for Battery

Floating. In order that a battery may be floated successfully the generator output voltage must be maintained within close limits, viz. approximately $\pm$ 2 per cent of the nominal value. Particularly is this necessary when the battery has a small capacity relative to the load current.

It is well known that the drooping output-voltage characteristic of a shunt-wound generator with increasing load current can be approximately levelled by the use of compounding. It is difficult, however, to get sufficiently close regulation in this way for battery floating, bearing in mind that the speed of the induction motor is affected by mains frequency changes. Further, each generator requires a separate motor, so that a load change in one generator shall not affect another, and the series field current must not include the battery charging current which is subject to large changes for a small voltage change. The B.P.O. have, therefore, found it much more satisfactory and convenient to standardize the use of automatic voltage regulators, of which there are three principal types—

1. Vibrating-contact regulators.
2. Carbon pile regulators.
3. Moving coil regulators.

Vibrating-contact Automatic Voltage Regulators. Fig. 14.19 and 14.21 shows the type of vibrating contact automatic voltage regulator, made by Isenthal & Co., Ltd., which is used on the B.P.O. standard 80 + 80 V motor-generators.

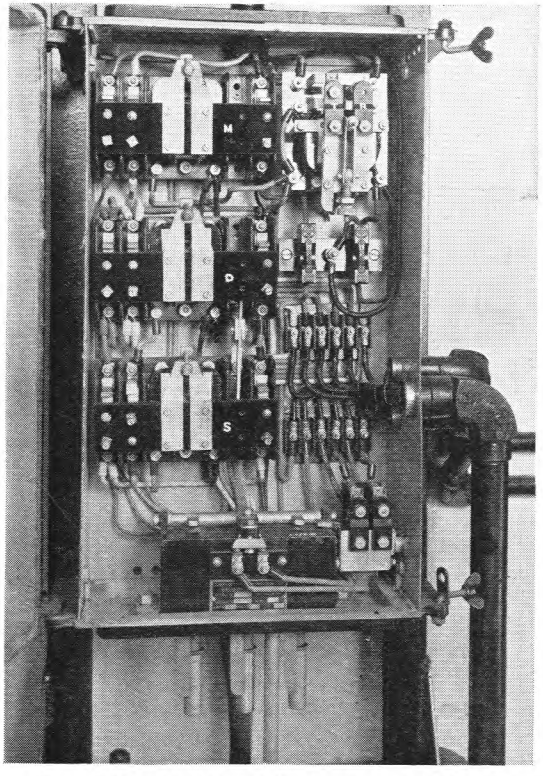


FIG. 14.20. AUTOMATIC STARTER FOR 3-PHASE MOTOR
(*By courtesy of H.M. Postmaster-General*)

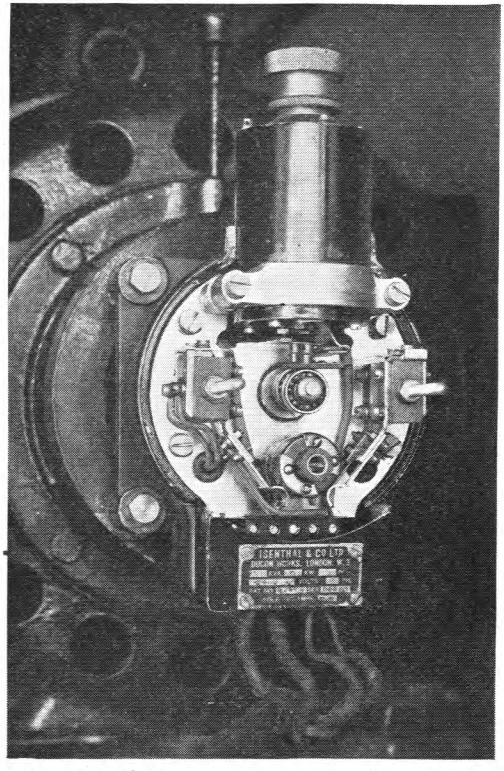
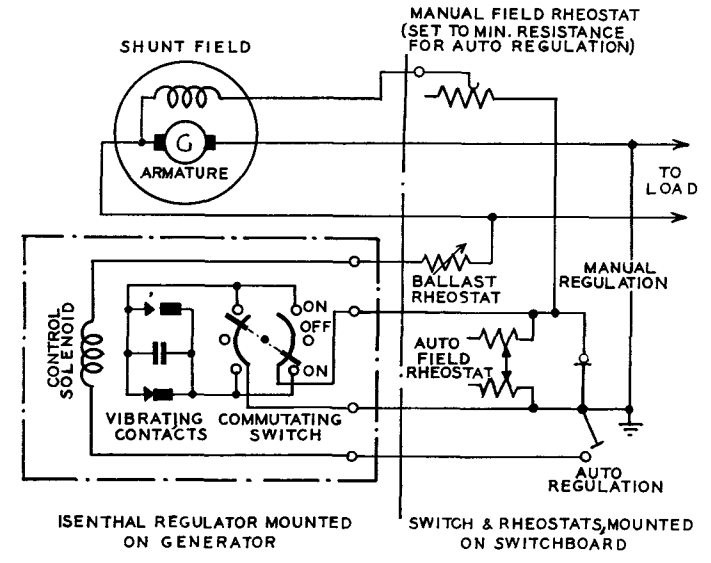


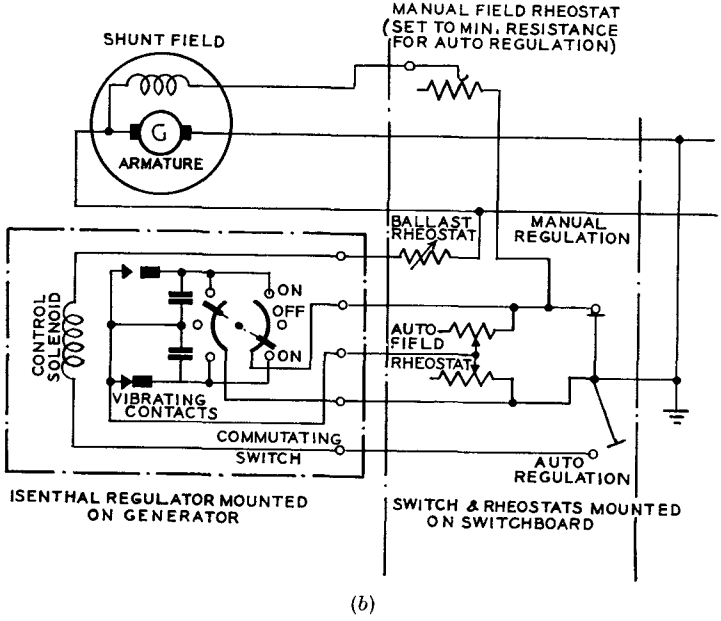
FIG. 14.21. VIBRATING CONTACT AUTOMATIC VOLTAGE REGULATOR (ISENTHAL & CO., LTD.) FITTED TO AN 80 V GENERATOR)
(*By courtesy of H.M. Postmaster-General*)

Each generator has a vibrating-contact unit mechanically coupled to it. Usually the unit is directly coupled to the generator shaft by a flexible spring coupling. When fitted to the larger generators it is often convenient to drive the unit by a belt, thus shortening the machine and allowing the regulator speed to be greater than the machine shaft speed, which gives the advantage of improved stability of regulation when the machine shaft speed is only about 1,000 r.p.m.

Two contact pairs are opened and closed cyclically



(*a*)



(*b*)

FIG. 14.22. VIBRATING CONTACT AUTOMATIC VOLTAGE REGULATOR (ISENTHAL & CO., LTD.)

(*a*) Parallel contact arrangement (*b*) Series contact arrangement

and, in sequence, by two eccentrics mounted on the regulator shaft which deflect the lower contacts. The upper contacts are carried by the armature of a solenoid, which is responsive to variations in the generator output voltage. Thus when, for instance, the generator voltage rises, the solenoid raises the upper contacts so that they are closed for a smaller proportion of the time than before. The function of the contacts, on closing, is to short-circuit sufficient resistance in the generator field circuit to initiate a larger increase of field current than is immediately required to correct the generator voltage. This increase is quickly followed by the initiation of a large decrease when the contacts next open. This principle, sometimes referred to as "overshooting," gives a very rapid correction of generator voltage changes.

The solenoid is connected across the generator terminals in series with a ballast rheostat which reduces the effect of temperature variations of the solenoid. The ballast rheostat, which is mounted on or near the power switchboard, is adjustable to give some control of the solenoid current and the solenoid armature control spring is also adjustable by turning the knurled knob on the top of the regulator casing. The contacts short-circuit an adjustable rheostat, which may be the normal manual shunt-field regulator; it is more convenient, however, to provide a separate adjustable rheostat, which can be pre-set to a suitable value for automatic regulation with the manual rheostat turned to its position of minimum resistance. The adjustment of the "auto" field rheostat is such that, if the contacts were held open, the generator voltage on no-load would fall to 15–30 per cent below the regulated voltage. With the contacts held closed, the generator on 25 per cent overload should give about 10 per cent more than the regulated voltage. A commutating device can be seen at the bottom of the casing, which is manually operated at least once daily to reverse the direction of current through the contacts and so prolong their life.

Two arrangements of the contacts and rheostat are possible as follows—

(*a*) *Parallel-Contact Arrangement.* In this arrangement, Fig. 14.22 (*a*), each contact in turn short-circuits the whole of the selected part of the field rheostat, giving large overshoot and very stable operation. The power-handling limitations of the contacts preclude the use of this circuit when

the average field current during automatic voltage regulation exceeds about 2 amps, but up to this limit this is the preferred arrangement. It provides voltage control within $\pm$ 1 per cent of the nominal value from no-load to 25 per cent overload, with simultaneous variation of the a.c. input voltage and frequency over the ranges $\pm$ 6 per cent and $\pm$ 2½ per cent respectively.

(*b*) *Series-Contact Arrangement.* In this circuit, Fig. 14.22 (*b*), each contact short-circuits only half of the selected part of the field rheostat, the latter being centre-tapped. Field currents up to five amps on automatic control can be used with this arrangement. The control is not quite so good as that given by the parallel contact circuit, but regulation can be maintained within $\pm$ 1½ per cent of the nominal voltage under the conditions specified in (*a*).

Carbon-pile Automatic Voltage Regulators. These regulators depend for their action on the change which occurs in the resistance between the end faces of a pile of carbon discs when the compression of the pile is varied. Fig. 14.23 shows a semi-automatic 80 + 80 V plant used by the B.P.O., in which carbon-pile automatic voltage regulators of the type made by J. Stone & Co., Ltd., are employed. The two regulators can be seen mounted at the top of the power switchboard, no attachment to the motor-generators themselves being required.

Fig. 14.45 shows a carbon-pile regulator, which although of a different type, illustrates the features to be found in those used for generator automatic voltage control. An electromagnet having a rotary armature is connected in series with an adjustable ballast rheostat across the generator output. A change of generator voltage produces rotation of the armature, and this motion is converted into linear motion and communicated by links to the carbon pile (or piles) and to a control spring. With no voltage applied to the electromagnet the control spring drives the mechanism against a back-stop and gives maximum compression to the pile. The carbon pile is connected in series with the generator shunt field, so that maximum pile compression corresponds to maximum field current. When a voltage is applied to the electromagnet the pile assumes a certain compression which is the result of a balance of the forces caused by the armature, the control spring and the resilience of the pile. The piles are composed of carbon discs, whose dimensions and material composition vary with the resistance and current range to be covered. The motion of the pile is damped by an air dashpot which comprises a graphite piston accurately lapped to a metal cylinder.

The carbon-pile regulator adjusts itself to large and sudden voltage changes less quickly than does the vibrating-contact type. Nevertheless it will give very good automatic regulation within $\pm$ 2 per cent of a nominal voltage, under the same conditions of varying load, voltage and frequency, as mentioned above in the case of the vibrating-contact regulator. The speed of response is sometimes increased by including a non-linear resistor, such as a silicon carbide disc, in the coil circuit.

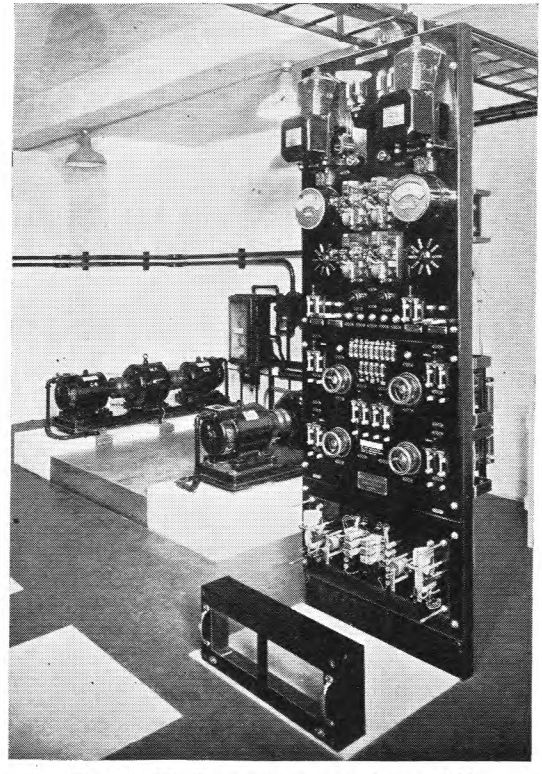


FIG. 14.23. SEMI-AUTOMATIC 80 + 80 V SINGLE-BATTERY FLOAT PLANT
(*By courtesy of H.M. Postmaster-General*)

In this type of resistor a voltage change (V) causes a current change (I) proportional to about V^4, so that its use gives a somewhat similar effect to the "overshooting" in the vibrating-contact regulator.

In the use of carbon-pile regulators care must be taken that the rated pile current is not exceeded, as the power that can be dissipated by the pile, as heat, is a limiting condition in the design. Care must also be taken, by suitable adjustment of the value of the compensating resistance, that the pile is never completely slack as, although this corresponds to a low-current condition, sparking is

very liable to occur between the rings and cause rapid deterioration.

A typical circuit for a carbon-pile automatic voltage regulator for generator control is shown in Fig. 14.24.

The movement of the regulator (Fig. 14.25) is similar in principle to that of a moving-coil voltmeter. Movement of the coil causes the sector to roll over the contact segments and so progressively short-circuit sections of the tapped resistor.

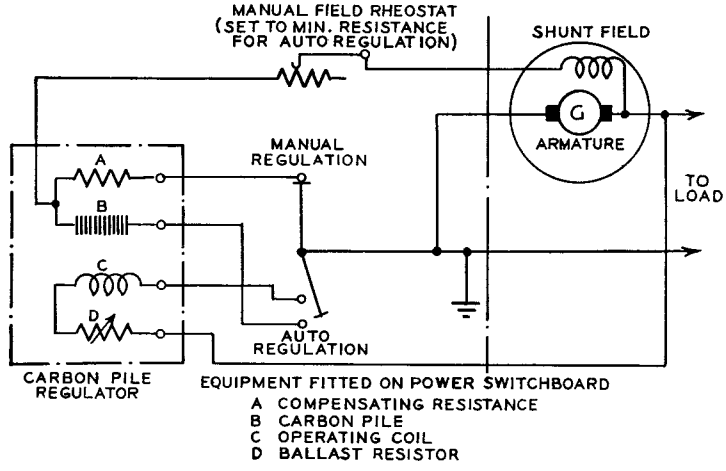


FIG. 14.24. PRINCIPLE OF CARBON-PILE AUTOMATIC VOLTAGE REGULATOR FOR GENERATOR CONTROL

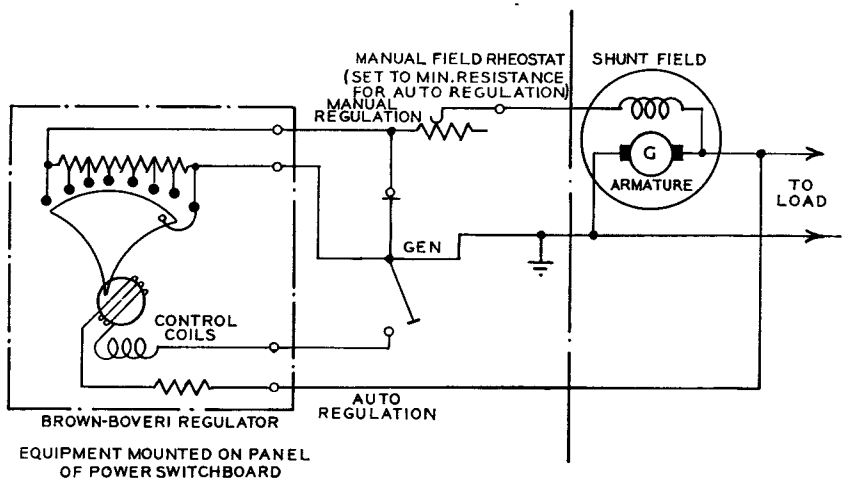


FIG. 14.25. PRINCIPLE OF MOVING-COIL AUTOMATIC VOLTAGE REGULATOR FOR GENERATOR CONTROL

Moving-coil Automatic Voltage Regulators. This type of regulator, made by the Swiss firm Brown-Boveri & Co., Ltd., has been used by the B.P.O. on a few large L.T. generators in which the field current to be controlled is beyond the range of the vibrating-contact type except when the latter is used with an exciter-generator.

The coil is spring-controlled and the movement is damped by an aluminium disc rotated between the poles of two permanent magnets. The damping movement is spring-connected to the driving system, so that it allows an initial rapid overshooting movement of the latter followed by a delayed recoil. The regulator is thus rapid in

operation and has been found to give very good regulation within ± 1 per cent of the nominal voltage on L.T. generators.

Ripple and Noise in d.c. Power Supplies

It will be clear from the section describing rectification that, whilst the output current from a simple dry-plate rectifier is unidirectional, the output voltage is not constant but contains a ripple. The fundamental frequency of the ripple when the rectifier is connected to a 50 c/s a.c. supply is as follows—

Type of Rectification	*Ripple Frequency*
Single-phase, half-wave	50 c/s
Single-phase, full-wave	100 c/s
Three-phase, half-wave	150 c/s
Three-phase, full-wave	300 c/s

Odd and even harmonics of these frequencies are also present, having diminishing amplitudes with increasing frequency.

The following give examples of the amplitude of the components when the a.c. input is a pure sine wave—

Single-phase, full-wave rectification

Frequency	*Percentage of d.c. Amplitude*
d.c.	100
100 c/s	47·1
200 c/s	9·4
300 c/s	4·04
400 c/s	2·25
800 c/s	0·55
1,200 c/s	0·25

Three-phase, Full-wave Rectification

Frequency	*Percentage of d.c. Amplitude*
d.c.	100
300 c/s	4·0
600 c/s	0·99
900 c/s	0·44
1,200 c/s	0·24
1,500 c/s	0·15

The output voltage of a d.c. generator also contains a ripple which is composed of the following—

1. Components at the frequency of the fundamental voltage generated in the armature, and odd harmonics of this frequency.
2. Slot ripple fundamental frequency and harmonics.
3. Commutator ripple fundamental frequency and harmonics.

Consider a four-pole generator driven by an induction motor at a speed near 1,500 r.p.m. at no-load, falling at full-load to about 1,440 r.p.m. The fundamental frequency of the a.c. in the four-pole generator armature will be nearly 50 c/s at no-load and about 48 c/s at full-load and the harmonics of these frequencies will be present in the generator output. None of these harmonic components has an amplitude greater than a small fraction of 1 per cent of the d.c. voltage, either at full-load or no-load, and taken together they probably amount to less than 1 per cent.

Slot ripple is caused by the presence of open slots in the armature surface. During rotation of the armature the slots pass any fixed point at a rate equal to $\frac{x.n}{60}$ per second, where "x" is the number of slots and "n" the armature speed in r.p.m. Thus the reluctance of the air gap at any such point is changing at a frequency of $\frac{x.n}{60}$ c/s and this causes the generation of ripple e.m.f.'s in the field and interpole coils. Further, and more important at full-load, the magnetic flux produced in the armature teeth by the armature current changes as the teeth pass the fringes of the field poles, and this change induces an e.m.f. in the armature conductors at the slot ripple frequency. This latter effect is dependent upon the load current. As an example, if the four-pole generator mentioned above had 32 slots, the slot ripple frequency at full-load would be $\frac{32 \times 1440}{60} = 768$ c/s.

The amplitude of the slot ripple at no-load would probably be a small fraction of 1 per cent of the d.c. voltage, but at full-load it might be about 1 per cent. To achieve such values it is common to skew the slots one slot pitch in their length and to bevel the pole tips.

The frequency of commutator ripple is $\frac{y.n}{60}$ c/s where "y" is the number of commutator segments and "n" is the speed in r.p.m. If "y" = 64 in the above example, the commutator ripple frequency at full-load would be $\frac{64 \times 1440}{60} = 1{,}536$ c/s.

The amplitude of the commutator ripple is independent of load and is very small compared with the slot ripple at full-load.

Smoothing

Telegraph Supplies. If we consider first a purely telegraph supply, such as the ± 80 V signalling supply, the effect of ripple is to cause signal distortion. Ripple of the amplitude found in the output of a generator is unimportant and the signalling supply can be taken direct from the generator without the provision of any form of smoothing.

The ripple in a simple rectifier output, particularly in the case of a single-phase rectifier, is of considerable amplitude at frequencies not many times greater than signalling frequencies, and the provision of smoothing is necessary.

Telephone Type Power Supplies. Ripple in the power supply to phonogram equipment, which is essentially telephone equipment, causes noise in telephone receivers. Smoothing must be provided to reduce the noise to the limit which has been standardized as the result of observations and tests.

The B.P.O. Type 3 M.C.V.F. telegraph equipment requires L.T. and H.T. power supplies which have the same voltage characteristics as telephone repeater station power supplies. These telegraph power supplies are therefore smoothed to the limits required for telephone repeaters, so that the supply may be used for both telegraphs and telephones.

The human ear has its greatest sensitivity at about 1,000 c/s, interfering noise at lower and higher frequencies being less important. Thus the components of the ripple voltage at various frequencies have to be "weighted" to bring them into their true relationship as causes of noise in telephones. A standard weighting curve is published by the C.C.I.F., and valve-voltmeters fitted with this type of weighting network, and known as "Psophometers," are used for measuring noise on d.c. supplies of the type just described.

The permissible limits of weighted or psophometric noise caused by the generators or rectifiers on the terminals of floating batteries are fixed by the B.P.O. as follows—

Telephone or Phonogram batteries 2mV.

Telephone Repeater or M.C.V.F. telegraph battery, L.T. 0·5 mV, H.T. 5·0 mV.

Principles of Smoothing. The methods used for smoothing the output voltage of generators and rectifiers are as follows—

(*a*) The provision of a choke in the output lead.

(*b*) The provision of a low-pass filter, usually of T section, comprising two chokes and a bank of electrolytic capacitors.

(*c*) The use of floating batteries or electrolytic capacitors.

A simple choke is suitable for a small generator in which the rated direct current is low and the principal ripple frequency, i.e. the slot ripple frequency, is fairly high. A simple choke is less suitable for a rectifier, as the principal ripple frequency is low and the inductance of the choke has therefore to be correspondingly increased, since the voltage drop is approximately proportional to ωL.

In B.P.O. practice very small generators are not now provided for L.T./H.T. and phonogram power supplies (except in rare cases when the mains supply is d.c.), so that in practice simple chokes are not used for these supplies.

The 80 + 80 V Westat rectifiers used by the B.P.O. include a choke, and when floating batteries are not being used a 2,000 microfarad bank of electrolytic capacitors is connected across each 80 V supply. The principal function of the capacitors is to provide de-coupling of the fluctuating loads which are connected to the rectifier, but the capacitors do at the same time reduce the ripple voltage on the supply terminals by reducing the load impedance relative to the impedance of the rectifier and choke.

Design of Smoothing Filters. In designing a smoothing filter for an L.T./H.T. or Phonogram supply, to meet the closer limits already mentioned the designer has to provide an economical as well as a technically suitable filter.

In considering the economics of the design an important factor is the limited life of the electrolytic capacitors. Their average life is probably not more than about four years, during which time the capacitance may have fallen to half its initial value. The initial capacitance may however be much greater than the nominal value.

In order to design a choke, or a T filter, the following information is necessary—

(*a*) The generator or rectifier noise e.m.f. and the frequency of its dominant component (if two or more rectifiers or generators are liable to be paralleled this must be taken into account).

(*b*) The limit of noise allowable on the battery.

(*c*) The impedance of the generator or rectifier and of the battery and its leads.

(*d*) The maximum direct current and allowable d.c. voltage drop in the filter.

Whilst (*b*) and (*d*) can be positively fixed, the other factors will usually have to be estimated from experience of other cases and from approximations calculated using empirical formulae. A design factor is used to allow for—

(*a*) Inaccuracies in estimated values.

(*b*) Deterioration of capacitors, or temporary reduction of the capacitance of the bank by complete failure of individual capacitors.

(*c*) Increasing noise e.m.f. with the age of generators. The design factor may be an allowance of the order of two to four times the estimated voltage attenuation necessary from generator (or rectifier) to battery.

Fig. 14.26 (*a*) and 14.26 (*b*) show the use of a choke and of a T section filter respectively.

If E = noise e.m.f. of generator or rectifier.
$\omega = 2\pi$ (the dominant frequency of the noise e.m.f.)
L_G = inductance of generator or rectifier.
L_C = inductance of each choke.
L_B = inductance of battery.
C = total capacitance of capacitors.
V = allowable noise P.D. on the battery,

then, if resistance is neglected, it can be seen from inspection of Fig. 14.26 (a) that for the case of a single choke coil

$$\frac{E}{V} = \frac{L_G + L_C + L_B}{L_B} = 1 + \frac{L_G + L_C}{L_B}$$

For the case of the T filter, Fig. 14.26 (b), the application of Kirchhoff's laws to the two circuits closed by the capacitor, gives two equations from which the following can be derived

$$\frac{E}{V} = 1 + \frac{2L_C + L_G}{L_B} - \frac{\omega^2 C\,(L_C + L_G)\,(L_C + L_B)}{L_B}.$$

Design Data. The following are useful approximations quoted by Harbottle, Sheppard and Richards in I.P.O.E.E. Printed Paper No. 173.

(1) *Noise e.m.f. and Frequency.* In calculating filters for rectifiers use the fundamental ripple frequency and assume values of noise e.m.f. as follows—

(a) Single-phase full-wave rectifier, 1·2 per cent of d.c. output voltage at 100 c/s.

(b) Three-phase full-wave rectifiers, 1·5 per cent of d.c. output voltage at 300 c/s.

For generators, assume a noise e.m.f. of 1 per cent of the d.c. output voltage at the slot ripple frequency.

(2) *Inductance of Generator or Rectifier.* In the case of a rectifier, neglect its inductance by comparison with that of the first choke.

In the case of a generator $L_G = \dfrac{1{\cdot}4\ V_{\text{d.c.}}}{In}$ approximately

where $V_{\text{d.c.}}$ = generator rated output voltage.
I = generator rated output current.
n = armature speed r.p.m.

(3) *Inductance of Battery.* The inductance may be calculated from an empirical formula if details of the layout and cabling are known. Measurements made on a number of batteries have given the following average values, which may be more generally useful than the formula—

24 volt battery:	17 μH
50 volt battery:	18 μH
130 volt battery:	38·5 μH

(Whilst the capacitance of a battery can always be neglected, the resistance of a battery of small cells and the associated battery leads may sometimes not be negligible by comparison with the inductive reactance.)

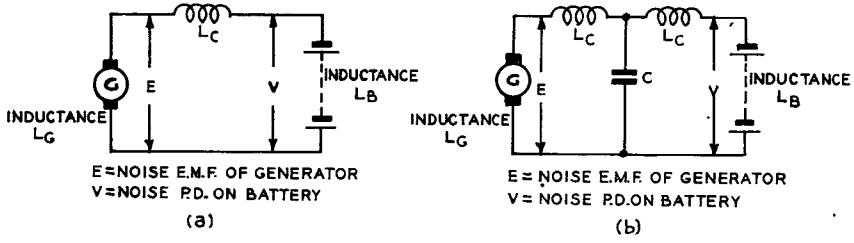


FIG. 14.26. PRINCIPLES OF SMOOTHING GENERATOR OUTPUT VOLTAGE
(a) Use of a choke (b) Use of a "T" section filter

Example.

For brevity, the various trials of comparative designs are omitted and only one solution is calculated. The generator has the following characteristics—

Rated output 25 V, 100 amps.
Speed 1,430 r.p.m. on full-load.
Number of armature slots 46.

Thus generator inductance is approximately

$$\frac{1{\cdot}4 V_{\text{d.c.}}}{In} = \frac{1{\cdot}4 \times 25}{100 \times 1{,}430} \times 10^6\ \mu H = 248\ \mu H.$$

$$\text{Slot ripple frequency} = \frac{46 \times 1{,}430}{60} = 1{,}097\ \text{c/s}.$$

Noise e.m.f. from generator is approximately 1 per cent of $V_{\text{d.c.}} = 250$ mV.

Allowable noise on battery = 0·5 mV.
Allowing a design factor of 4, we design for

$$\frac{E}{V} = \frac{250 \times 4}{0{\cdot}5} = 2{,}000.$$

Try a T filter having two similar chokes each 500 μH and a bank of capacitors of 2,000 μF.

$$\frac{E}{V} = 1 + \frac{2L_C + L_G}{L_B} - \frac{\omega^2 C\,(L_C + L_G)\,(L_C + L_B)}{L_B}$$

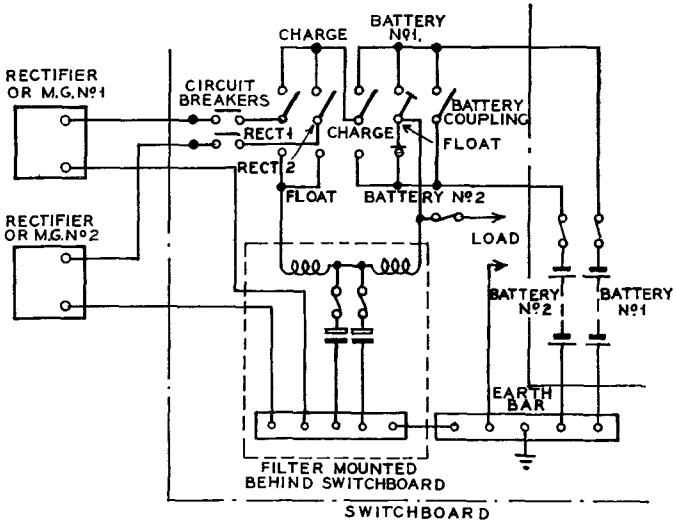


FIG. 14.27. CABLING OF MAIN AND STANDBY RECTIFIERS (OR MOTOR GENERATORS) SHOWING CONNEXION OF FILTER

The first term can clearly be neglected.
Thus

$$\frac{E}{V} = \frac{2 \times 500 + 248}{17} - \frac{4\pi^2 \times 1{,}097^2 \times 2{,}000\,(500 + 248)\,(500 + 17)}{17 \times 10^{12}}$$

$$= \frac{1{,}248}{17} - \frac{8\pi^2 \times 1{,}097^2 \times 748 \times 517}{17 \times 10^9}$$

$$= 73 - 2{,}162 = 2{,}000 \text{ approximately.}$$

Layout of Filter and Cabling. The layout of the filter and all associated cabling must be designed so that the effectiveness of the filter is not impaired by noise induced into the circuit on the noiseless (or load) side of the filter.

When main and standby rectifiers or motor-generators are provided it is not considered necessary to duplicate the filter. Fig. 14.27 shows a suitable cabling plan for such a case.

The electrolytic capacitors should be connected by short leads and fused in at least two sections so that they will not all be disconnected together. The fuses should have 10 amp rating (or as high a rating as the design of small plants will allow), in order to keep the resistance in the capacitor circuit low.

Smoothing chokes and capacitors can be seen at the bottom of the nearest rectifier cubicle in Fig. 14.17.

Power Switchboards

In designing a rectifier power plant it is often possible to accommodate all the auxiliary controlling and switching equipment in the rectifier cubicles or in a cubicle containing smoothing equipment. Sometimes, however, and for all motor-generator plants, a power switchboard is provided.

Power switchboards of the type used in telegraph practice are built with $\frac{7}{8}$ in. thick slabs of an insulating and fire-resisting material of which the basis is asbestos, finished with a smooth, glossy black or grey surface. The slabs are mounted upon angle-iron frameworks, securely bolted to the wall and floor (very small panels may be solely wall mounted on an angle-iron frame).

The height of the top of the standard switchboard is 6 ft 6 in. and the lowest panel should not come within 6 in. of the floor, the space at the bottom being filled in with sheet iron. Figs. 14.23 and 14.28 show typical examples of a switchboard for a single power supply (80 + 80 V).

When there are several supplies, individual panels are provided and lined up side by side (Fig. 14.29). In some cases a switchboard can be lined up with the front face of a suite of rectifier cubicles (Fig. 14.30).

Cabling may be brought to the switchboard supported on overhead cable racks or in floor chases or using a combination of the two methods. The terminals on the back of the switchboard are suitably placed for the chosen method of cabling.

The general rule in equipping a switchboard is to place on the front of the board, as far as is practicable, only equipment which is required to be frequently seen or handled in operating the plant. All other equipment should be mounted on the back of the switchboard. Bulky items are sometimes placed on the floor, or mounted on the wall, behind the switchboard. All cabling and wiring is situated on the back of the switchboard.

The mains items found on a switchboard are as follows—

1. Circuit-breakers. The circuit-breakers provide individual protection for the generators or rectifiers and are mounted on the front of the switchboard at the top. Generator circuit-breakers provide protection against over-load, and against reverse-current from the battery (or from a parallel-running generator) when the generator output fails for any reason. Rectifier circuit-breakers provide protection against over-load but they cannot be reliably used to disconnect a rectifier whose output has failed. This is explained later in the section describing protection.

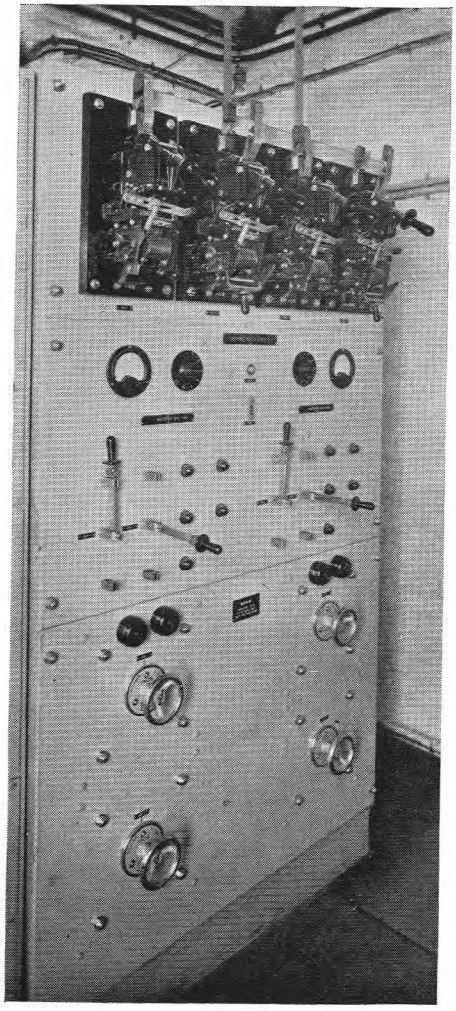


FIG. 14.28. 80 + 80 V, 2 + 2 kW SINGLE BATTERY FLOAT, MOTOR GENERATOR POWER SWITCHBOARD

(*By courtesy of H.M. Postmaster-General*)

The main current-carrying contact is made between a copper block and a multi-leaf bronze spring contact which is flexed when the circuit-breaker is closed. The main contacts are supplemented by a pair of arcing contacts, made of carbon, which make first and break last and so preserve the contact surface of the main contacts. The circuit-breaker is closed by hand, the contacts being operated through a toggle-link mechanism which allows of quick-release by the trip bar associated with the over-current and reverse-current devices.

In many cases the setting of the circuit-breaker release point on over-current and reverse-current is obtained by adjusting the spring tension of a solenoid operated armature. A more accurate control is obtained if the series (over-current) trip coil is replaced in the main circuit by a small contact-ammeter with forward and reverse contacts either of which, on closing, operates a shunt trip coil in the circuit-breaker from the battery supply.

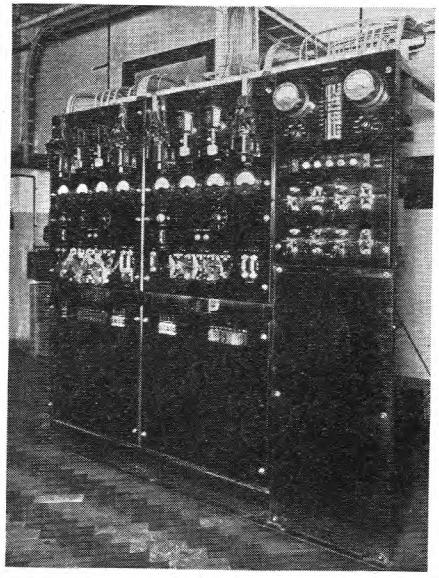


FIG. 14.29. L.T., H.T. AND 80 + 80 V DIVIDED BATTERY FLOAT, RECTIFIER POWER SWITCHBOARD

(*By courtesy of H.M. Postmaster-General*)

Circuit-breakers are often fitted with delay facilities so that a momentary over-load will not cause release. The delay may be provided by the use of oil-dashpots, clockwork mechanisms or

bimetallic thermal elements. Auxiliary contacts are provided for use in alarm and control circuits.

2. Meters. An ammeter and a voltmeter of B.S. first grade accuracy are mounted below the circuit-breakers at about eye level. A multi-point rotary selector switch is mounted near each meter so that readings can be taken at a number of points in the switchboard circuit. The necessary ammeter shunts are mounted at the rear of the switchboard and voltmeter leads are lightly fused between the circuit point and the voltmeter switch.

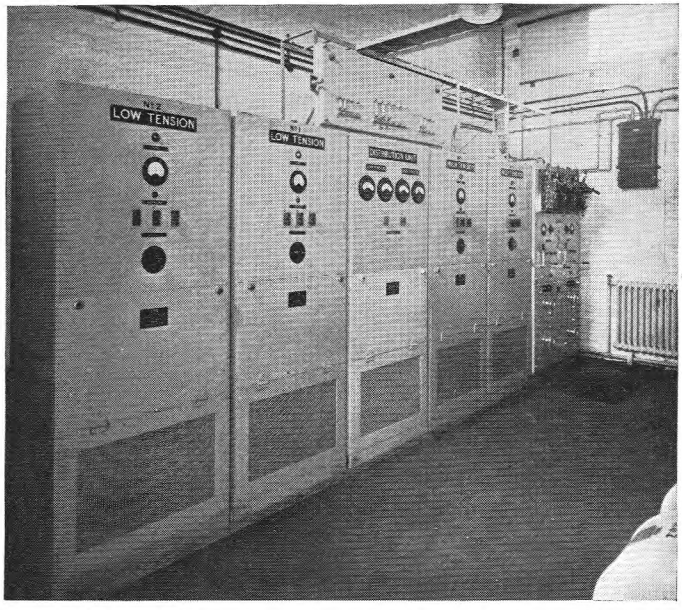


FIG. 14.30. L.T. AND H.T. RECTIFIER CUBICLES AND 80 + 80 V GENERATOR SWITCHBOARD FOR SINGLE BATTERY FLOAT OPERATION

(By courtesy of H.M. Postmaster-General)

3. Switches. The main switches are open knife-switches mounted in a row across the middle of the switchboard. Those normally required are—

(*a*) A slow-break switch for each generator or rectifier, to connect the rectifier to the battery (either battery at will, in the case of double battery float switchboards, using double-throw break-before-make switches).

(*b*) A slow-break "float" switch to connect the load bus-bar to the battery which is floating. This is a double-throw make-before-break switch which ensures continuity of the load supply.

(*c*) A quick-break "coupling" switch for coupling the batteries of a divided battery float system during discharge.

Switches are required on generator switchboards for selecting automatic or manual voltage regulation; these are tumbler switches or small knife-switches.

4. Voltage Regulators on Generator Switchboards. (*a*) Manual shunt-field rheostats are mounted on the lower part of the switchboard. The rheostat is mounted behind the board but the spindle is brought through the board to a handwheel and pointer at the front. It is always arranged that clockwise motion of the handwheel causes increasing generator voltage.

(*b*) The field and ballast rheostats associated with Isenthal automatic voltage regulators are of the slider type; as they rarely need adjustment they are mounted on the back of the switchboard or on a wall mounting framework behind the board.

When carbon-pile regulators are employed, they should be mounted in a high position on the front of the switchboard where they are accessible and least likely to collect dust.

The Brown-Boveri type of regulator is always mounted on the front of the switchboard.

5. Contactors. Contactors are power-operated switches. The solid copper main contacts are spring-loaded so that they are compliant and close with a slightly rolling motion. The contacts of d.c. contactors are provided with arc shields, as well as magnetic blow-out coils which extinguish the arc formed when the contacts open by driving it out of the contact gap.

The switchboards for fully attended stations do not make much use of contactors; an example is the battery paralleling contactor, provided on divided battery float plants having only a few hours battery reserve so that the two batteries are automatically connected in parallel for discharge. Switchboards for automatic or semi-automatic plants make more use of contactors.

Contactors are frequently provided with auxiliary contacts for use in control and alarm circuits.

6. Fuses. The main fuses in the various load leads are of the cartridge type mounted either behind or on the front of the switchboard. Alarm fuses of the bead indicating type are connected in parallel with the main fuses and mounted on the front of the switchboard. Voltmeter fuses are of the glass-tube type.

On 80 + 80 V switchboards a special − 80 V fuse is provided for supplying station alarm circuits.

7. Alarm Lamps. Alarm lamps are mounted on

the front of the switchboard and are clearly labelled to indicate their purpose.

8. Relays, etc. Telephone type relays and auxiliary components used principally in alarm circuits are mounted under covers either behind or on the front of the switchboard. The relays must be conveniently placed for maintenance.

9. Earth Bar and Terminals. All main cables to the switchboard are terminated in soldering sockets and are usually secured by nuts to screwed studs or bolts. The sockets should not be secured by the same nut as is used to secure a terminal bolt, switch-post, etc., to the switchboard. A common earth bar is provided for terminating all the cables on the earthed side of the supply.

Battery Operation

There are broadly two types of power installation, viz.—

(*a*) All-mains installations employing rectifiers or machines of small capacity.

(*b*) Larger plants employing rectifiers or motor-generators in conjunction with batteries.

Battery plants may be operated in two principal ways—

1. Charge-discharge Operation. Two batteries are provided, each of which will supply the full-power requirements for (usually) not less than 24 hours. One battery is used to supply the load whilst the other is being recharged from a rectifier or motor-generator. This was at one time the standard method for supplying telegraph signalling loads in the few cases in which batteries were used.

The principal advantage of the method is that the rectifier or generator can be very simple as it is never connected to the load.

The following principal disadvantages outweigh the above advantage—

(*a*) The total battery capacity is large as each battery must in turn carry the load for the designed period.

(*b*) The battery plates have a relatively short life due to the continual charge and discharge cycle.

(*c*) The batteries "gas" and spray acid during the latter part of the charging period, so making the conditions in the battery room uncongenial.

(*d*) Considerable maintenance attention is necessary and when distilled water is used for topping up the cells the amount required becomes expensive.

(*e*) There is a considerable wastage of electric power as the batteries do not return as much energy to the load as is used in their charging.

Consequently charge-discharge working is not now used for telegraph power plants in the B.P.O., except in a very few cases where the main supply is d.c and the battery voltage is suitable for direct charging from the mains, whilst the load is too small to make the provision of motor-generators for floating duty economical. Such cases are very rare, and as the use of a.c. mains becomes universal they will disappear.

2. Battery Floating. Almost all the battery power plants in the telegraph service of the B.P.O. are operated on the "floating" principle. A battery is

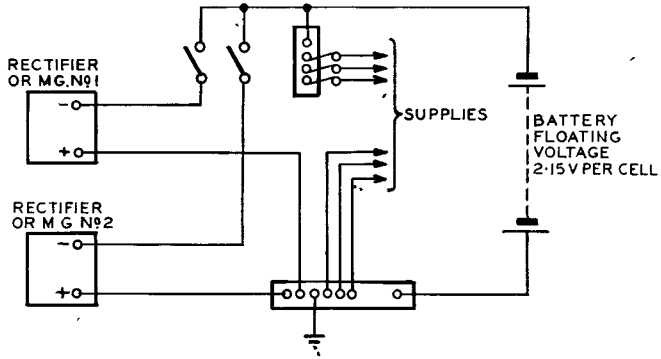


FIG. 14.31. SINGLE BATTERY FLOAT POWER PLANT: SCHEMATIC CIRCUIT DIAGRAM

connected across the bus bars, i.e. across the generator (or rectifier), and the load. The aim is that the generator or rectifier should normally supply the whole load current, the battery merely floating across the supply in a state of readiness to supply the load should the output from the generator or rectifier fail. The battery is not in a complete state of inactivity because irregularities in the bus bar voltage cause the battery to momentarily charge or discharge and so behave in a similar manner to a smoothing capacitor.

Further, in a practical system, quite apart from these momentary charging and discharging currents, the battery either charges very slowly or discharges very slowly according to the system used. The two systems used for telegraph power plants by the B.P.O. are—

(*a*) Single-battery floating.

(*b*) Divided-battery floating.

Single-battery Floating. Fig. 14.31 shows the essentials of a single-battery float power plant. As the name implies there is only one battery, which is always connected to the load. Its capacity must be sufficient to meet an emergency discharge for the designed period and will be equal to that of one of the two batteries in an equivalent charge-discharge plant. As the battery can never be disconnected from the load, except perhaps in some real emergency, it must be kept in a fully-charged condition

without the possibility of applying to it a voltage higher than that permitted on the load. To keep the battery in good condition on this basis it must take a very small trickle charging current, to replace the losses which are continuously occurring in the cells due to local action. The value of this trickle charging current in amperes should be about $\frac{1}{1000}$ of the ampere-hour capacity of the cells and this is obtained when the voltage applied to the battery is approximately 2·15 to 2·17 V per cell.

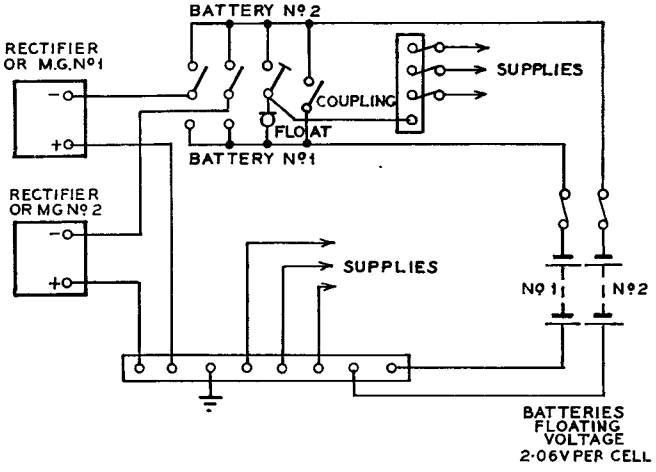


Fig. 14.32. Divided-battery Float Power Plant: Schematic Circuit Diagram

The lower figure must be maintained if there is to be no risk of the cells gradually losing charge. It is possible to float a battery satisfactorily using a rectifier or generator having only manual voltage control, but frequent adjustment is necessary particularly if the capacity of the batteries is small relative to the load, to ensure that none of the cells becomes partially discharged.

It is much more satisfactory to provide the rectifier or generator with automatic voltage control and this is now standard on almost all B.P.O. floating battery power plants. Regulation of the floating voltage within $\pm$ 2 per cent of its nominal value is sufficiently close to ensure that the battery is kept charged and in good condition.

After an emergency discharge it is possible to restore about 75 per cent of the charge of the battery in a reasonable time without exceeding the normal floating voltage, but the recharging is hastened if the voltage can be raised to 2·3 V per cell and the conditions imposed by the load will sometimes allow of this.

Divided-battery Floating. Fig. 14.32 shows a simple divided-battery float circuit. There are two similar batteries, one of which is normally on floating duty at approximately 2·06 V per cell. At this voltage the cells are not kept fully charged and have lost about 10 per cent of their charge after one week. One object of the system is to secure a smaller range of load-voltage than the single battery float system affords. The losses incurred during floating have therefore to be made good without raising the load-voltage, which implies that the battery must be disconnected from the load for recharging. Thus, during one week whilst one battery is on floating duty the other is disconnected from the load and fully recharged.

At one time the charge was restored to the battery by trickle charging throughout the week that it was off load. It is now normal practice to give the battery a charge at normal charging rates (say a 10 hour rate, i.e. $\frac{1}{10}$ of the ampere-hour capacity of the battery expressed in amperes) and then leave it idle for the remainder of the week. This avoids the provision of facilities for trickle charging and is better for the battery. The total battery capacity available for an emergency discharge is only about 1·9 times that of one battery, since the floating battery may be 10 per cent discharged.

Therefore each battery should have about 0·55 of the capacity of one battery of an equivalent charge-discharge system. In the event of an emergency discharge, the two batteries are usually paralleled (manually or automatically) as in this way the cells discharge at a lower rate relative to their ampere-hour capacity and give a better efficiency.

Compared with single-battery float operation, the advantages of divided-battery float operation are—

(*a*) A smaller range of load voltage between the floating and discharged states of the battery.

(*b*) Easier maintenance, as each battery can be taken off load in turn.

(*c*) More control over the condition of individual cells.

The disadvantages are—

(*a*) More individual cells to maintain.

(*b*) More room required by the cells.

In the case of large power installations, the use of divided-battery float operation is strongly favoured in view of the greater ease of maintaining the batteries.

Secondary Batteries. The B.P.O. uses exclusively the lead-acid type of cell for stationary battery installations associated with telegraph power plants. The reader is referred to any good book on technical electricity for a description of the chemical reactions which accompany the charging and

discharging of this type of cell and for details of the types and manufacture of the plates.

The B.P.O. employs two types of cell for stationary batteries—

(*a*) *Open Type Cells.* The cells are contained in open glass boxes and made in the following capacities 72, 96, 120, 200, 250 and 300 ampere-hours. Larger cells from 400 ampere-hours upwards are built in lead-lined wooden boxes from plates having capacities of 100, 150, 200, 300 and 430 ampere-hours. The positive plates are of the Planté type, made from pure lead by the process known as "forming."

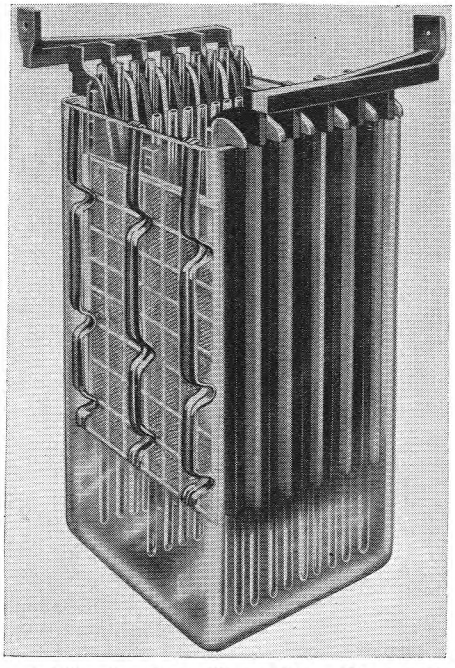


FIG. 14.33. AN OPEN TYPE GLASS-BOXED CELL
(*By courtesy of D.P. Battery Co., Ltd.*)

The negative plates, which are of the pasted type, occupy the first and last positions in each cell, there being one positive plate fewer than there are negative plates. The plates have projecting lugs by which they are hung from the sides of the boxes, heavy glass slabs being interposed when lead-lined wooden boxes are used. The bottom of the plates is well clear of the cell bottom, to leave room for detached fragments of plate material to collect without risk of short-circuiting pairs of plates. The plates are separated by vertical glass tubes, on top of which are laid glass sheets to arrest most of the acid spray which is created when the cells are gassing.

Connexion between all the positive plates in a cell is made by solidly burning them (a fusion process) to a solid lead bar which has a lug for the external connexion. All the negative plates are similarly connected.

Each cell is provided with a floating hydrometer for indicating the specific gravity of the electrolyte.

Open type cells are built up from their components, filled with electrolyte and given their first charge at their installation site. Fig. 14.33 shows an open type glass-boxed cell.

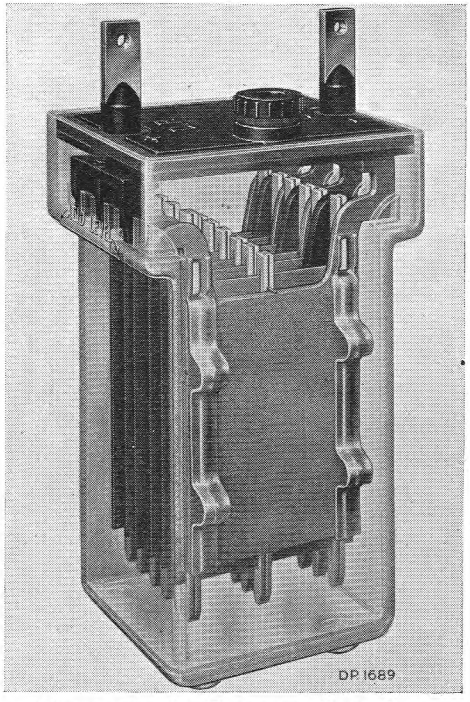


FIG. 14.34. AN ENCLOSED TYPE CELL
(*By courtesy of D.P. Battery Co., Ltd.*)

(*b*) *Enclosed Type Cells.* These cells, Fig. 14.34, are made in five capacities, namely 10, 20, 50, 75 and 125 ampere-hours, and their most notable features are—

1. They can be transported from the factory or depot already filled with acid and fully charged.
2. They can be used on floating duty in the same room as apparatus, because acid spraying has been virtually eliminated.

The glass boxes are fitted with sealed ebonite lids and the small gas vents which have to be provided are proof against the escape of acid spray.

As in the open type cells, the positive plates are of the Planté type and the negative plates are of the pasted box type. Wooden separators are

provided between the plates. Unlike glass tubes, the solid wooden separators give a positive overall protection against short-circuits. This feature is necessary as the sealed lid prevents access for clearing a short-circuit between plates. The whole assembly is kept compact by pressure from lead springs placed between the glass box and the end plates.

The floating type of hydrometer cannot be used. A syringe type is employed, which has a float in a glass tube into which acid can be drawn from the cells by compressing and then releasing a rubber bulb.

(When space is limited the B.P.O. occasionally uses enclosed cells of larger capacity instead of open-type cells. These cells, sometimes referred to as traction type cells, have pasted plates tightly packed in enclosed ebonite boxes. As the plates cannot be seen they are not quite so convenient for maintenance, and the cells have also a greater range of voltage under discharge than open-type cells.)

Assembly of Cells into Batteries. The large open type of cell in the lead-lined wooden box can only be used in one tier, so that a battery of these cells occupies a large floor area. Each cell box is supported on four or more porcelain insulators on a low stand, solidly constructed of heavy timber.

The general arrangement is shown in Fig. 14.35. The inter-cell connectors are lead bars burnt to the cell terminal bars. The boxes must be slightly spaced in the rows to provide insulation and to allow of a cell being withdrawn for maintenance. For the latter purpose it is also essential that the aisles between rows of cells should be of ample width. The cells are usually installed in double rows; when the battery is being used to provide a high degree of smoothing, e.g. in a L.T. or 50 V battery, the loop formed by the double rows is advantageous in minimizing the inductance of the battery.

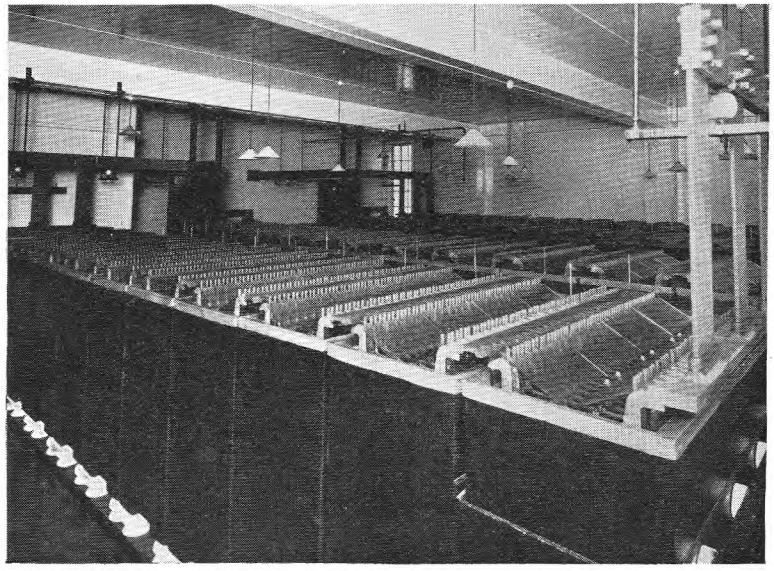


FIG. 14.35. A BATTERY OF WOODEN-BOXED CELLS
(By courtesy of H.M. Postmaster-General)

The connexions from the batteries to the power switchboard may consist of solid copper bus-bars or of lead-sheathed or braided rubber-covered cables, supported on cable racking. A cartridge-type fuse is provided in each unearthed battery lead, usually in an individual fuse mounting on the racking at the end of the particular battery.

The glass-boxed cells are accommodated on wooden battery racks, which are heavily constructed and may have two or three tiers and be suitable for either one or two rows of cells. The larger cells may only be used on two tier single row racks on account of their weight, but two of these racks may be placed side by side to make a double row.

If space allows battery racks should be kept away from walls; this is rarely realizable in practice and so the racks which go against the wall must only hold a single row of cells to allow of maintenance access.

Fig. 14.36 shows a typical rack of cells. Small cells may alternatively be mounted on a shelf type of battery rack constructed against a wall.

Both types of glass-boxed cell stand on rubber ring insulators. The fuse panels are usually mounted on the end of the battery racks. The connexion between cells are made with bolted lead strips in the case of enclosed cells and with flexible stranded conductors terminated in sockets in the case of open-type cells.

Maintenance of Batteries. The electrolyte in lead acid cells is pure dilute sulphuric acid which is adjusted in a new fully-charged cell to have a specific gravity of 1·215 at 60°F.

The ampere-hour rating of cells used by the B.P.O. is based on their discharge to a P.D. of 1·83 V at the 9-hr rate of discharge, or sometimes to 1·85 V at the 10-hr rate. Thus, a fully-charged 72 A-hr cell discharged at 8 A will reach a P.D. of 1·83 V in approximately 9 hours and the specific gravity of the electrolyte will fall to about 1·180 at 60°F.

The initial charge of a battery is begun at approximately the 18-hr rate and completed at the 9-hr rate, but in charge-discharge practice subsequent charges are usually begun at a higher rate, e.g. up to twice normal ($4\frac{1}{2}$-hr rate) until the cells begin to gas at about 2·35 V per cell, when the rate is dropped below the normal rate to about the 12-hr rate.

When cells are floated at not less than 2·15 V per cell they should remain fully charged. Their condition can be judged by the specific gravity of the electrolyte and by the appearance of the plates. The positive plates should be chocolate brown and the negative plates dark grey and both should look clean and bright. Cells operated on the divided battery float principle lose about 10 per cent of their charge in a week and the specific gravity falls linearly with loss of charge to about 1·212 at 60°F. They may be recharged at about the 9- or 10-hr rate.

When specific gravity measurements are made, the temperature of the electrolyte must be noted and the readings corrected to give the equivalent value at 60°F before any judgment is made. The higher the temperature the less is the specific gravity and the correction to be applied is 0·0003 per degree F.

Cells gradually lose some of the water in their electrolyte by evaporation and the loss must be made good periodically to keep the level of the electrolyte constant. It is very often possible to use tap water for topping up the cells when it is known by analysis to be sufficiently free from chemical impurities. Otherwise distilled water is used. The loss by evaporation is small in the case of cells that are floated but much greater when they are used on a charge-discharge duty. Cells should only be topped up with acid instead of water, when it is quite certain that there has been a loss of active electrolyte, for example by prolonged spraying. Cells should not be left for long in an uncharged condition as insoluble lead sulphate is likely to

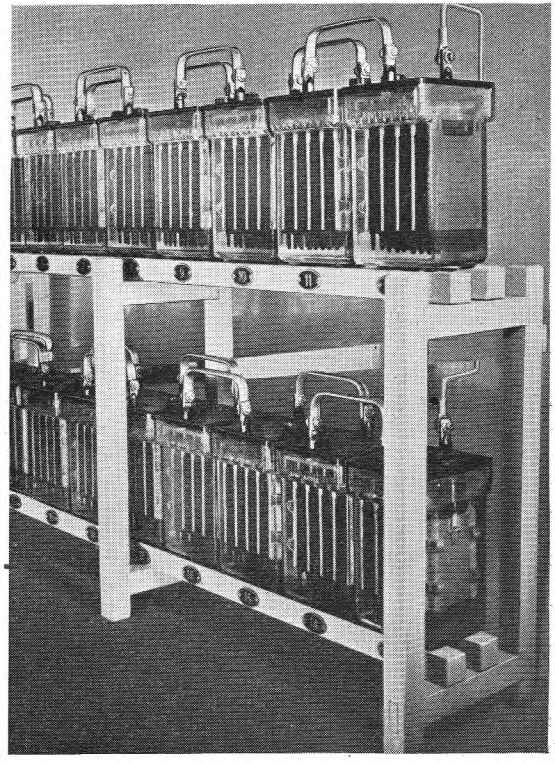


Fig. 14.36. A Rack of Enclosed Type Cells
(*By courtesy of D.P. Battery Co., Ltd.*)

form on the plates and cause a permanent loss of capacity and increased internal resistance. The plates then appear light grey with a white deposit on them. The boxes must be kept clean and dry to prevent any tendency to creepage of the electrolyte from the cells. The spray plates on open type cells must be kept in position to keep out dirt. Terminals must be kept tight and protected from corrosion by the application of petroleum jelly.

Fig. 14.37 shows the shape of typical voltage characteristics of cells on discharge. It will be apparent that if cells are discharged at high rates, the limiting voltage required by the load may be reached before the cell is fully discharged. This factor is covered later in the chapter. Furthermore, the higher the discharge rate the lower is the

efficiency of the battery whether reckoned on an ampere-hour or watt-hour basis. This effect is illustrated in Fig. 14.38 and is also taken into account when designing a power plant.

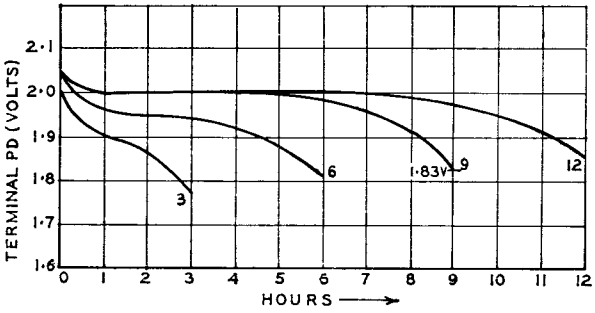


FIG. 14.37. TYPICAL VOLTAGE CHARACTERISTICS OF SECONDARY CELLS ON DISCHARGE

Earthing

There are two aspects of earthing to be considered—

(*a*) Protective earthing, which is to prevent the metal frames, etc., of power plant and power-consuming equipment from acquiring a dangerous voltage with respect to earth potential in the event of a fault causing the power supply to be accidentally connected to the frame. The protective earth enables protective devices, i.e. fuses or circuit-breakers, to operate in the case of such faults.

(*b*) Earthing of the power supplies themselves. All telegraph power supplies are earthed on one pole. In most cases this is also a protective provision as it keeps the potential of the supplies within certain limits with respect to earth potential. Satisfactory earthing is of particular importance, however, in the case of $\pm$ 80 V telegraph supplies, because the return path of signalling currents in most d.c. telegraph circuits is via earth.

Earthing of Power Plant. In most buildings in which power plant is likely to be installed there is a main earth bar, usually associated with the main distribution frame (M.D.F.). A subsidiary earth bar is then provided in the power room and is connected to the main earth bar by a continuous cable of 19/16 S.W.G. section bare stranded soft copper. The earth bar on the 80 + 80 V power board often serves as the subsidiary earth bar for the power plant. If there is no existing earth system, an earth electrode system of driven spikes, buried plates or buried lead strips has to be provided when power plant is installed.

The main earth bar or the subsidiary earth bar should also be connected by 7/16 S.W.G. bare stranged soft copper cables to—

(*a*) the lead sheaths of the cables which lead in the underground cables carrying the d.c. telegraph circuits, and

(*b*) if possible, a main water pipe at the point where it enters the building, i.e. on the street side of the main cock.

The metal frames of all rectifiers, motor-generators, starters, power-boards, etc., must be securely earthed to the subsidiary earth bar, using 19/16 or 7/16 bare stranded conductors according to the rating of the plant. All tee joints in this cabling must be sweated (soldered). All the protective earthing cables terminating on the subsidiary earth bar must be fitted with soldering sockets which should be bolted and sweated to the earth bar.

Where the protective earthing cables are connected to the frames of motor-generators, etc., the connexions must be securely bolted and spring washers should be used. The rotor shaft of motors supplied from the mains should be earthed by a brush running on the coupling.

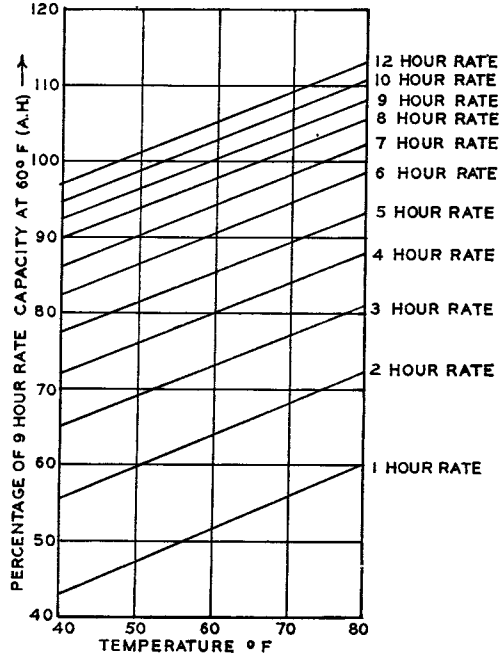


FIG. 14.38. EFFECT OF DISCHARGE RATE AND TEMPERATURE ON THE EFFICIENCY OF A SECONDARY BATTERY

The earth bar on each power switchboard, (L.T., H.T., 50 V, 6 V, etc.) is connected to the subsidiary earth bar by a 19/16 S.W.G. bare stranded conductor. As already stated in the section describing switchboards, the earth bar on each switchboard is used as a central point for terminating all leads on

the earthed side of the particular supply, i.e. battery, generator, rectifier and load distribution leads.

Earthing of Apparatus and Instruments. In the distribution of the various power supplies to the equipment loads it is desirable that the current on the earthed side of each load shall return direct to the appropriate power switchboard by the "earth return" distribution cable, and not by accidental routes through protective earth cabling, conduits, etc., connected to the equipment. (The protective

(3) An uninsulated protective earth cable connecting the equipment racks to the earth bar on the ± 80 V power switchboard.

In the case of teleprinters which derive their motor and signalling supplies from a ± 80 V power plant, the signalling earth is provided by an insulated cable from the power switchboard to an insulated earthing bar mounted in or near the distribution board (fuse-box) which serves the teleprinters. From this earthing bar an insulated

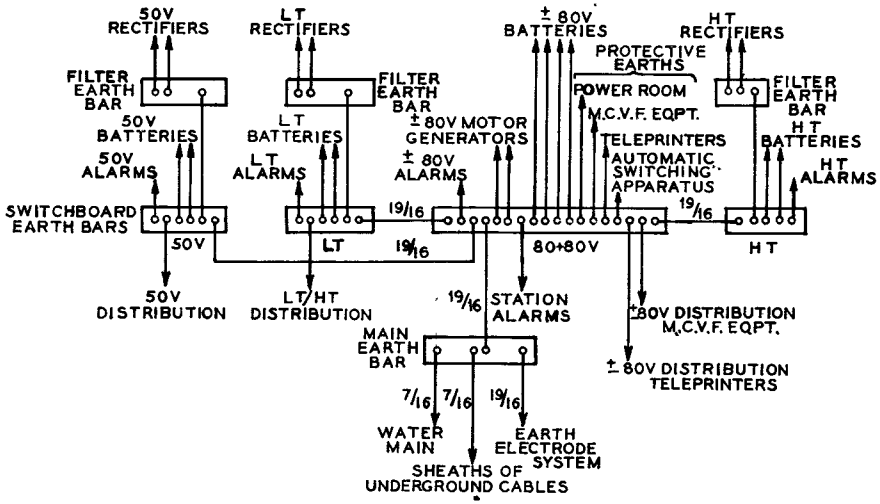


FIG. 14.39. TYPICAL EARTH CABLING SYSTEM FOR POWER PLANT

earth leads all terminate on the earth bar of the ± 80 V power switchboard where this is installed; when there is no ± 80 V switchboard the protective earth leads terminate on the earth bars of the individual power switchboards.) For this reason power distribution cables to equipment are insulated on the earthed side as well as on the live side. If this precaution is not taken, electrically silent supplies or telegraph signalling supplies may pick up unwanted electrical noise from other supplies, possibly including the a.c. mains and fault currents proper to protective earth cabling may be carried by the earth return distribution cable.

For example the earth cabling to M.C.V.F. telegraph equipment (TYPE 3) consists of the following—

(1) An insulated earth return distribution cable common to the L.T. and H.T. supplies, terminating on the L.T. switchboard earth bar.

(2) An insulated earth return distribution cable for the ± 80 V supplies, terminating on the ± 80 V switchboard earth bar (which is also the subsidiary earth bar for the complete power plant).

signalling earth lead is taken to each teleprinter. The protective earth lead for the teleprinter frame, metal framed table, etc., is derived from separate uninsulated protective earth cabling to the ± 80 V switchboard earth bar.

When, in smaller installations, teleprinters derive their power from the mains, the protective earth on the mains conduit (or cable sheath or earth wiring) is used as the protective earth on the teleprinter installation. The signalling earth, however, is provided by insulated cabling to an earth bar connected to the water main and to the sheaths of the underground cables.

Fig. 14.39 shows a typical earth cabling system.

Cabling and Busbars

The following methods are adopted in providing power cabling—

(*a*) The mains distribution fuse box, mounted on the power room wall, is usually cabled to the motors and their starters, and to rectifiers using rubber-covered (V.I.R.) braided cable in steel conduit. Occasionally it is more convenient to use

rubber-covered lead-sheathed cables without conduits. The cabling is often carried in floor chases (shallow trenches) with removable wooden covers.

(*b*) Leads between generators, rectifiers and smoothing filters and the power switchboard are cabled in rubber-covered lead-sheathed or braided cable carried in floor chases or on steel cable racks.

(*c*) Battery leads to the power switchboard are cabled in rubber-covered lead-sheathed, or braided V.I.R. cable on racking. Floor chases are occasionally used, in which case lead-sheathed cable is specified.

(*d*) Power distribution leads to apparatus and instrument rooms usually consist of lead-sheathed cables carried on cable racking.

In some large M.C.V.F. telegraph installations, copper or aluminium busbars are used, either for the whole of the route or in the apparatus room only; in the latter case they are combined with lead-sheathed cables to the power room. 50 V busbars are always provided in telegraph automatic switching apparatus rooms.

(*e*) Connexions on the back of the power board are made with copper bar and rubber-insulated cable according to the rating and purpose of the leads.

Paper insulated lead-sheathed cable is used for leads of large cross-section as it is cheaper, though less easily terminated, than rubber-covered cable.

All conduits and cable sheaths are earthed. Cables are terminated in soldering sockets which are secured by nuts and washers to screw terminals.

Busbars are supported on insulators from suitable hangers which may carry cable racking. In the apparatus rooms the busbars follow one of the main aisles. Busbars are painted in distinctive colours, those which are not earthed being taped before painting. Joints in copper busbars are sweated and bolted, whilst flame-brazed joints are used for aluminium busbars.

Rating of Cables and Busbars. The cross-sectional area of all cables must be not less than that specified by the Institution of Electrical Engineers in their "Regulations for the Electrical Equipment of Buildings."

In addition all rectifier and generator output cables, battery cables and distribution cables must be of sufficiently large section to keep the voltage drop within limits governed by the design of the power installation. This is almost always a more stringent requirement than the I.E.E. rating, the latter being based on the permissible temperature rise of cables.

The following Table gives some idea of the power (or current) and voltage-drop ratings which are used in practice for floating-battery power plants. The design of the plant and the type of load may necessitate the adoption of different values. The general problem will be better understood from the example of a design which is given later.

CURRENT RATINGS

Connexion	Current Rating
Main distribution box to motors and rectifiers	Rated input current (Note 1)
Generator or Rectifier to power Switchboard	Rated output current plus maximum field current (Note 1)
Generator shunt field lead	Maximum field current
Smoothing filter to power Switchboard	Maximum load current (Note 2)
Battery to power switchboard	Maximum discharge current
Distribution Cables, power switchboard to apparatus and instrument rooms	Maximum load current (Note 3)

Notes.

1. Rated currents are the full-load currents quoted on the rating plates of motors, generators and rectifiers.
2. In single-battery float plants, the filter must also carry the battery recharging current.
3. The signalling earth distribution cable is normally made half the cross-sectional area of the ± 80 V cables.

VOLTAGE DROP RATINGS

Connexion	Voltage Drop
Generator or rectifier to power switchboard, each lead	0·5 V (Note 1)
Battery to power switchboard, each lead	0·25 V (Note 2)
Power switchboard to furthest sub-distribution point in apparatus or instrument room, each lead,	
± 80 V	1·0 V (Note 3)
L.T. and H.T.	0·15 V
Common LT/HT Return . .	0·15 V
24 V or 50 V	0·15 V

Notes.

1. Where a separate filter is used, the allowance for the generator or rectifier leads includes the filter leads.
2. A separate allowance is made for the voltage drop in the power switchboard and in battery fuses.
3. Occasionally where the discharge leads are very long an additional cell may be used in each 80 V battery to increase the allowable voltage drop.

Protection of Power Supplies

When an item of apparatus, or a cable, or part of the power plant itself, fails in such a way as to take a fault current from the power supply, it must be automatically disconnected, to prevent damage by overheating and to avoid unnecessary interference with other parts of the system. The aim should be to disconnect the minimum amount of plant to clear the fault and to keep the rest of the plant working.

In a typical floating battery power plant the following are the principal protective devices. They are shown in a simplified schematic diagram in Fig. 14.40.

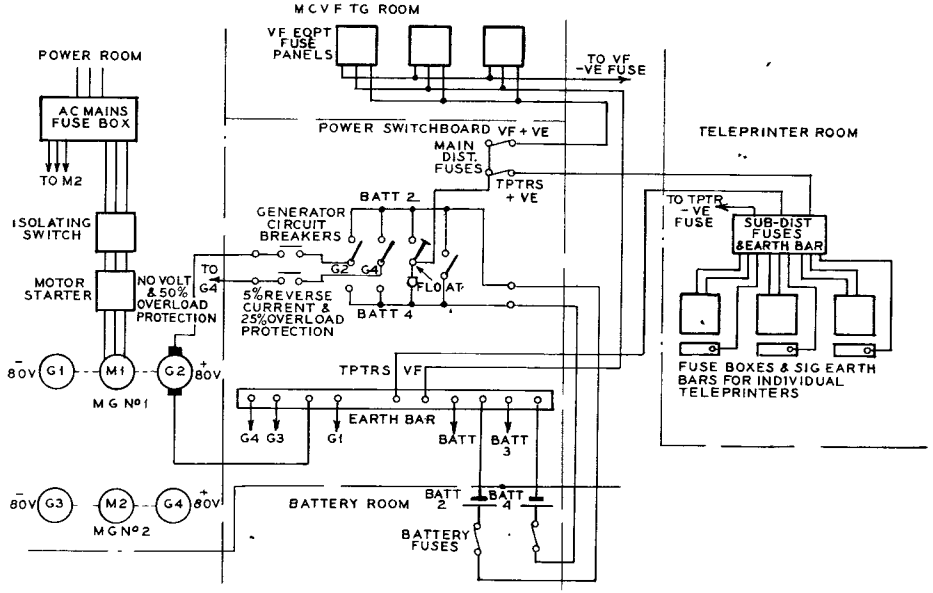


FIG. 14.40. SCHEMATIC DIAGRAM SHOWING PRINCIPAL PROTECTIVE DEVICES IN A TYPICAL FLOATING BATTERY POWER PLANT

1. Sub-distribution Fuses in Apparatus and Instrument Rooms. These fuses must disconnect any section of the load which becomes faulty, without allowing the main distribution fuse on the power switchboard to blow.

The most awkward case commonly met is the teleprinter, which requires a starting current about five times its running current. A fuse sufficiently small to give real protection is liable to blow when the motor starts. Better protection can be given by the use of small circuit-breakers fitted with thermal delays, and these are now installed in many cases by the B.P.O.

2. Distribution Fuses on the Power Switchboard. These fuses are to protect the main distribution cables. The fuse rating chosen, which is the safe carrying current, should be sufficiently large to carry the maximum discharge current when one sub-distribution fuse is about to blow on a fault. In practice, as the distribution cables are designed for a very low voltage drop and have a large cross-section relative to the load to be carried, the distribution fuse can be of ample rating. (A fuse may be considered to blow almost instantaneously when the fault current is twice the rating of the fuse.)

3. Generator or Rectifier Output Circuit-breakers. The circuit-breaker must protect the generator or rectifier against any fault in the switchboard, smoothing filter or the battery cabling, and against any reverse-current from the battery when the output of a generator fails. The over-current protection is normally set to cause the circuit-breaker to open on a 25 per cent over-load. When the circuit-breakers are designed to give delayed release, the delay should be 10–20 sec on 25 per cent over-load, and less than 3 sec at 100 per cent over-load.

The reverse-current protection on generator circuit-breakers should release the circuit-breaker on a reverse-current equal to 5 per cent of the rated generator output current. This rather critical requirement is necessary because a motor generator, on failure of the mains supply, will "motor" from the battery supply with the generator taking quite a small current relative to its rated output.

In the case of a selenium rectifier plant it is sometimes desirable that a mains operated contactor be

provided to disconnect the rectifier elements from the battery in the event of mains failure. This is because the selenium rectifier is not always efficient as a d.c. blocking rectifier. The difficulty arises when the number of discs in series is chosen to give high efficiency under normal operating conditions, so that the battery reverse voltage per disc may be about 13–16 V. Depending upon the temperature of the discs there is a critical reverse voltage above which a large reverse-current will flow when the a.c. is disconnected. Whilst this large reverse-current is not likely to damage the rectifiers it is a serious drain upon the batteries during mains failure. Copper oxide rectifiers (and some selenium rectifiers) are not subject to this difficulty.

In some small rectifier plants circuit-breakers are not used, and fuses are provided on the rectifier rated to carry the rated output of the rectifier.

4. Rectifier or Motor-generator Input Fuses or Over-current Release Devices. These devices give protection against faults occurring within the rectifier or motor-generator.

The usual setting for over-current release in motor starters is release in 20 to 40 sec on 50 per cent over-load. A.c. over-current release devices on rectifiers may be set for 25–50 per cent over-load, the delay of operation being very much a matter for choice according to the particular design of plant. There is often difficulty with transformer surge current when switching on the a.c., and it may be necessary to immobilize the over-current protection during this operation. When fuses are used they can be rated for the rated input of the rectifier.

5. Battery Fuses. It is very undesirable for the battery fuse to fail unnecessarily and it is therefore rated as highly as the current rating of the battery cables will allow. In no case, however, should the fuse rating in amperes be numerically higher than half the ampere-hour capacity of the cells, otherwise the cells may be damaged.

The protection described above covers all the main items of power plant and cabling. There is other fuse protection for the various alarm circuits and for electrolytic capacitors in smoothing filters.

Alarm indications are provided wherever the release of a protective device or the blowing of a fuse would not be clearly self-evident from its particular effect on the operation of the plant.

Outline Design for a Floating Battery Plant

This section shows the method of approach to the main design figures for a typical floating-battery power plant.

The information required by the designer is—

(*a*) The maximum load current, and the range of current when it is variable. It is usually possible to estimate the latter from traffic data but any practical confirmation that can be obtained is valuable.

(*b*) The required voltage of the power supply and the permissible limits of voltage variation.

(*c*) The characteristics of the mains supply and any restrictions on the starting current of motors and on the power factor of connected loads.

(*d*) The number of hours for which the battery must be able to maintain the load during mains or plant failure (usually called the battery reserve).

(*e*) The available space for power plant and batteries.

(*f*) The length of the cable runs between the power room and the battery, apparatus and instrument rooms.

Example of a ± 80 V Power-plant Design. Suppose that the battery is to supply signalling and motor power to a large telegraph instrument room. Assume the available information in the above categories is as follows—

(*a*) Maximum load current 36 A.

(*b*) The working range of the teleprinter motors decides the permissible variation of voltage in the instrument room as approximately 150–170 V for positive and negative supplies in series, i.e. 75–85 V on each supply.

In addition the positive and negative supply voltages should not differ by more than four volts, as a signalling requirement.

(*c*) Available power supply 400 V, 3 phase, 50 c/s a.c. Motor starting current not to exceed 1·5 times the motor rated current, and the power factor of the a.c. load not to be less than 0·8 at rated load.

(*d*) The battery reserve to be six hours at the maximum load.

(*e*) (Consideration of the accommodation aspect of the design is beyond the scope of this chapter.)

(*f*) Cable run from power room to battery room, 50 ft.

Cable run from power room to instrument room, 200 ft.

Rating of Plant. A 4 + 4 kW (48 A) motor-generator plant will supply the 36 A load and leave a margin for possible growth of the load. Duplicate motor-generators will be provided. The complete plant will be designed on the basis of an ultimate load of 48 A.

Type of Battery Operation. The most important factor in the choice between single-battery and divided-battery floating is the permissible voltage range at the load.

Consider the two following conditions—

(*a*) Minimum load with the battery floating.

(*b*) Maximum load with the battery fully discharged.

In the first case we can consider the voltage drop in the battery and distribution cables and in the switchboard to be negligible; thus the maximum floating voltage of the battery can be 85 V.

In the second case assume—

Voltage drop in each battery cable: 0·25 V

Voltage drop in each distribution cable: 1·0 V

Voltage drop in switchboard and battery fuse: 0·5 V

As the major part of the load is the 160 V motor load, we can neglect the earth return cables at this stage and say—

Minimum allowable voltage of each (positive and negative) battery when fully discharged

$$= 75 + 1{\cdot}0 + 0{\cdot}25 + 0{\cdot}5$$
$$= 76{\cdot}75 \text{ V}$$

If we consider single-battery float operation, with a floating voltage not less than 2·15 V per cell, 40 cells would give a nominal floating voltage of 86 V, which is rather high, particularly as the automatic voltage regulation may be 1 per cent or 2 per cent high. By using 39 cells the nominal floating voltage would be reduced to 83·8 V, but the battery could only be discharged to 1·97 V per cell which is not practicable.

In divided-battery float operation, at 2·06 V per cell when floating, the nominal floating voltage with 40 cells would be 82·4 V and the cells could be discharged to 1·92 V per cell. With 41 cells the nominal floating voltage would be 84·5 V and the cells could be discharged to 1·87 V per cell.

It is seen that divided-battery float operation meets the conditions, and the choice would probably fall on 40 cells, so that the teleprinter motors would be operated well within their voltage limits.

Cable Sizes. The following are the calculations for the principal cables.

D.c. Cabling. The d.c. cabling should be calculated on the basis of the allowable voltage drop and then checked for current rating. The resistivity (ρ) of copper may be taken as about 1·75 microhms per cm cube.

(*a*) *Distribution Cables.* Consider first the case of the distribution leads, each 200 ft long which are to carry 48 A with 1·0 V drop. (We will assume, that in view of the length, separate motor and signalling cables will not be provided.)

$$\text{R} = \frac{\rho l}{A} \qquad \therefore A = \frac{\rho l}{R}$$

As cable cross-sectional areas are tabled in square inch units, we convert ρ into inch units thus—

$$\rho = \frac{1{\cdot}75}{2{\cdot}54^2} = 0{\cdot}27 \text{ microhms per in. cube.}$$

$$\text{then } A = \frac{0{\cdot}27 \times 10^{-6} \times 200 \times 12}{\frac{1}{48}}$$
$$= 0{\cdot}0311 \text{ sq in.}$$

The standard cable size 19/0·044 (i.e. 19 wires, each of 0·044 in. diameter) having a cross-sectional area 0·03 sq in. would be used, which has a d.c. rating of about 65 A.

For the earth conductor the area should be about half that of the positive and negative conductors. A suitable choice would be 7/0·052, i.e. 0·0145 sq in. cable, having a d.c. rating of about 45 A. This would not be damaged if one of the 80 V supplies were short-circuited.

(*b*) *Battery Cables.* Consider now the battery cables. The allowable voltage drop per cable is 0·25 V and as two batteries of like polarity will be discharged in parallel, the maximum current per cable will be 24 A. Each cable is 50 ft long and each employs the same size of cable.

$$\text{Thus } A = \frac{0{\cdot}27 \times 10^{-6} \times 50 \times 12}{\frac{0.25}{24}} = 0{\cdot}015 \text{ sq in.}$$

If we choose the next lower standard size, i.e. 7/0·052, i.e. 0·0145 sq in., its current rating of 45 A would limit the choice of battery fuse to the standard 40 A rating. In the ultimate, when the load is 48 A, it would be desirable to have a heavier fuse, so that there would be no risk of premature fusing before the second battery could be paralleled, following the opening of the generator circuit-breaker. It would be better, therefore, to choose 7/0·064, i.e. 0·0225 sq in. which has a current rating of 56 A and would allow the use of a 50 A fuse.

(*c*) *Generator Cables.* The length of the generator cables depends upon the plant layout adopted by the designer. Assume each lead to be 20 ft long.

The maximum current is 48 A plus the field current, say 50 A total.

The permitted voltage drop is 0·5 V.

$$\text{Then } A = \frac{0{\cdot}27 \times 10^{-6} \times 20 \times 12}{\frac{0{\cdot}5}{50}}$$
$$= 0{\cdot}0065 \text{ sq in.}$$

The nearest cable 7/0·036, i.e. 0·007 sq in., has a d.c. rating of only 29 A, and it is clear that in this case, on account of the short length of lead, the cable size must be based upon the current rating. The choice will be 7/0·064, i.e. 0·0225 sq in., which has a d.c. current rating of 56 A. Both cables are of the same size.

A.c. Cabling. The full load current of the motor

will be known from the manufacturing data or from the motor rating plate. It can however be estimated as follows—

Total approximate output of motor-generator $= 2 \times 48 \times 82{\cdot}5$ W.

Overall efficiency = say 72 per cent.

$$\therefore \text{Input power} = \frac{2 \times 48 \times 82{\cdot}5}{0{\cdot}72} \text{ W}$$

Power Factor, $\cos\phi$ = say 0·85.

A.c. Input Voltage = 400 V.

Now, 3 phase power $= \sqrt{3}$. V.I. $\cos\phi$.

$$\therefore \sqrt{3} \times 400 \times I \times 0{\cdot}85 = \frac{2 \times 48 \times 82{\cdot}5}{0{\cdot}72}$$

$$\therefore I = 18{\cdot}7 \text{ A.}$$

The appropriate cable size is 7/0·036, i.e. 0·0070 sq in., rating 23 A for up to four cables run in one conduit. However, to avoid unnecessary interruptions of supply, it is desired to set the motor over-current release at 50 per cent over-load. The a.c. distribution fuse should therefore, for preference, be increased to 30 A and the cable to 7/0·044, i.e. 0·01 sq in., rating 30 A.

Ampere-hour Capacity of Batteries. We may assume that at any time (considering either the positive or negative 80 V supply) one battery will be fully charged and the other discharged by 10 per cent due to losses on floating duty. Thus the available capacity will be 1·9 times the capacity of each battery.

The two batteries combined are to supply 48 A for six hours. Therefore, a first approximation to the capacity of each battery is $\frac{6 \times 48}{1{\cdot}9} = 152$ A-hr.

To find the rated capacity of cell to give this actual performance we must take account of the following facts—

1. The cells are normally rated on a 9- or 10-hr discharge rate.

2. At the higher discharge rate proposed, the efficiency of the cells will be less.

3. The design of the plant limits the terminal voltage of the battery to 1·92 V per cell whereas the normal rating is based on discharge to about 1·83 V per cell.

The method of calculation is as follows—

Reference is made to a set of discharge curves appropriate to batteries of the type and size in which the design is likely to result, as found from the first approximation shown above. Fig. 14.37 shows a typical set of discharge curves from which it can be estimated that a terminal voltage of 1·92 V after six hours is obtained at a discharge rate of about 7½-hr. From Fig. 14.38 it can be seen that at a temperature of 60°F a battery discharged at the 7½-hr rate has about 96 per cent of the efficiency it would have when discharged at the 9-hr rate, on which its rated capacity down to 1·83 V is based.

Taking these two corrections together, as well as the factor $\frac{2}{1{\cdot}9}$ allowing for the 10 per cent loss of capacity on floating duty, we have—

Current required = 24 A.

Discharge rate necessary to give 1·92 V at 6-hr = 7·5-hr rate.

Correction for cell efficiency at 7·5-hr rate, relative to that at 9-hr rate $= \frac{100}{96}$.

Correction to allow for 10 per cent loss of capacity of the floating battery $= \frac{2}{1{\cdot}9}$.

Cell capacity, in terms of its 9-hr rating to a terminal voltage of 1·83 V per cell

$$= 24 \times 7{\cdot}5 \times \frac{100}{96} \times \frac{2}{1{\cdot}9} = 198 \text{ A-hr.}$$

Thus, in B.P.O. practice the choice would be the 200 A-hr open-type glass-boxed cell.

Rating of Protective Devices. The following would be appropriate fuse ratings and over-current settings.

Fuse or Protective Device	Current Rating of Cables Protected (Amps.)	Maximum Normal Current (Amps.)	Fuse Rating or Over-current Setting (Amps.)
± 80V Distribution Fuse	65	48	50
Battery Fuse	56	24	50
Generator Circuit-Breaker	56	48	60 in < 20 sec 96 in < 3 sec
Motor Over-Current Release	—	18·7 (running) 28 (starting)	28 in 20–40 sec
A.C. Distribution Box Fuses	30	18·7 (running) 28 (starting)	30

Power Alarms

It is difficult to devise a foolproof alarm system which is suitable for all types of power plant. The power alarms have to be combined with those for apparatus and instrument rooms to give a comprehensive system of station alarms. To make station alarm systems uniform is difficult, in view of the numerous combinations of equipments that are possible. The following indicate the usual facilities provided—

Power Failure. In motor-generator installations

an alarm is initiated by release of a generator circuit-breaker on reverse-current (usually due to mains failure) or on over-load. In rectifier installations a special a.c. failure relay (or relays) is provided, to indicate failure of any phase of the a.c. supply. Where d.c. circuit-breakers are provided over-load release will also be indicated. A green "power failure" alarm pilot lamp lights on each switchboard, or cubicle, affected and a prominent blue "power room failure" lamp and an urgent bell are operated in the power room. An urgent bell and a blue power room lamp are also operated in the apparatus room, and sometimes, in the case of the $\pm$ 80 V supply only, a lamp is lighted in the instrument room. The latter is merely a preliminary warning to instrument room supervisors of the possible impending need for economy in the use of teleprinters.

A "receiving attention" key on the $\pm$ 80 V switchboard may be operated to cause the bells to be silenced; the alarm lamps remain alight and a white "receiving attention" lamp also lights. When the power is restored a white "power restored" lamp is lighted in the power room and a non-urgent bell is rung.

Fuse Alarms. Battery fuses are not alarmed but all other important fuses are. A red "fuse alarm" pilot lamp is lighted on the switchboard or cubicle affected, and the blue "power room failure" lamp and urgent bell are operated in the power room and apparatus room. In this case the bells can be silenced only by replacing the fuse.

Transfer of Alarm. By the operation of another key on the $\pm$ 80 V switchboard the bell alarms can be transferred from the power room to the instrument room at night, a white pilot lamp indicating that this has been done. The same key allows the instrument room power failure alarm to be cut off, again with a white pilot lamp indication.

Indication of Apparatus Room Alarms. Alarms originating in the apparatus room light a red "apparatus room" lamp in the power room and ring the urgent or non-urgent bell as appropriate. These alarms include the M.C.V.F. speaker call-alarm.

At large telegraph centres the station alarms consist of lanterns similar to those used in automatic telephone exchanges. The lanterns have distinguishing colours and markings so that an alarm can be quickly localized to a particular section of the station.

Typical Power Installations

In this section a brief description is given of some typical B.P.O. power plants and of power equipment for unit teleprinter installations.

1. Unit Teleprinter Installations (a.c. Mains). *Standard Installation.* In the great majority of installations an a.c. mains supply is available and a single bridge rectifier is now provided as standard to supply both the motor and the signalling power for one teleprinter. This is the rectifier No. 66 A

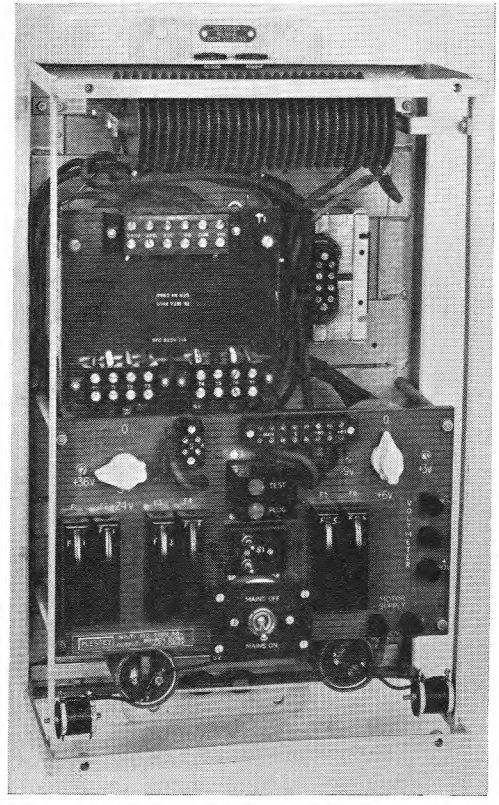


FIG. 14.41. BRITISH POST OFFICE RECTIFIER No. 66A (COVER REMOVED) FOR SUPPLYING 160 V MOTOR AND 80 + 80 V SIGNALLING POWER FOR A TELEPRINTER

(*By courtesy of H.M. Postmaster-General*)

(Figs. 14.41 and 14.42). The mains transformer $T1$ has primary taps for adjustment to the mains voltage and secondary taps for adjustment to the teleprinter motor load. The motor is supplied with unsmoothed rectified current at 160 V. A true centre point for the signalling supply, regardless of the setting of the transformer secondary tapping switches, is derived by the use of the auto-transformer $T2$. The signalling supply is smoothed by the double-wound choke L and the electrolytic capacitors C_1 and C_2. The bleeder resistors R_1 and R_2 prevent the voltage from rising too high on light

load. The rectifier bridge is composed of selenium elements.

Earlier Installations. A large number of installations exist in which separate rectifiers were provided for motor and signalling supplies namely—

1. A rectifier No. 43A or No. 22 (bridge type) for the unsmoothed motor supply at 110 V d.c. (for voltage regulation curves and simplified circuits see Fig. 14.10, and 14.3).
2. A rectifier No. 26B (voltage doubler type) for point, which is therefore derived from a potentiometer consisting of two 2,000 Ω resistors shunted by 10 μF paper capacitors. When a local supply is required a separate unit known as Auxiliary Apparatus Unit TG. 4505 is added. This provides an additional potentiometer, comprising two 4,000 Ω resistors shunted by a single 80 μF electrolytic capacitor, in which the centre point is left unearthed. The arrangement is shown in Fig. 14.43.

2. Unit Teleprinter Installations (d.c. Mains). In

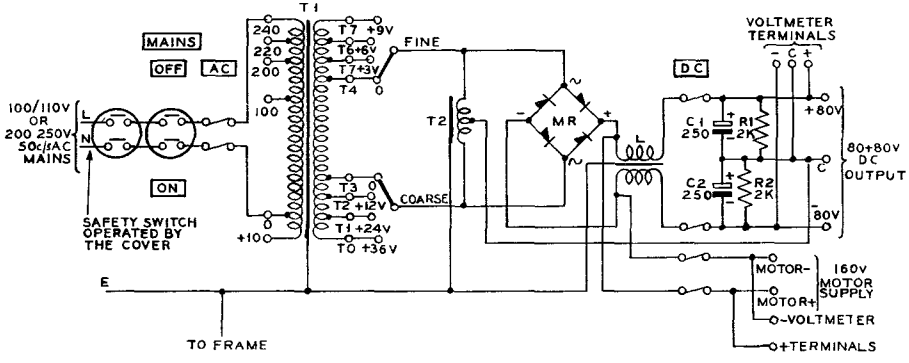


FIG. 14.42. SCHEMATIC CIRCUIT DIAGRAM OF BRITISH POST OFFICE RECTIFIER NO. 66A

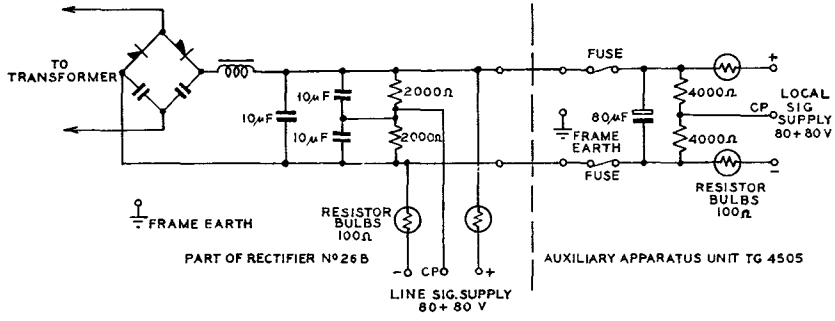


FIG. 14.43. USE OF A BRITISH POST OFFICE RECTIFIER 26B TO PROVIDE 80 + 80 V SIGNALLING SUPPLY

the ± 80 V signalling supply (for type of circuit see Fig. 14.43).

Local Signalling Supply. In addition to supplying signalling power for the transmitted signals, the rectifier is often required to provide a "local" signalling supply for either a local record of the transmitted signals or for a receiving relay. The design of the rectifier No. 66A ,and notably the inclusion of capacitors C_1 and C_2 of large capacitance (each 250 μF) allows line and local supplies to be provided, up to a total of 60 mA, without noticeable mutual interference. The positive and negative supplies remain balanced within about three volts. In the case of Rectifier No. 26B the rectifier proper does not provide a signalling centre offices in which the mains supply is d.c., the teleprinter motor is supplied direct from the mains.

The signalling supply for one teleprinter is obtained from a small double-wound dynamotor (known as Rotary Converter No. 4) which provides a 160 V d.c. output. The dynamotor is flexibly mounted inside a metal case and makes very little noise. A centre-tapped potentiometer unit (Auxiliary Apparatus Unit TG. 1,020) is provided to derive the positive and negative line signalling supplies from the converter 160 V output. The potentiometer consists of two 2,000 Ω resistors, each shunted by a 10 μF capacitor together with fuses and resistor bulbs (see Fig. 14.44). When a local supply is required, this may be derived from

the d.c. mains by providing a suitable potential divider. As the local supply need not have an earthed centre point, the earth to be found on one side of the d.c. mains supply is no disadvantage.

It should be noted that in no circumstances may the d.c. mains be used in the direct provision of line signalling supplies because of the risk to life.

satisfactorily supplied by one rectifier. Rectifier No. 55A is often used in renter's installations having more than ten teleprinters, but the load is then sectionalized and the rectifier outputs are not paralleled. Smoothing and de-coupling is provided by electrolytic capacitors totalling 1,750 microfarads on each side of the supply.

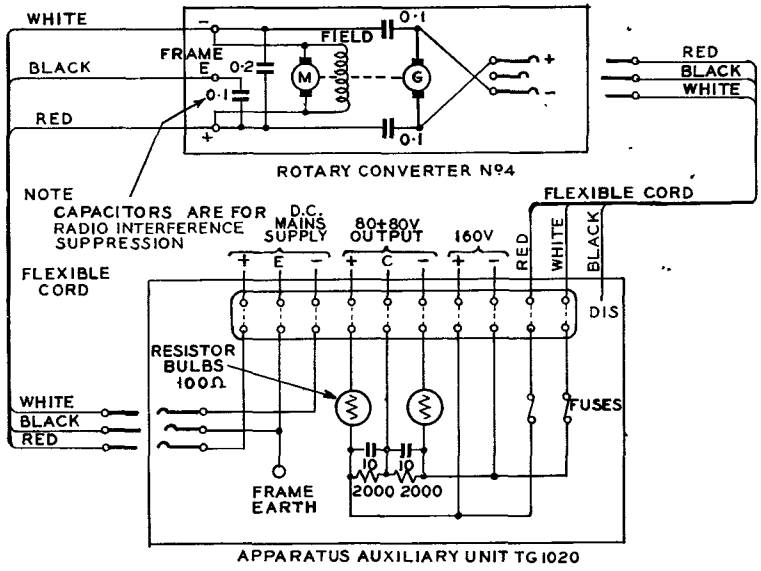


FIG. 14.44. USE OF BRITISH POST OFFICE ROTARY CONVERTER NO. 4 TO PROVIDE 80 + 80 V SIGNALLING SUPPLY

3. ± 80 Volt Power Plants. The following indicates the range of units and plant available in B.P.O. practice. The description is confined to a.c. plants. When the mains supply is d.c. it is necessary to provide motor-generators, with or without floating batteries, or batteries worked on a charge-discharge basis.

(*a*) *Rectifier No. 60A.* The rectifier is similar in design to Rectifier No. 66A except that the whole of its output is smoothed. It is suitable for supplying up to 20 signalling circuits, operating either independently or in a broadcast. The positive and negative supplies remain balanced within five or six volts.

The two capacitors (on the positive and negative supplies) each total 1,000 microfarads. This value is decided by the de-coupling of the individual loads, to prevent mutual interference, and is more than enough to smooth the rectifier ripple to an acceptable degree.

(*b*) *Rectifier No. 55A.* This rectifier is a floor mounting Westat-type of 3·75 A output at ± 80 V, intended to supply both teleprinter motors and signalling circuits. Ten teleprinters can usually be

(*c*) *Small Floating Battery Plants.* The smallest floating battery plant, output 6·75 A, consist of—

1 Rectifier No. 56A
1 Rectifier No. 57A
1 Power Board, either single or divided-battery float.
80 or 160 cells (usually Enclosed, Secondary Cells No. 3, 50 A-hr) for S.B.F. and D.B.F. respectively.

Rectifier No. 56A is a floor mounting Westat type rectifier of 6·75 A rating at 86 + 86 V, this being the adjustment suitable for a single-battery float installation having 40 cells in each supply. The rectifier can be readily adjusted to 82·5 to 84 volts for divided-battery float operation. This is the main floating rectifier and is normally continuously on load. A typical voltage regulation curve for a Rectifier No. 56A is shown on Fig. 14.12.

Rectifier No. 57A comprises two single-phase, full-wave rectifiers in one case. Each rectifier is independently adjustable, using rotary tapping switches and a variable resistor, to give any output from 3 A, 80 V, to 15 A, 110 V, there being no automatic voltage control. The Rectifier No. 57A is a

standby rectifier in case of failure of the Westat rectifier. It is also used for restoring the battery charge after a mains failure, and for charging the idle battery in divided-battery float installations.

Fig. 14.13 shows a Rectifier No. 56A (left) and a Rectifier No. 57A with their front covers off. The associated divided-battery float power switchboard is the right hand section in Fig. 14.29. A plant of twice the output (13·5 A) is obtained by duplicating the Rectifier No. 56A only. The two Rectifiers No. 56A are paralleled on their d.c. output and adjusted to share the load satisfactorily with varying load and input voltage.

(*d*) *Larger Floating Battery Plants.* When a larger output than 13·5 A is required a motor-generator plant is provided. The two standard sizes which are extensively used are 2 + 2 kW (24 A) and 4 + 4 kW (48 A). Beyond this output the generator size is increased in multiples of 2 kW, i.e. 6 + 6 kW, etc.

A complete standard plant comprises—

2 similar motor-generators and manual starters.

1 power switchboard, either single or divided-battery float.

80 or 160 cells for S.B.F. and D.B.F. respectively, of capacity to suit the particular requirements.

The divided-battery float plant is most commonly used for public service installations in which a large battery reserve is required. The single-battery float plants are most frequently installed for renters' installations, sometimes with as little as two hours battery reserve.

Fig. 14.19 shows the motor-generators of a 24 A single-battery float plant whilst Figs. 14.28 and 14.30 show the power switchboard of the same plant.

Plants for partially attended operation and incorporating various automatic features have been used in certain special applications. Fig. 14.23 shows a small plant of this type. In all these plants each motor-generator supplies the whole load during alternate weeks. The second machine provides a complete reserve; it is also used to recharge the idle battery in divided-battery float installations and may be paralleled with the normally running generator to restore the battery charge quickly after an emergency discharge.

4. L.T./H.T. Power Plants. (*a*) *Rectifier No. 58A.* This rectifier consists of a large cubicle containing main (floating) and standby rectifiers for both L.T. and H.T. supplies. It also includes the smoothing filters and all meters and switches necessary for operating a single-battery float system, for which it was primarily designed. By the addition of a simple switchboard the rectifier plants may be used for divided-battery float operation.

The rating of the rectifiers is as follows—

L.T. main (Westat type) 20 A, 28 V.

L.T. standby (manually regulated) range 5 A, 26 V to 30 A, 30 V.

H.T. main (Westat type), 2 A, 153 V.

H.T. standby (manually regulated) range 0·5 A, 142 V, to 3 A, 163 V.

For single-battery float operation, the L.T. battery consists of 13 cells and the H.T. battery of 71 cells; for divided-battery float operation the duplicate batteries contain as before, 13 and 71 cells.

Whereas an 80 + 80 V supply can be allowed to vary over quite wide limits, e.g. from 75 to 85 V, the L.T. and H.T. supplies have to be stabilized within fairly close limits if the M.C.V.F. telegraph equipment is not to introduce an undesirable degree of signal distortion.

Considering the single-battery float case, the bus-bar voltage at the power switchboard varies exceptionally over the approximate range 23·5 to 30 V (L.T.) and 138 to 163 V (H.T.) The supply voltages at the M.C.V.F. equipments are required to be about 21·5 V (L.T.) and 130 V (H.T.), preferably within the limits of ± 1 per cent in both cases. This is achieved by introducing a series (load) carbon pile automatic regulator (or regulators in the case of larger plants) in the distribution leads. The regulators are usually associated with the M.C.V.F. telegraph equipment, and are mounted on the rack verticals at the end of the suites of racks, in association with a sub-distribution fuse panel. Regulators will supply five to ten M.C.V.F. systems according to the type of regulator.

Fig. 14.45 shows an L.T. load carbon pile regulator. Taking the L.T. case as an example, and neglecting the voltage drop in the leads, the carbon pile must be able to drop not less than 30–21·5 V at minimum current and maximum input voltage, and not more than 23·5–21·5 V at maximum current and minimum input voltage. Links are provided to short-circuit the pile, if necessary, at the end of an emergency discharge of the battery. The carbon piles are connected in the unearthed distribution lead in both L.T. and H.T. supplies. The drop in the carbon pile represents quite an appreciable loss of efficiency.

Thus the Westat rectifiers have full load efficiencies of about 66 per cent (L.T.) and 62 per cent (H.T.), but the overall efficiency when allowing for the distribution leads and, principally, the load carbon pile regulators is approximately as follows—

$$\text{L.T. Efficiency (overall) } 66 \times \frac{21{\cdot}5}{30} = 47 \text{ per cent}$$

$$\text{H.T. Efficiency (overall) } 62 \times \frac{130}{153} = 53 \text{ per cent}$$

Fig. 14.46 shows schematically the connexion of carbon pile automatic voltage regulators in a typical L.T./H.T. floating battery installation.

(*b*) *Larger Rectifier Plants.* (1) Fig. 14.30 shows a suite of five cubicles comprising—

Duplicate 28 V, 100 A L.T. cubicles.

Duplicate 153 V, 10 A H.T. cubicles

and a distribution cubicle containing common L.T. and H.T. smoothing filters with a distribution fuse panel mounted above it.

This plant was designed for single-battery float operation with a 13 cell L.T. battery and a 71 cell H.T. battery. It can be adapted to divided-battery float operation by the addition of a switchboard. The rated output of the plant is 100 A L.T., 10 A H.T., one cubicle of each type being always in reserve. A third cubicle of each type may be added and the load may then be increased to 150 A L.T. and 15 A H.T. The battery voltages are the same as when using rectifier No. 58A, and series automatic voltage regulators are again employed.

Fig. 14.14 shows a close view of an L.T. cubicle; the moving-coil induction regulator and a.c. astatic relay can be seen in the lower half and some of the rectifier elements (enclosed in cooling funnels) in the upper half.

(2) Figs. 14.16 and 14.17 show a suite of three rectifier cubicles forming a semi-automatic L.T./H.T. plant.

The two outer cubicles are an L.T. and an H.T. automatic cubicle, each containing—

Main rectifier unit.

Main tap-changing transformer with automatic voltage control.

Smoothing filter.

Alarm equipment, etc.

The central cubicle contains reserve L.T. and H.T. equipments each comprising—

Reserve rectifier unit.

Reserve tap-changing transformer with manual voltage control.

The reserve rectifiers are brought into use by changing over links in the main cubicles, the smoothing filters in the main cubicles being still in use.

This type of plant will re-connect automatically to battery at the conclusion of a mains failure.

Plant of this type has been installed having the following ratings, the largest occupying four cubicles instead of three.

L.T.	H.T.
60 A	7·5 A
110 A	15 A
150 A	20 A
250 A	25 A

(3) A new type of divided-battery float rectifier plant is being introduced employing moving coil regulators. Either two or three L.T. cubicles and either two or three H.T. cubicles may be used. The automatic voltage regulating relays will be of the d.c. astatic type and one relay will control two rectifiers in parallel.

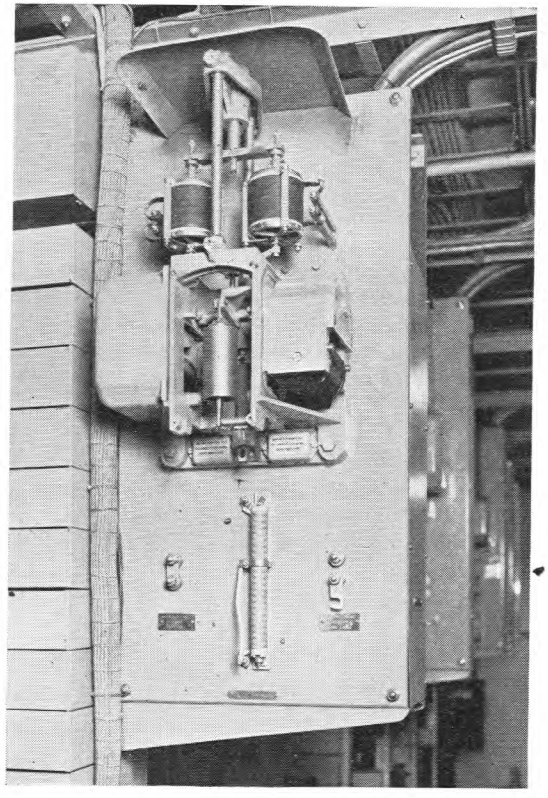


FIG. 14.45. L.T. CARBON PILE AUTOMATIC VOLTAGE REGULATOR

(*By courtesy of H.M. Postmaster-General*)

(*c*) *Motor-generator Plants.* Motor-generators have been used for a number of large plants and for smaller plants in buildings having d.c. mains supplies. Two types have been employed—

(1) A straightforward divided-battery float plant with duplicate motor-generators and batteries, the L.T. batteries having 12 cells and the H.T. batteries 63 cells. The two batteries together have sufficient capacity to maintain the load for 24 hours.

The normal floating voltages are about 25 V L.T. and 131 V H.T. The L.T. supply to the equipment is 21·5 V, using a series carbon pile regulator, the terminal voltage of the floating battery after discharge being about 22 V. The H.T. supply does not

use a carbon pile regulator and the equipment voltage at the end of a battery discharge falls to about 120 V although it remains at about 126 V for a large part of the 24 hour period. This is not an ideal arrangement and it is current practice always to use an automatic voltage regulator in the H.T. supply.

(2) In another type of motor-generator plant a single-battery float scheme is used in which the L.T. battery of 10 cells is continuously floated at about 21·75 V and the H.T. battery of 60 cells is continuously floated at about 130 V. No carbon pile automatic voltage regulators are therefore required in the distribution busbars. The L.T. and H.T. batteries are only required to carry the load for a few seconds and the actual reserve is in the ± 80 V batteries. The main L.T./H.T. generator runs continuously, excepting during mains failure or when it has to receive maintenance attention. The reserve L.T./H.T. motor-generator is driven from the 80 + 80 V batteries by a 150/170 V d.c. motor, which is started automatically whenever an L.T. or H.T. circuit breaker (or both) opens in the main generator output. The two positive and negative 80 V batteries are paralleled before the d.c. motor is started. When the reserve L.T./H.T. motor-generator has run up to normal speed its generators are automatically connected to the batteries.

If the failure is not a mains failure and only the L.T. or the H.T. main circuit-breaker has opened, then only the appropriate reserve generator is connected to the battery. In the brief period of about seven seconds before the reserve generators connect to the batteries the latter discharge at a high rate as only small cells are provided. A heavy charging current therefore flows when the reserve generator is connected and the circuit-breakers need efficient delay mechanisms to prevent their release on over-load; the surge of charging current quickly subsides. The only disadvantage of this plant is the lack of a duplicate mains driven motor-generator when the main set requires an extensive overhaul.

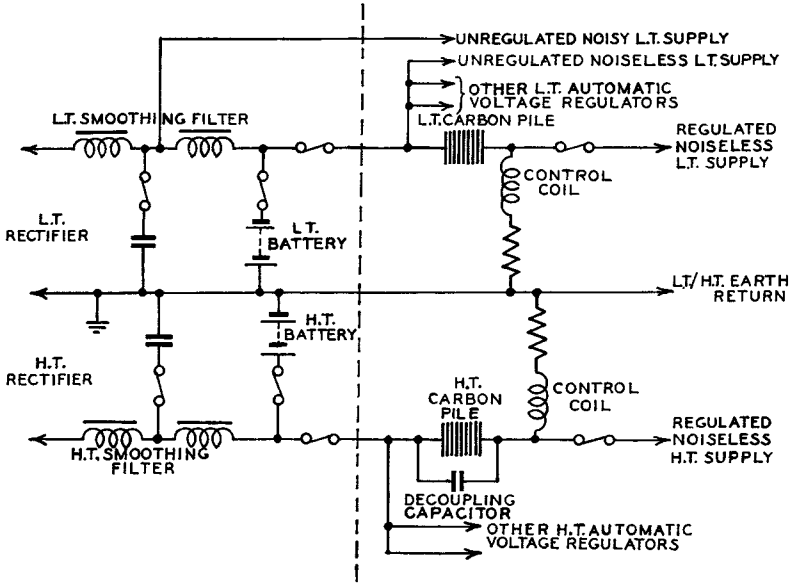


FIG. 14.46. SCHEMATIC DIAGRAM SHOWING CONNEXION OF CARBON PILE AUTOMATIC VOLTAGE REGULATORS IN A TYPICAL L.T./H.T. FLOATING BATTERY INSTALLATION

5. 24-volt Phonogram Power Plants. Single-battery float rectifier power plants employing 12 cell batteries are provided for phonogram supplies at small offices. The floating voltage is actually about 26 V. For the smallest installations use may be made of Rectifiers No. 38 which are available in various ratings from 0·75 A to 6 A. For larger rectifier installations a Westat type rectifier of 23 A rating is used.

Motor-generators operating on a divided-battery float basis are used for the largest installations and when the mains supply is d.c.

6. 50-volt Power Plants. 50-volt power plants have not often had to be provided specifically for telegraphs in the past but are now coming into use.

Small floating battery plants may be provided by the use of Rectifiers No. 47, which are available in various ratings from 1 A to 20 A.

For the teleprinter automatic switching centres and for the larger new phonogram centres a divided-battery float rectifier plant has been developed incorporating moving coil induction regulators or other suitable regulators. A complete plant comprises—

Two similar rectifier cubicles.

A smoothing and switching cubicle.

Duplicate batteries of 25 cells each.

One rectifier is normally on floating duty and the second is in reserve. A single d.c. astatic voltage relay which will give automatic voltage control within $\pm$ 1 per cent may be switched to either voltage regulator; the voltage regulators may also be manually controlled by means of pushbuttons.

A transformer, separate from the voltage regulator, is provided to accommodate any three-phase power supply from 346 to 440 V and to allow of readjustment for ageing of the rectifier elements. The rectifier rating is chosen to suit the particular centre at which the plant is installed, whilst the plant operates within the overall voltage limits 46–52 V which are standard for telephone type automatic switching apparatus.

7. 6-volt Power Plants. *Small teleprinter switchboards.* The 6 V supply for the signalling lamps of small teleprinter switchboards is normally supplied by a transformer from the a.c. mains. If battery reserve is required, a trickle charged battery of three cells may be provided, to be brought into use during a mains failure by the operation of a switch at the teleprinter switchboard. Alternatively, the supply may be taken at all times from a small rectifier floating a battery of three cells.

Larger Teleprinter Switchboards. (*a*) In the case of larger teleprinter switchboards a simple form of single-battery float plant is used to supply six volt loads up to 60 A. The rectifiers are rated at 15 A and 30 A, two of the latter type being paralleled to supply a 60 A load. The battery consists of three enclosed cells, or sometimes of two or three groups of three cells of the largest enclosed type connected in parallel to avoid the use of larger open type cells. This is because the cells have often to be placed in a cupboard near the teleprinter switchboard apparatus rack, in order to reduce voltage drop in the cables to a minimum.

The rectifier has no automatic voltage control features, but between 20 per cent and 100 per cent of rated load, and with simultaneous mains voltage variations of $\pm$ 6 per cent, the output voltage remains between 6 and 7 V, the normal floating voltage being 6·5 to 6·6 V. The voltage of the battery on discharge may fall to about 5·4 V.

The switchboard lamps tolerate voltage variations between about five and seven volts quite satisfactorily. Even slightly lower voltages are workable but higher voltages are not recommendable due to the greatly reduced life of the lamps.

(*b*) For six volt loads above 60 A, the load is again supplied direct from a transformer and means are provided to generate a.c. power during a mains failure. A small motor-alternator of about 1 kVA rating, which takes its input supply from the $\pm$ 80 V batteries, starts automatically on the occurrence of a mains failure and is automatically connected to the transformers in place of the "dead" mains. The break in the supply has a duration of only two or three seconds. When the mains supply is restored the load is switched back to the mains with only a negligibly short break of supply and the motor-alternator stops.

8. A.C. Supplies. There are a number of cases in which an a.c supply has to be generated for either normal or standby use.

(*a*) *Four Circuit Outstation M.C.V.F. Telegraph Equipment* (*Type* 3). This equipment requires an a.c. supply of about 0·5 kVA. When only d.c. mains are available the practice is to provide duplicate motor-alternators. Motor-generators No. 9A, or similar machines, having a rated output of 1 kVA at 230 V 50 c/s are used for this purpose. The motor restarts automatically at the end of a mains failure. The output voltage and frequency are closely regulated.

In the case of Motor-generators No. 9A barretters are used in the motor and alternator field circuits to achieve this close regulation. (A barretter usually consists of a nickel-iron alloy filament enclosed in a glass bulb containing hydrogen or helium. The function of the barretter is to maintain a sensibly constant current in a circuit when a variable voltage is applied to it. The barretter runs normally at a voltage and temperature at which it has a high-temperature coefficient of resistance. As the voltage changes, the temperature and resistance change sufficiently to compensate approximately for the voltage change.)

(*b*) *Standby a.c. Supplies.* The use of a motor-alternator to provide a.c. standby for the six volt transformers of large teleprinter switchboards was described above. The same type of machine is used to provide standby a.c. for certain essential services at teleprinter automatic switching centres, notably for the valves used in the equipment which generates and distributes test and service signals.

(*c*) *Type* 4. *M.C.V.F. Telegraph Equipment.* This equipment is essentially a.c. mains operated,

except in the case of the ± 80 V supply. Where there is only a single six- or twelve-circuit system no special precautions are taken to safeguard the continuity of the a.c. supply; the usual facilities offered by transportable and mobile engine-alternators are considered adequate. In centres with two 12- or 18-circuit systems a motor-alternator of the type described in (*a*) or (*b*) above is provided, supplied from ± 80 V batteries. This safeguards the supply, but a short break of service of a few seconds duration occurs at the instant of mains failure.

At still larger centres absolute continuity of the a.c. supply, regulated in voltage within ± 1·5 per cent is ensured by the use of the following type of motor-alternator which is available with a range of ratings of 4, 10 and 15 kVA. The motor alternator runs continuously and the equipment supply is at all times taken from the alternator. The set consists of a three-phase a.c. induction motor, a 150/170 V d.c. motor to run from the ± 80 V batteries, a flywheel and a single-phase alternator with its exciter and automatic voltage regulating equipment. Normally the a.c. motor drives the other machines and the flywheel, the d.c. motor idling. On failure of the a.c. mains the flywheel maintains the drive until battery power is automatically connected to the d.c. motor whereupon it drives the load, the a.c. motor then idling. The speed of the d.c. motor is automatically regulated to counteract the effect of the falling battery voltage.

When a satisfactory a.c. mains supply is restored the a.c. motor automatically resumes driving the set and the battery is disconnected from the d.c. motor. The automatic operations are controlled by contact voltmeters and frequency meters.

A reserve machine is available, and when changing over from one to the other the alternators are semi-automatically synchronized before transferring the load. At very large stations the load is sectionalized between two or more machines but only one standby machine is provided.

CHAPTER 15

THE PUBLIC TELEGRAPH SERVICE

It is desirable that the telegraph engineer should understand not only the functioning and technical details of telegraph apparatus but also the ways in which the various types of equipment are used to give service. In this chapter therefore a description is given of the purpose and composition of a Public Telegraph Service and the methods of working used. Particular reference is made to the organization and methods employed in the United Kingdom, and details of instrument room design and practice.

Function of the Public Telegraph Service. The function of the public telegraph service is to receive messages from the public and to deliver them to addressees quickly, reliably and free from error. For this purpose means must be available for the receipt, transmission and delivery of telegrams and the arrangements for receipt must be widely dispersed and well-known to the public.

Acceptance of Telegrams. In the United Kingdom there are upwards of 12,000 telegraph offices serving approximately 50 million people; almost all of the offices accept telegrams over their counters. Even so there is not always a telegraph office near to the would-be sender of a telegram and there are few telegraph offices which are open at all times of the day. To deal with this situation telegrams are accepted by telephone ("Phonograms") and anyone can send a telegram from any telephone, public or private, simply asking for "Telegrams," or dialling an appropriate code, and then dictating the message to the office thus reached. There are several hundred offices, known as "Appointed Offices," where telegrams are written down from telephone dictation but only a few are open at night. In many cases it is therefore necessary to connect a caller to an office known as a "Night Appointed Office," far distant from his telephone. Telegrams received by telephone are charged for as if they had been handed in at a public office, but where the call is from a private telephone a local call fee is added.

Equipment for Receiving Telegrams by Telephone

The amount of phonogram traffic handled varies widely as between one appointed office and another and equipment has been designed to meet the consequent differing needs. In all cases the equipment is used for handling telephone-telegram traffic to and from neighbouring offices, in addition to phonograms for forwarding and delivery. Depending upon the volume of traffic, the transmission of telephone-telegram traffic (i.e. T.T. traffic) from one office to another is effected either by means of calls made over the telephone exchange system or via a direct telephone circuit between the offices concerned.

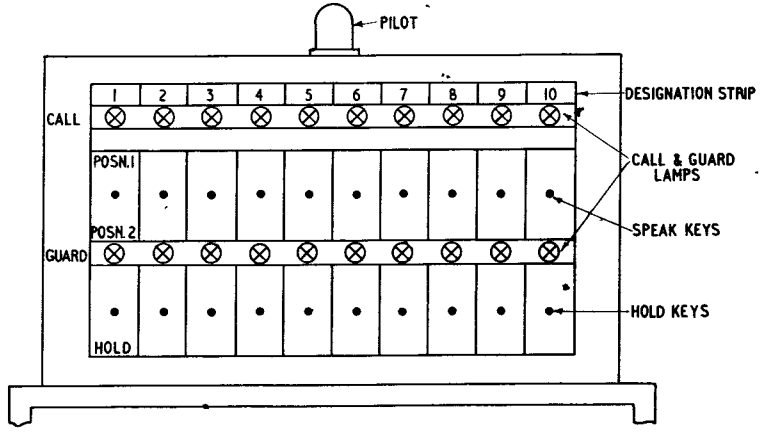


Fig. 15.1. Cordless Panel Phonogram Equipment

Cordless Panel Equipment. The simplest type of equipment caters for offices having not more than ten phonogram circuits, nor normally more than four operating positions. The equipment consists of a lamp and key panel provided on a basis of one for two operators. A sketch of the equipment is shown in Fig. 15.1.

The arrival of a call lights a calling lamp on each panel and to accept the call an operator throws the associated connecting key, down if she is to the right of the panel and up if she is to the left. This connects the call to her head and breast set telephone, extinguishes the calling lamps and at the same time lights the guard lamps associated with the circuit on all panels. At the conclusion of the dictation of the telegram, the restoration of the operator's connecting key releases the circuit and extinguishes the guard lamp. The keys can also be used for originating calls. One "Hold" key per circuit is also fitted.

Separate Panel Equipment. Separate panel equipment provides for offices requiring more facilities than are given by the cordless panel equipment. It is normally provided where more than four and not more than ten positions are needed but there are a number of four-position suites in existence which were installed before the cordless panel equipment was produced.

One equipment panel is provided for each pair of operators and a complete two-position section

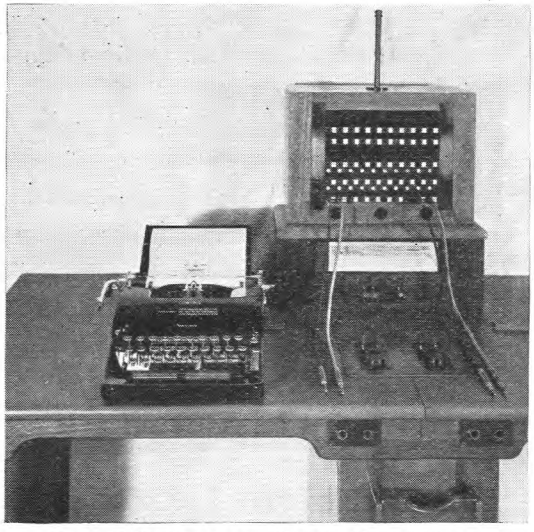


FIG. 15.2. SEPARATE PANEL PHONOGRAM EQUIPMENT

(By courtesy of H.M. Postmaster-General)

occupies 5 ft 7½ in. of table space, each additional pair of positions en suite requires only a further 5 ft of tabling. A complete appearance of all circuits is provided on each panel which normally has a maximum capacity of 80 circuits. Lamp calling is provided on incoming circuits and the incoming ends of both-way circuits. Delayed answer flash can be provided if necessary. Indication of engagement of a circuit in the multiple is given by the normal click test as in telephone exchange practice. Facilities for speaking, ringing and dialling are provided by the use of a two-way key and a double-ended cord, whilst a further cord provides holding facilities in conjunction with one side of another key. The second operated position of the latter key cuts out the operator's transmitter. Where an office is equipped for typewriter reception the transmitter cut-out is operated by a foot switch. The only other facilities of note are keys to enable the calling signals to be extinguished on all panels but one, to assist concentration working in slack periods, and a rheostat control is also provided to enable the operator to vary the volume of received speech to suit the characteristics of the particular connexion in use. Fig. 15.2 shows a view of a typical separate panel position with a foot operated transmitter cut-out but no dial.

Single- and Double-tier Equipment. Single-tier equipment is used for suites of 10–15 phonogram positions and double-tier equipment is used where 16 or more positions are needed. There is a considerable amount of this equipment in service but it is now regarded as obsolescent and will be replaced as opportunity offers by "Automatic Queuing Equipment." Fig 15.3 and Fig. 15.4 give views of a typical single-tier phonogram installation and a double-tier phonogram installation respectively.

The single-tier type of equipment provides, on a five panel two-position basis, a complete ancillary of calling signals and a complete multiple appearance of outgoing circuits; both-way circuits appearing in each. The calling signals are all provided with "delayed call flashing" to draw attention to any calls left unanswered beyond a predetermined period. The jack panels are raised six inches above the key shelf to facilitate the use of typewriters and, on end positions, the multiple is banked to save operators working at these positions from having to reach across their neighbours. A foot operated transmitter cut-out is provided and an amplifier controlled by two keys can be brought into circuit with the operator's head-set to give a gain of 5 or 10 db or insert a loss of 5 db. The operator can therefore adjust the volume of received speech to suit varying circuit characteristics and instrument room noise levels.

Two cord circuits are provided in each position and speaking, ringing, holding and, where necessary, dialling facilities are provided. In this type of switchboard the extension of calls to an inquiry position is possible and the cord circuits are therefore provided with supervisory lamps.

Where a phonogram switchboard of this type is located in a manual exchange area, but also originates calls to automatic exchanges, a "dial guard" is associated with the dial key. This lamp serves to remind the operator to restore the dial key when dialling has been completed.

Double-tier equipment differs from single-tier in that it has two sets of jack panels mounted one above the other. The panels are mounted over a double-sided table with the upper panel facing one way and the lower the other. Generally a slot running longitudinally down the middle of the tables beneath the jack panels provides access to a belt conveyor which carries message forms to a collection point at the end of the suite.



FIG. 15.3. A SINGLE TIER PHONOGRAM INSTALLATION
(By courtesy of H.M. Postmaster-General)

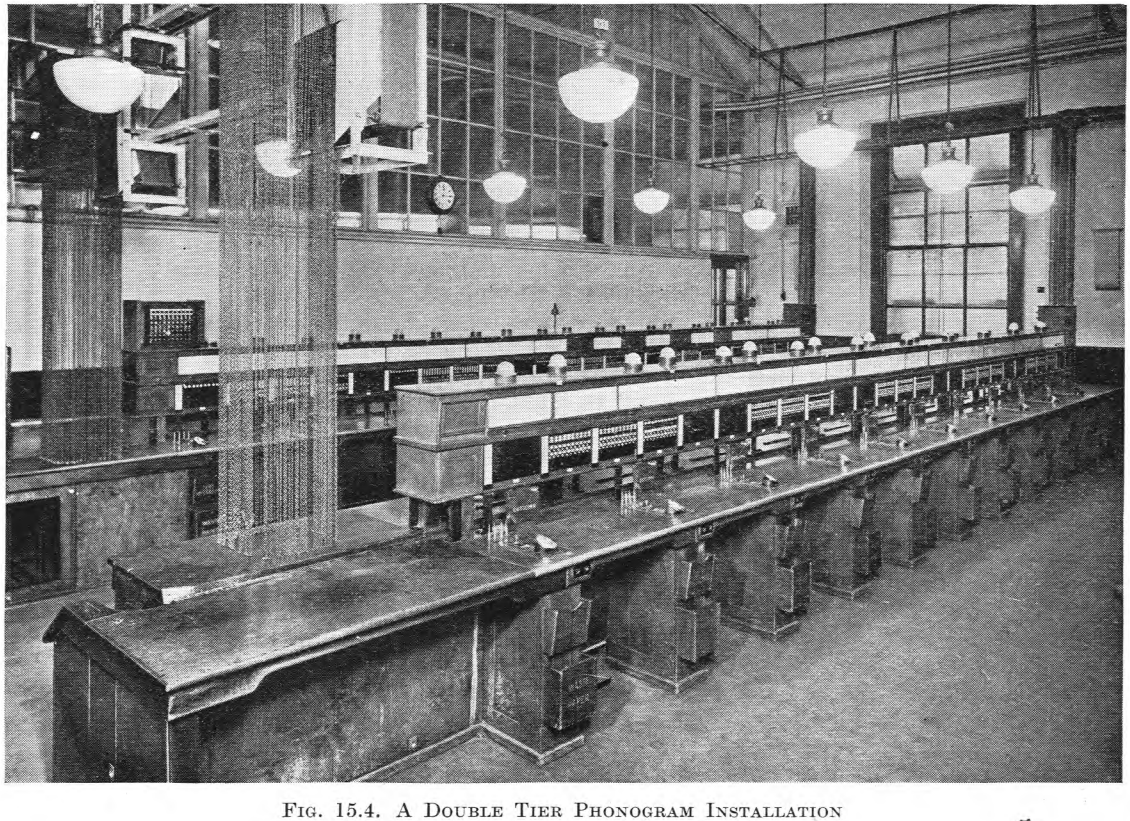


FIG. 15.4. A DOUBLE TIER PHONOGRAM INSTALLATION
(By courtesy of H.M. Postmaster-General)

Other facilities provided with this type of equipment in addition to those given by single tier equipment are—

(*a*) A translucent dome mounted on top of each position which is illuminated by a green lamp when the operator is free and a red lamp when a call is being handled.

(*b*) A message distribution panel, which can be seen on the top of the rear suite of positions in Fig. 15.4, consists of a number of keys, lamps,

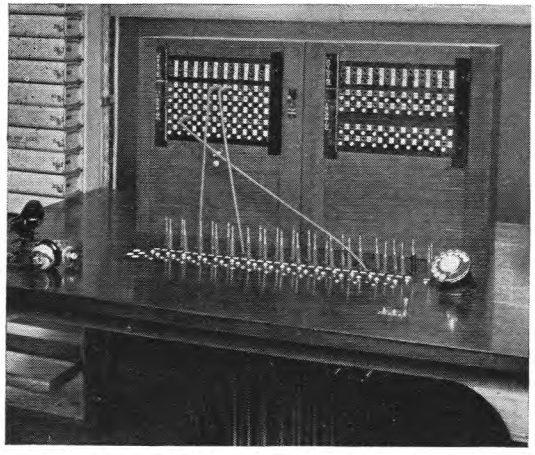


FIG. 15.5. A MANUAL PHONOGRAM CONCENTRATOR

(*By courtesy of H.M. Postmaster-General*)

and labels corresponding to the direct telephone-telegram circuits terminating on the suite, and a number of lamps and labels corresponding to the positions in the suite. If a particular telephone-telegram circuit is in use, the corresponding lamp on the panel glows. If the officer responsible for distributing outgoing traffic among the operators has a message which needs to be sent over an engaged circuit she presses the corresponding key. This lights a lamp on the panel, indicating at which position the circuit is in use, and a "circuit hold" lamp on that position which indicates to the operator that she should hold the circuit as another message is about to be handed to her for the office to which she is already connected. A reset key is provided to extinguish the "circuit hold" lamp.

(*c*) Free-line signals are provided on groups of ten or more outgoing or both-way circuits.

Manual Concentrator Working. This method of phonogram working has been used successfully in cases of emergency and, in certain circumstances, as a means of maintaining service during the period of changeover from a manual system to an automatic distribution system. The calling signals and answering jacks of the incoming circuits, together with the outgoing circuits, are accommodated on a panel, or panels, of a concentrator position.

The operators' positions, known as phonogram positions, are terminated on the concentrator by means of cords and plugs and a maximum of 30 phonogram positions may be provided. A "Clear" (white) and a "Guard" (red) lamp is associated with each phonogram position cord and plug. Facilities are also provided on the concentrator for the transfer of calls to the inquiry position or supervisor, also for the concentrator operator to originate or receive calls. An order-wire between the phonogram positions and the concentrator is also provided. A typical concentrator is shown in Fig. 15.5.

Each phonogram position is provided with a combined "Ring and Dial" key for originating outgoing calls, together with a combined "order-wire and clear" key and a "Guard" key. Green and red position lamps are fitted, also a transmitter cut-out foot-switch. A dial is provided if required.

On the receipt of an incoming call, the concentrator operator inserts the plug of a free phonogram position into the answering jack of the calling line. This causes the green lamp on the phonogram position to glow, thus indicating that a call is connected. On completion of the transaction and the subsequent clear-down by the calling subscriber, the green lamp on the phonogram position is extinguished and the white "clear" lamp on the concentrator position glows to inform the concentrator operator that the call may be cleared-down. The operator of the phonogram position operates the position guard key at the conclusion of the call and this lights the concentrator position guard lamp and phonogram position red lamp to indicate that she is unable to accept a further call at this stage. When the details on the message form have been filled in and the message disposed of for onward transmission, the phonogram operator releases the position guard key. The lamps cease to glow and a further call may be connected.

The order-wire key, which is non-locking, is operated when it is desired to open or close down a position for the receipt of traffic or to originate an outgoing call. Details are passed over the order-wire to the concentrator position operator. When a number of telegrams to different telephone subscribers has to be transmitted over the exchange network from a phonogram position, the clear key provides a facility whereby an established connexion, either via a manual exchange or an automatic exchange, may be cleared down and a further call made, without the assistance of the concentrator operator.

The main disadvantage with this system is that, except during very slack periods of traffic, a concentrator operator is required purely for the distribution of incoming and outgoing traffic. To alleviate this disadvantage, however, arrangements can be made for two or four of the phonogram positions to be equipped for separate panel working and for the incoming and outgoing lines to be transferred to these panels during quiet periods of traffic, e.g. at night-time or week-ends.

Automatic Distribution Equipment. In future it is expected that all phonogram suites requiring more than ten positions will be of the automatic distribution type. This type of equipment has been in use in a few large centres for some time and has given very satisfactory performance.

With this type of position, calls are received on automatic equipment which routes each call, as it arrives, to a disengaged operator. If no disengaged operator is available the call enters a queue and whilst the call is in the queue the caller receives ringing tone. Calls are released from the queue for connexion to operators in the order in which they arrive, and are distributed to operators' positions in cyclic order as they become disengaged. The capacity of the queue is varied automatically in accordance with the number of operators available and, if at any time the incidence of calls causes the capacity of the queue to be exceeded, the caller receives the engaged signal. The length of the queue is at all times so arranged that the engaged signal is not given unless the caller would have to wait two minutes before an operator would be likely to become available.

There is, of course, no multiple or answering field with this type of equipment and in addition to a typewriter the operator has only a dial, three keys and a few lamps No key is required to admit a call to an operator's position; a green lamp on her position lights when a call is routed to her. At the conclusion of a call she operates a non-locking release key to clear the position, in readiness for the receipt of another call. The remaining keys on her position are a two-position locking key (one position of the key giving access to the exchange network and the other to switches from which direct telephone-telegram circuits are available) and a two-position non-locking transfer key. The transfer key routes the call with which the operator is dealing, either to the inquiry suite or to the section supervisor, depending on the position to which the key is operated. A momentary operation effects the transfer, and the operator remains in circuit. The call cannot be cleared until it is released either by the officer to whom it has been transferred or by the calling subscriber. Pedestal mounted lamps indicate the condition on each position as follows—

A white lamp shows that the operator is disengaged and ready to receive traffic, a green lamp shows that the operator is engaged on an incoming call, and a red lamp shows that an outgoing call is being handled. A "queue full" lamp is also provided on each position so that each operator knows when heavy pressure is being experienced. A wall display intended mainly for the information of the supervising staff, shows the number of calls in the queue, in steps of five, and also when "queue full" conditions are reached.

The advantages of the automatic distribution equipment are

(*a*) Calls are answered in order of arrival.

(*b*) The speed of answer is independent of the alertness of the staff.

(*c*) There are no problems of operator "reach."

(*d*) There is no multiple panel immediately in front of the operator to block her view and the flat topped position makes the phonogram room more like an office.

(*e*) There is no problem of lamp signals being dimmed or apparently extinguished by strong daylight.

(*f*) Concentration during slack hours presents no problem, as calls are only routed to staffed positions.

(*g*) There are indications that the work output of the operator is increased, presumably because of the improved working conditions.

A detailed circuit description of the call queuing and automatic distribution equipment* is beyond the scope of this book but Fig. 15.6 shows in block schematic form the items of equipment providing the call queuing and automatic distribution facilities, as well as the complementary services for outgoing calls, transfer calls, etc. Fig. 15.7 shows a phonogram installation at Newcastle after modification for use with automatic distribution equipment and it is interesting to compare this with Fig. 15.4, the same office when previously equipped with double-tier phonogram switchboards.

Teleprinter Reception and Pneumatic Tubes. Special arrangements are made for the acceptance of telegrams from very large users of the service either by means of Printergram Service, teleprinter private wire, or pneumatic tube. The Printergram Service is for the use of teleprinter subscribers connected to the telex service to enable public telegrams to be sent and received. Each telex subscriber has a teleprinter, operated on a

* A full description of the Phonogram Automatic Distribution Equipment is given in an article by H. E. Wilcockson and H. Walker, *I.P.O.E.E. Journal*, Vol. 42, Parts 3 and 4.

d.c. signalling basis, connected to an exchange line which terminates at a teleprinter switching centre through which connexion can be obtained to other operated over the telephone exchange system and each telex subscriber rented a normal telephone exchange line with a telephone associated by means

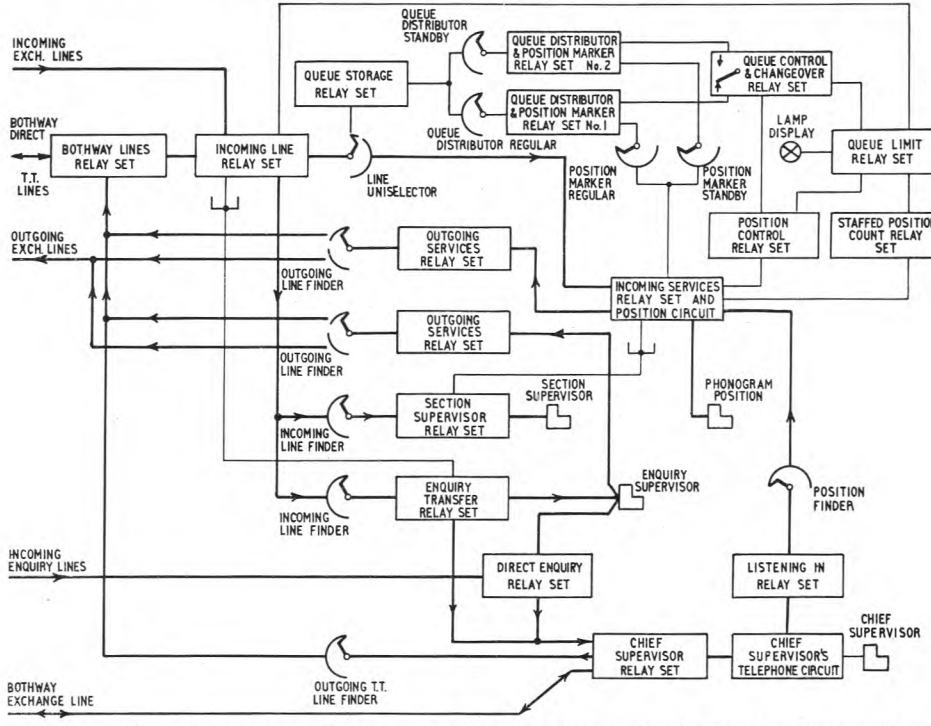


FIG. 15.6. BLOCK SCHEMATIC DIAGRAM OF CALL QUEUING AND AUTOMATIC DISTRIBUTION PHONOGRAM EQUIPMENT

telex subscribers and also to a special suite of teleprinter positions, i.e. Printergram positions, provided in the larger telegraph offices.

Until 1954 the telex service in the U.K. was of a changeover switch with a single-tone 1,500 c/s VF signalling converter and teleprinter. Telex calls were set up on a telephone basis and when the desired connexion was established the two connected parties operated their "telephone-teleprinter" switches to "Teleprinter" thereby enabling simplex teleprinter communication to take place. Operation of either teleprinter caused the 1,500 c/s tone to be keyed on-off by the teleprinter transmitter and the receiving VF converter amplified and rectified the received signals to operate the teleprinter. A local record of transmitted messages was also obtained by means of a leak circuit into the local VF converter. Thus for Printergram service over the telephone exchange network the telex subscriber would either ask the local exchange operator for "Printergrams," or dial a special code, depending whether his exchange line was connected to a manual or automatic telephone exchange.

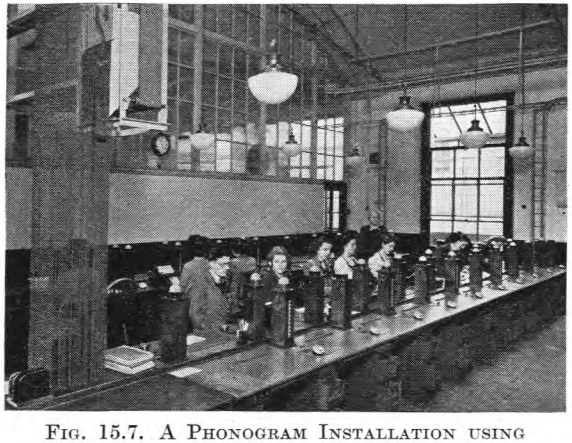


FIG. 15.7. A PHONOGRAM INSTALLATION USING AUTOMATIC CALL DISTRIBUTION EQUIPMENT
(By courtesy of H.M. Postmaster-General)

When the amount of telegram traffic between a public telegraph office and a user justifies a permanent connexion between the two offices then either a teleprinter private wire circuit or a

pneumatic tube is provided between the user and the telegraph office, depending upon the relative economics of these two methods for the volume of traffic concerned.

Transmission of Telegrams

A telegram after acceptance has to be forwarded to the office from which it is to be delivered, either by using telephones, teleprinters or both. A type of transmitting apparatus, using facsimile transmission technique, is also used to a limited extent.

Telephone Working. The annual cost of providing and maintaining a teleprinter is substantial and it takes several months of training to produce an efficient keyboard operator.

Offices which forward only a small number of telegrams per day obviously do not justify a costly instrument and expensively trained staff to dispose of traffic which occupies a matter of a few minutes in each hour. At offices of this type it is normal to forward and receive telegrams by telephone, and depending upon the volume of traffic, either the normal telephone exchange system is used to effect connexion to a neighbouring appointed office, or a direct telephone circuit (i.e. a direct telephone-telegram circuit) to that office is provided. The former method is termed "Exchange Telephone-Telegram traffic" and the latter "Direct Telephone-Telegram traffic."

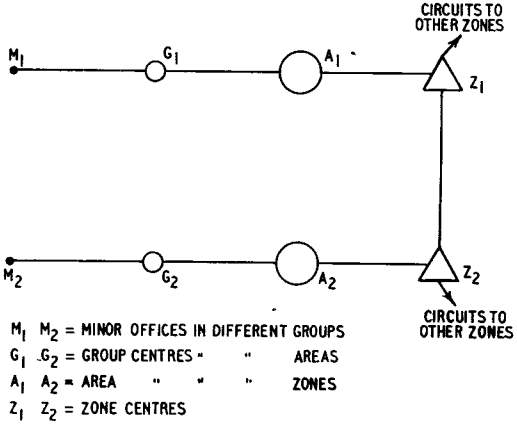


FIG. 15.8. A PUBLIC TELEGRAPH BASIC NETWORK OF POINT-TO-POINT TELEGRAPH CIRCUITS SHOWING PARTS OF TWO ZONES

Facsimile. It seems probable that in the future those offices which have enough traffic to need a direct circuit for telephoning telegrams will be provided with direct-recording facsimile equipment (see Chapter 13) so long as it is cheap and very reliable and preferably does not require the use of special and relatively expensive paper for reception. The use of this equipment should increase accuracy of transmission and reduce staff costs. Little operating skill is required and no attention to the machine is needed at either the sending or receiving office during the process of transmission. Errors arising from words either not heard or heard incorrectly, which occur with telephone transmission will, of course, be eliminated.

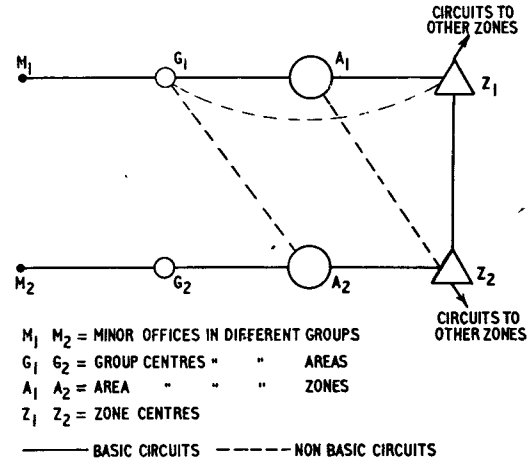


FIG. 15.9. PORTION OF A POINT-TO-POINT PUBLIC TELEGRAPH NETWORK SHOWING EFFECT OF INTRODUCING NON-BASIC CIRCUITS

Point-to-point Working. Until about 1950 the public telegraph system in the United Kingdom was divided into a number of "zones," each zone was divided into "areas" and each area into "groups." Within each group there was a number of minor telegraph offices. The basic network consisted of circuits inter-connecting all zone centres, connecting each zone centre to its dependent area centres, each area centre to its dependent group centres, and each group centre to its dependent minor offices. Fig. 15.8 shows a skeleton diagram of the principles of layout of the network.

A telegram handed in at one minor office for an address served by another similar office might then have been transmitted from the originating office and re-transmitted at two group centres, two area centres and two zone centres before reaching the delivery office. Fortunately telegrams suffering this kind of routing were rare, partly because much of the traffic was between large centres and partly because there were many so-called "non-basic" circuits provided where there was enough traffic to justify their use. Fig. 15.9 indicates a typical

lay-out showing how provision of non-basic circuits cuts down re-transmissions.

By the use of multi-circuit voice-frequency telegraph equipment the cost of provision of telegraph circuits was reduced very materially and at the same time circuits having improved transmission characteristics were provided. The utilization of switching systems for the interconnexion of

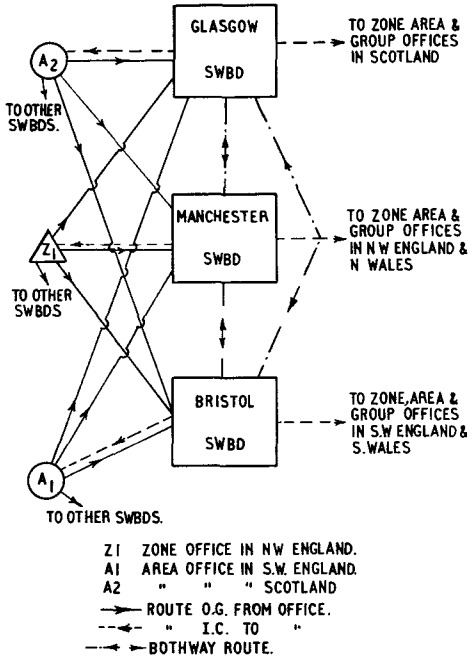


FIG. 15.10. LAYOUT OF PART OF TELEPRINTER MANUAL SWITCHING NETWORK SHOWING TYPICAL ZONE AND AREA OFFICE CONNEXIONS

telegraph circuits thus became economically and technically possible. The design and technical details of teleprinter manual switching systems are described in Chapter 8 and here it will suffice to consider the effect of such a system on the cost and quality of the service rendered to the public.

Manual Switching. It is, of course, out of the question to connect all telegraph offices to a switching network but the larger offices which handle the majority of the traffic are normally connected. As a result, traffic between these offices is transmitted once only and the time and labour which would otherwise be sent in circulating and re-sending the messages at one or more re-transmitting points is saved.

To speed up the process of transmission the zone and area centres, which handle the bulk of the traffic, are connected as shown in Fig. 15.10. As a result, a message received at one of these offices can be disposed of to any office on the switching network by a connexion set up via only one switchboard. Group centres and a few minor offices are normally connected as shown in Fig. 15.11. They have therefore to go through two switchboards to set up connexions, except for traffic being sent to another office connected to the same switchboard. The complete layout is a compromise between economy in circuits and economy in operating time.

To cut down the number of routings through two switchboards, circuits are provided direct from the outgoing multiple of the switchboards to large distant offices wherever this can be justified economically. The effect of this is shown in Fig. 15.12.

It will be appreciated that the manual switching scheme involves providing outgoing circuits from each zone and area centre to each of a number of

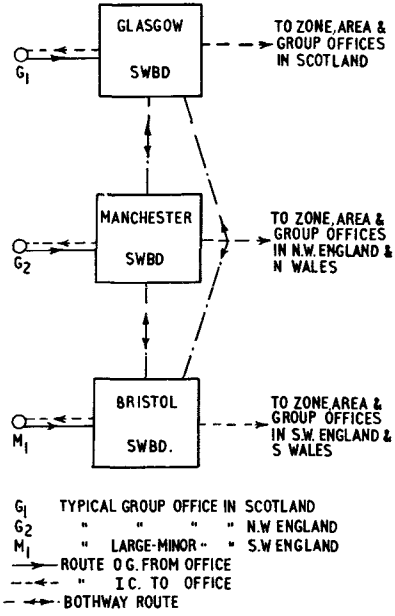


FIG. 15.11. LAYOUT OF PART OF TELEPRINTER MANUAL SWITCHING NETWORK SHOWING TYPICAL GROUP AND LARGE MINOR OFFICE CONNEXIONS

manual switchboards, seven in the B.P.O. system. At many of the smaller area centres these circuits carried little traffic and it was therefore found desirable, to avoid over provision of teleprinters and unnecessary staff movement, to arrange for one instrument to have access to two out-going circuits. Even so, some staff movement between outgoing positions was unavoidable and during the

slacker periods of the day this applied even to the larger offices. In considering the limitations of the manual switching scheme the following other factors need to be considered—

1. One switchboard operator is needed to handle every call and on many calls from the smaller offices routing through two switchboards is necessary.

2. The time taken to set up a call is dependent upon the speed of answer and connexion given by an operator and the time of clear is similarly prolonged by the need for a switchboard operator to respond to a clearing signal. At times of heavy traffic, when the need for speedy disposal of messages is greatest, the tendency is for speeds of answer and clear to be at their worst.

3. An office having to provide additional staff to meet a peak load on the switchboard can only do so by taking staff from other traffic handling duties.

4. Because it is economically possible to provide only a few switchboards, they are widely spaced geographically with the result that many of the circuits connecting an office to a switchboard are extremely long.

As an example, when a teleprinter manual switching system was employed in the U.K. for the Public Telegraph Service, an area centre in S.W. England had direct connexions to Glasgow, Bristol, Leeds, Manchester, Birmingham and two switchboards in London (i.e. Central and Northern) and thus required the permanent and exclusive use of some 2,000 miles of circuit to secure connexion of its outgoing traffic alone.

Automatic Switching. It was with the foregoing considerations in mind that the automatic switching scheme described in Chapter 9 was designed. It provides the following advantages from the viewpoint of commercial management—

1. The number of positions required to handle the traffic outgoing from an office is determined solely by the number of messages required to be sent. Any office on the network can be reached by dialling from one position in another office, and additional positions need only be staffed when the load warrants this. An outgoing operator can therefore remain at one position throughout her period of duty.

2. Incoming calls are offered to positions in succession, always beginning with the first choice, so that the spread of traffic over the positions is automatically restricted to the number simultaneously engaged at any time.

3. Since switching centres do not need to be staffed by operators, they can be made smaller and more widely dispersed. The average length of a circuit from an office to a switching centre is therefore much reduced.

4. The number of circuits is decided by the traffic, and there is no need to connect an office to a number of different centres. This again tends to reduce the length, and also the number, of circuits required, especially at the smaller area centres.

5. Connexion, after dialling an average of four digits, is almost instantaneous and clearing is equally rapid, so that the occupied time of the operator and the circuit for a message is reduced as compared with the manual scheme. Speed of connexion is virtually independent of load, provided that engaged conditions are not encountered, and speed of clear remains small and constant at all times.

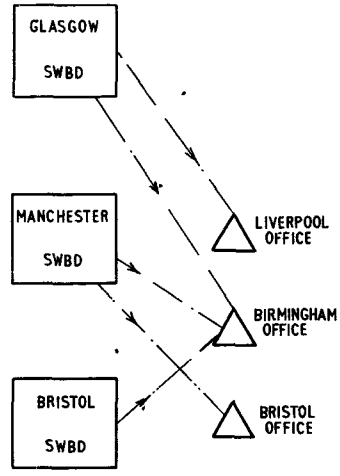


FIG. 15.12. TYPICAL CASES OF SPECIAL PROVISION OF CIRCUITS FROM TELEPRINTER SWITCHBOARDS TO LARGE "OUT OF AREA" OFFICES

6. Immediate advice is automatically given to the outgoing operator when her call is through, and also if for any reason it fails. A variety of indications is provided to meet the differing conditions which may be encountered and it is a simple matter to frame operating instructions to ensure that the proper action is taken to deal with each condition.

The upshot of all this is that an automatic teleprinter switching scheme provides more efficient and rapid service at lower costs. In the U.K. the conversion of the Public Telegraph Service to an automatic teleprinter switching system was completed in 1954 and the network comprises some 500 telegraph offices connected to 22 automatic teleprinter switching centres. The results achieved in the operation of this network have justified the initial expectations and its introduction was not

only effected smoothly but has also proved popular with operating staff.

Tape Relay Working. A method of handling traffic which is widely used in America is known as Tape Relay Working. This method uses point to point circuits with retransmission but seeks to overcome the disadvantages of high handling costs and multiple "through office" delays by eliminating, as far as possible, the human element at retransmitting points.

The essence of the scheme is that each message is punched at the originating office on to tape which will operate an automatic transmitter. When a message is first punched the destination code is inserted before the address and the tape is then fed into an automatic transmitter associated with an outgoing circuit which will take the message on the first stage of its journey.

At the first, and any subsequent, re-transmitting office the signals from the automatic transmitter actuate a printing reperforator and this reproduces the original tape which is then either torn-off for re-transmission or fed direct into another automatic transmitter. In early types of office using the latter method, an operator examines the destination code on the tape and uses a plug and cord to connect the automatic transmitter to a cross-office circuit leading to a further printing reperforator which in turn feeds an automatic transmitter sending out to the next circuit on the route of the message. If the cross-office circuit is engaged, the equipment is so arranged that the automatic transmitter at the receiving side of the office remains idle until the circuit becomes free. When this happens the circuit is seized and the automatic transmitter starts.

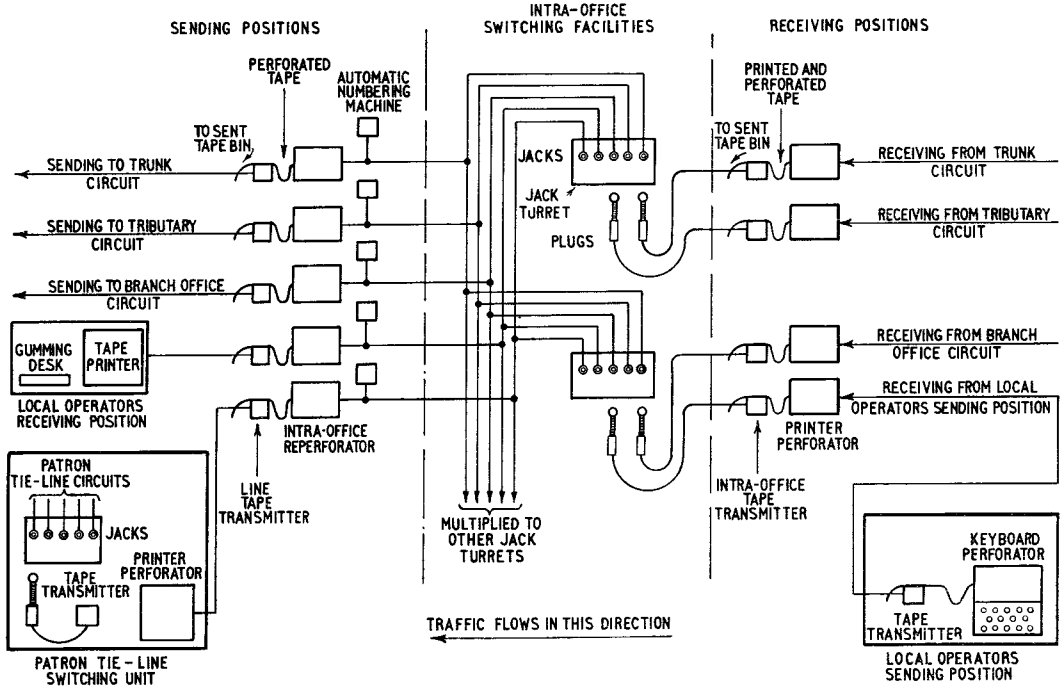


FIG. 15.13. TYPICAL EARLY AMERICAN TAPE RELAY SWITCHING CENTRE

A diagram showing the lay-out of a typical office is in Fig. 15.13.

Later developments of the scheme have sought to reduce the human element in re-transmission and to this end the plug and cord cross-office connexions were first replaced by push button operation, and later by automatic switches actuated by a code punched into the tape at the beginning of each message. It is interesting to note that in order to keep traffic flowing smoothly it is essential for the cross-office circuits to work at a higher speed than the external circuits.

The advantages of the tape relay scheme are—

1. That all inter-office circuits can be worked duplex and that, so long as sufficient traffic is offered, they remain 100 per cent occupied. This results in extremely economical use of line plant which becomes more important as circuits get

longer and more expensive. It is thus at its best in large countries like the United States of America.

2. Once a message tape has been punched and checked there is no further possibility of human error in the text.

3. With the latest automatic routing types of arrangement scarcely any operating staff is needed to deal with traffic passing through an office.

The noteworthy commercial disadvantages of the scheme are—

1. It is inherently slower in operation than an automatic switching system because messages have to be processed before being put on circuit. Re-transmissions, even when they are effected automatically, take an appreciable time and, in order to keep circuits fully loaded, some accumulation of waiting traffic is necessary with a consequent increase in the overall transmission time of a message.

2. The quantity and complexity of apparatus in the large re-transmitting office, together with the considerable and highly skilled engineering staff, needed to avoid messages piling up because of breakdowns or sudden rushes of traffic.

3. The difficulty of dealing with queries about messages lost, delayed or mutilated.

In the U.K. the use of tape relay working is mainly confined to a few private wire networks, e.g. civil aviation organizations. However, modern developments in the use of magnetic forms of signal storage have provided a stimulus to the design of such systems and increasing uses can be expected, particularly on long-distance circuits, e.g. those in the Overseas Telegraph Service.

Delivery of Telegrams

Hand Delivery. The oldest method of delivering telegrams, and still the most common, is by a messenger sent from the delivery office to the address of the recipient.

When juvenile labour was cheap and readily available delivery by boy messenger on foot or using a pedal cycle was reasonably economical and satisfactory. With the raising of the school leaving age, the coming of full employment and the accompanying increase in rates of pay, hand delivery has become a very expensive business. In an endeavour to reduce costs, by increasing the number of telegrams delivered per man-hour, many small offices have ceased to deliver and the work has been concentrated on offices large enough to employ a team of messengers (now known as young postmen) with motor cycles, who can deliver a batch of messages spread over a large area without causing a serious increase in the time taken to deliver any of them.

This process of concentration and mechanization of delivery achieves some reduction in delivery costs but they nevertheless still remain as a very high proportion of the total cost of dealing with a telegram.

Delivery by Telephone. Offices of the types described in the section of this chapter dealing with Acceptance of Telegrams, deliver telegrams by telephone as a part of their normal function, and other offices may deliver telegrams by this means in certain circumstances.

Unless the addressee is close to the delivery office it is cheaper to deliver by telephone than by hand and since telephoning is usually done from the larger offices it frequently happens that a re-transmission is saved as well. These are advantages from the viewpoint of the carrier but the user has the corresponding benefits of receiving his telegram, on the average, some 20 minutes sooner and of being able to receive it during hours when staff for hand delivery is not available. Telegrams delivered by telephone fall into three main classes—

1. Those addressed to telephone numbers and to addresses prefixed by the word telephone.

2. Those to registered abbreviated telegraphic addresses where the Post Office has instructions that the registrant accepts telephonic delivery.

3. Fully addressed telegrams received after normal hours of hand delivery, when consultation of records shows that the addressee is a telephone subscriber.

Other Methods of Delivery. Renters of Telex installations can, and normally do, receive their incoming telegrams on rented teleprinters just as they hand in their outgoing telegrams by this means. In order that telegrams for these renters may circulate to offices equipped with Printergram facilities, the word Telex is included in the address of any telegram for such a renter. The address may take one of several forms depending on the extent of the originator's knowledge of the addressee's installation. After the prefix Telex there may be a full address, a registered abbreviated address, or the number of the addressee's Telex installation. From all points of view the third of these types of address is to be preferred because each of the others involves consultation of records. This costs staff time and imposes some delay in the delivery process so that its avoidance benefits both the user and the carrier.

The largest users of the telegraph service have direct teleprinter circuits or pneumatic tubes to a neighbouring telegraph office and these are used for receiving as well as forwarding telegrams. Because of their very high installation and running costs the provision of new understreet tubes is now a rare occurrence.

Registered Abbreviated Addresses. Users of the public telegraph service who consider that their traffic justifies such a course can obtain, at an annual fee, what is known as a Registered Abbreviated Telegraphic Address. Such an address generally consists of a code word which, subject to certain essential restrictions, can be chosen by the registrant, and the name of the telegraph office from which his telegrams are to be delivered. In provincial towns which have a postal district numbering scheme, the town and postal district number are substituted for the name of the office of delivery and, in London, district codes are used in lieu of postal district numbers.

Indicator words are added in some cases to indicate the normal method of delivery and to facilitate circulation. The following examples in which coined code words are used may be found to be of interest.

Address	*Significant Features*
Frozenmist London Telex	To be delivered from London C.T.O. by Printergrams.
Backplate Souphone London	To be delivered by telephone from the South London Ring Office.
Outspun Wire London	To be delivered by direct Teleprinter circuit from London C.T.O.
Sourpuss Piccy London	Address in the Piccadilly Area.
Corncob Leeds 1	Provincial address in a town having a postal numbering scheme.
Crumbrush Swansea	Provincial address in a town not having a postal numbering scheme.
Flagrant Hayes Middx.	Provincial address where the name of the town alone, i.e. Hayes, is inadequate and a suffix, i.e. Middx. (abbreviation for Middlesex) has to be used to identify the delivery office.

Handling of Foreign Telegrams on the Inland Telegraph System. All of the "carriers" of foreign telegraph traffic have their own offices and some have a number of offices spread about the country. Even so they cannot arrange economically for the receipt and delivery of all their traffic. The B.P.O. therefore accepts telegrams at any of its telegraph offices for any destination, irrespective of the international carrier concerned.

Arrangements are made for transfer of the traffic to the appropriate international carrier, if the P.O. Cable and Wireless and Commonwealth network does not serve the distant country or if the sender specifies another carrier in his instructions. These arrangements are, of course, agreed by the carrier and they may consist of an actual physical hand-over of the messages to a nearby office of the carrier, the sending of the messages to a post office which can readily hand-over the traffic, or sending direct to an office of the carrier. The bulk of the "foreign" traffic handed-in at provincial post offices has to be sent to London for retransmission overseas or via pneumatic tube or other means to the offices of the main international carriers in London. Similarly when foreign telegrams arriving in the United Kingdom cannot be conveniently delivered by the international carrier, they are transferred to the B.P.O. for delivery to be effected.

During the last few years the main London office of the Post Office Cable and Wireless system has been connected to the Teleprinter Automatic Switching Network which serves the Inland Telegraph System of the U.K. and this has considerably simplified and expedited the process of handling foreign traffic in this country handed-in at, or due to be delivered by, post offices.

Telegraph Instrument Room Design and Practice

The Telegraph Instrument room is the room in a telegraph office in which all the apparatus required by the operating staff for the transmission and reception of telegrams is installed.

The arrangements adopted must be such as to ensure that the flow of traffic through the office, throughout the whole of the working day, takes place with the greatest possible expedition and accuracy. Close attention must be paid to the circulation and distribution arrangements for the traffic to ensure that it is despatched to its destination by the quickest possible means even under breakdown conditions when normal routings cannot be followed.

It is desirable that the arrangements made for terminating circuits on instrument positions should be as flexible as possible, so that the staffing can be concentrated or expanded as required to meet the fluctuating traffic load. It is necessary too if a line or instrument becomes faulty that it can be rapidly patched-out of service and replaced by a spare line or instrument. Certain testing facilities are also necessary, especially in large offices, to facilitate the carrying out of routine checks and for localizing faults.

Prior to the general introduction of M.C.V.F. telegraph working a large number of physical circuits were in use, many of them working under duplex conditions and employing various forms of telegraph instrument and signalling systems. In these earlier times the amount and variety of equipment to be accommodated were often considerable and because of this, and the need to introduce greater flexibility in the interconnexion of lines and instruments, it became common practice to mount the subsidiary apparatus required

for each line, e.g. relays and shunted capacitors, on a separate panel. These panels were erected on apparatus racks away from the instrument tables, e.g. at the end of the instrument room or in an enclosure. The lines were connected in the instrument room to a "Test Board" and thence to the subsidiary apparatus and instruments via a concentrator jack field, wired so that the appropriate signalling voltage and terminating equipment for a particular line remained associated with it when the line was patched to another operating position in the instrument room.

With the introduction of teleprinter working on point-to-point circuits in M.C.V.F. telegraph systems, it became possible to introduce a considerable degree of standardization in instrument rooms as it was then possible to standardize the operating instrument and signalling voltages on these circuits. This led to the use of standardized tables and instrument positions and yielded considerable advantages from both an engineering and traffic viewpoint. With all tables and instrument positions identical, installation work and changes in circuit allocations were expedited and maintenance work simplified.

In recent years, many of the point-to-point teleprinter circuits in the Public Telegraph Service have been replaced by circuits connected firstly to a manual teleprinter switching system and finally to an automatic teleprinter switching system. During the transitional stages of these conversions the operating positions in instrument rooms have had to be segregated, depending upon their use, because the operator's position signalling set is different for point-to-point and switched working.

The B.P.O. public telegraph teleprinter system has now been completely converted to an automatic teleprinter switching system so that all teleprinter operating positions are standardized. Nevertheless, in order that the reader may obtain a comprehensive grasp of the principles required to be employed in the engineering and operation of instrument rooms served by either point-to-point teleprinter circuits or manual or automatic teleprinter switching services some information will now be given of these methods.

Considering a large instrument room served by both physical and VF circuits and operating point-to-point and manual and automatic switching circuits then the apparatus to be accommodated is as follows—

(*a*) The operator's tables carrying the teleprinters and other position equipment.

(*b*) The traffic circulation table. This is the focal point for all messages dealt with in the telegraph office, whether they be received from the public office counter, from phonogram or TT circuits, printergrams, or from point-to-point or switching circuits. Its function is to provide means by which the message forms are conveyed as quickly as possible between the points of reception and despatch. Hence all the inward and outward pneumatic tubes and conveyors terminate at the circulation table.



FIG. 15.14. MANUAL TELEPRINTER SWITCHBOARD INSTALLATION WHICH WAS EMPLOYED IN C.T.O. LONDON PRIOR TO 1955

(*By courtesy of H.M. Postmaster-General*)

(*c*) Apparatus racks, including test and control boards. Generally speaking the apparatus racks are placed at one end of the instrument room.

The location of the circulation table is determined chiefly by the most convenient and economical position for the provision of the band conveyors serving the various parts of the office. Telephone-telegram and phonogram positions are generally installed in a separate room, partitioned off from the instrument room. This arrangement is very desirable in order to reduce the noise level in which the phonogram and TT operators have to work. The speed and accuracy of the operators' work in this case is very dependent upon the accuracy with which spoken messages are received and so necessitates quiet working conditions.

Where a teleprinter manual switchboard is required this may be accommodated either in a section of the main instrument room, or in a separate room, depending upon local conditions and the size of the installation. Large capacity switchboards are usually situated in a separate room and Fig. 15.14 shows a typical switchboard which was employed in London before the conversion of the Public Telegraph Service to an automatic switching system. Although the arrangements detailed in the following description are

those which have been standardized in the past by the B.P.O., non-standard arrangements may sometimes be necessary to meet special local conditions.

Operating Positions—Instrument Tables. A double-table is the standard adopted in large offices for mounting the teleprinters and certain subsidiary apparatus. Two tables each 2 ft 3 in. in height with a top 1 ft 9 in. deep are placed back to back with a sufficient space between them in which to install a conveyor belt for carrying message forms. The width of each operator's position is usually 4 ft 9 in. although 4 ft 6 in. is sometimes used for positions employed only for forwarding traffic. Operators on positions dealing with incoming traffic have to gum the received message tape on to the telegram form and for this reason need a little more space than a transmitting operator.

Cable chases are provided underneath the table top at the rear, in which to run the lines and power and signalling leads to the several instrument positions in each suite of tables. The wiring for each position is brought out through traps mounted over the cable chase. Only apparatus essential from an operating point of view is mounted on the tables and the principal items are as follows—

(*a*) *For Point-to-Point Teleprinter Circuits.*

A Teleprinter No. 3A. (See Note.)

A five-way jack for connexion of the teleprinter to the circuit.

A three pin, five amp socket and switch for the teleprinter motor supply and protective earth.

A centre-zero milliameter which is connected in series with the transmitting line.

(*b*) *For Teleprinter Manual Switching Circuits*

A Teleprinter No. 3X. (See Note.)

A 17-way jack for connecting the teleprinter to the circuit.

A three pin, five amp socket and switch for the teleprinter motor supply and protective earth.

A centre-zero milliameter which is connected in series with the transmitting line.

A pedestal on which is mounted a "Call" lamp.

A "Clearing" key.

A "Paper Failure Alarm" cut-off key.

Note. Teleprinters No. 3 are no longer employed in the B.P.O., having been replaced by Teleprinters No. 11B with the introduction of teleprinter automatic switching. The latter machine would therefore be used nowadays if a point-to-point public circuit was required.

(*c*) *For Teleprinter Automatic Switching Circuits.*

A Teleprinter No. 11B.

Power and signalling cords and plugs which connect the teleprinter to the circuit and motor power supply. A combined power, line signalling and supervisory signalling unit, on the face of which is mounted the dial and keys and lamps required by the operator.

A circuit-breaker for the motor circuit, mounted beneath the table.

Cabling of Instrument Rooms. The cabling in instrument rooms between the operating positions and the I.D.F., power board and apparatus racks, etc., is carried out in floor chases, or where this is not possible in overhead racking. The precise cabling arrangements vary, depending upon the size and layout of an office and whether the positions are operating on point-to-point or manual or automatic switching circuits. The motor and signalling power cabling will depend upon whether a centralized rectifier and battery supply is used or whether individual rectifiers are employed for each position. Individual rectifiers are only used in small offices having less than eight teleprinters.

When the teleprinter positions are arranged in suites, as is the case in large offices, it is normal practice in order to avoid the provision of a large number of small cables to provide a cable distribution point at the end of each suite for the lines and miscellaneous signalling leads and a power fuse distribution box and signalling earth for the motor power and signalling supplies. Individual operator's positions are connected by separate cables, run along the suite in the cable chase provided underneath the top of the tables, to the distribution point at the end of the suite of tables. A common signalling earth lead interconnects all the operating positions in the suite. From the distribution point on the table suite larger capacity cables carry the line and miscellaneous signalling connexions, as required, to the I.D.F. and other apparatus. The power distribution box is cabled back to the main power distribution board to which the 80 V + 80 V rectifiers and battery are connected.

In small offices, the individual line circuits are separately cabled directly to a connexion block on the operator's position. Similarly, an individual mains power feed and signalling earth is connected to each position and terminated on a power fuse-switchbox or circuit-breaker. The rectifier (or rectifiers) for the motor and signalling power is fitted either underneath the operating table, or on an adjacent wall.

Panel Mounted Apparatus. The panel mounted apparatus comprised the following items.

The Control Board—to which was brought the Send and Receive ends of all VF circuits connected to the instrument room. The function of the control board was to provide the traffic staff with facilities for testing, patching-out and making-up

circuits, it was also used as a concentrator if desired.

The control board consisted of one or more unit racks built up with a frame work of channel iron on which was accommodated the jacks and connexion strips for terminating the Send and Receive ends of VF circuits. A typical unit of a control board used in the B.P.O. provided for five 18-circuit systems, i.e. 90 send and 90 receive channels and public service, was allocated for use as a part-time private wire and this was catered for on the control board by wiring the *PW* local end to the bushes of the VF jacks as shown in Fig. 15.16. The circuit was then connected when required for PW use by inserting a metal plug into each VF jack, the insertion of the plug causing the instrument room teleprinter to be disconnected from the circuit.

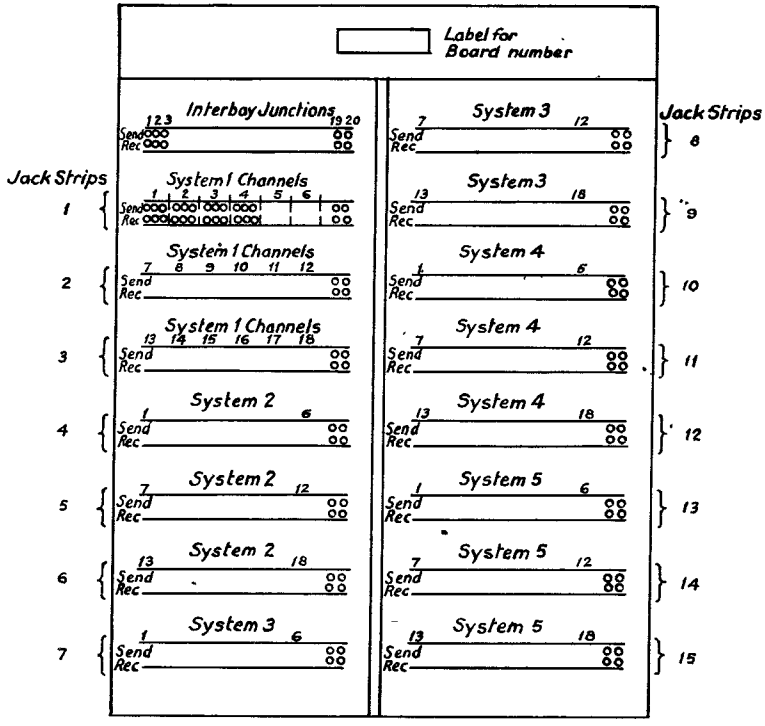


FIG. 15.15. CONTROL BOARD FOR 90 CIRCUITS: LAYOUT AND DESIGNATION OF JACK STRIPS

Fig. 15.15 illustrates the layout of the face equipment. The *S* and *R* leg of each VF circuit was wired via three pairs of jacks on the control board in the manner shown in Fig. 15.16. The jacks labelled "VF" and "EXTN" were employed for patching and the "TEST" jack for monitoring and testing to either the VF circuit or instrument room position equipment. In the event of a fault developing on a VF circuit, a fresh circuit was picked up by inserting one end of the connecting cord into the VF jacks of a spare circuit and the other end into the EXTN jacks. Similarly, by connecting the TEST jacks to the test position jacks, by means of the connecting cords, tests could be carried out from the test teleprinter.

In certain cases a circuit, when not in use for

Each jack strip on the control board contained 20 jacks and could thus accommodate six channels on each strip, leaving jacks Nos. 19 and 20 spare for miscellaneous uses. These spare jacks were utilized for providing transfer circuits to the teleprinter test and observation set and also to the concentrator and test board. (*Note.* Concentrator and test boards became obsolescent in instrument rooms as the majority of circuits became routed on VF circuits. The few remaining physical circuits were in most cases short, and test and concentrator facilities for these were provided on the control board by connecting them via jacks, in the same manner as a VF circuit.)

When more than one control board was fitted, inter-rack junction circuits were provided between

them so that connexion could be made to any board without necessitating the use of long cords. All the *S* and *R* legs from the M.C.V.F. terminal equipment and to the instrument room positions, together with transfer circuits to the concentrator and test board, were terminated on tag blocks on the control board. By means of plugs and cords, any VF circuit could be connected to any concentrator position terminated on the same rack, or via the inter-rack junction if on different racks. In the adequate traffic facilities for testing, patching and concentrator working.

Test Board. A test board was originally provided in instrument rooms to form a central point at which access could be obtained, by plug and cord connexions via line jacks, to all physical circuits connected to the office, whether terminated or through-connected. It was thus readily possible to test circuits and make any circuit changes necessary to meet the needs of traffic, or to deal

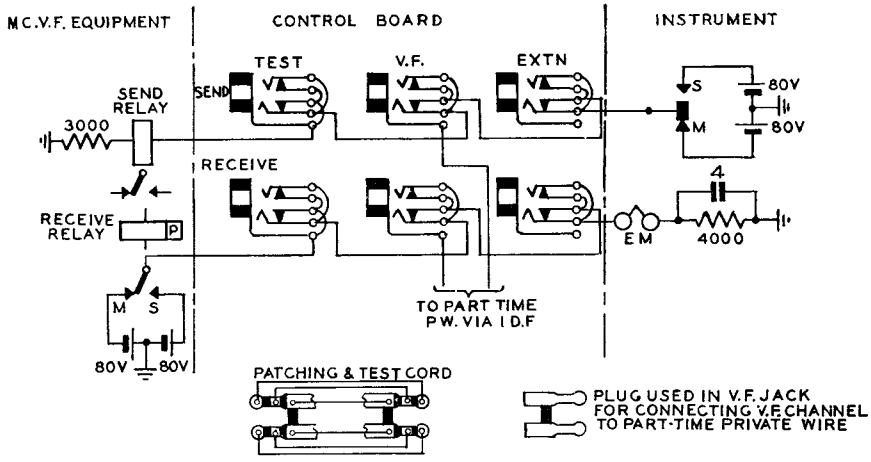


FIG. 15.16. WIRING OF CONTROL BOARD JACKS FOR A V.F. TELEGRAPH CHANNEL

latter case, of course, two cords had to be used, one on each control board rack.

The Concentrator Panel was provided originally for use in conjunction with panel mounted physical circuits when it was necessary to keep a particular voltage and line terminating circuit, e.g. shunted capacitor, associated with a particular line. The wiring of the jacks on the concentrator were such that when it was necessary to patch a line to a fresh operator's position the required signalling voltage and terminating circuit conditions appropriate for that line were automatically connected when the patching operation was made.

Each line was connected to the instrument room operator's position equipment via two jacks on the concentrator, i.e. a line jack and an instrument jack. By means of plugs and cords any instrument could be connected to any line.

With the change-over from physical lines to VF working the need for concentrators of this form largely disappeared because the terminating circuit arrangements for VF circuits are standardized and $\pm$ 80 V signalling is uniformly used on all circuits. For circuits routed on VF circuits the control board, as already described, provided with breakdown conditions. It thus fulfilled similar functions for physical circuits to those provided later by a control board in the case of VF circuits.

In many cases a combined Test and Control Board was used, which provided the necessary arrangements for testing and patching of both physical and VF lines.

The test board was simply an assembly of jacks through which the lines were routed, one line jack interconnected to one instrument jack being provided for each *S* and *R* wire of a circuit. Normally the line was connected through to the instrument until a plug was inserted in one of the jacks. Facilities were provided on the test board for connecting the circuit to a line testing set, which enabled the line to be earthed, looped or disconnected as required during testing operations. Bridge megger facilities were provided and a morse key and sounder and also a telephone were provided for alternative connexion to any circuit.

Fuse and Power Panel. This accommodated the equipment necessary to provide for the distribution of the $\pm$ 80 V signalling voltage to the instrument tables. The shunted capacitors in series with

the electromagnets of the teleprinters were also mounted on this unit for point-point circuits.

Power supplies for miscellaneous 80 V services, e.g. clocks, timing stamps, etc., could also be served from this panel. The signalling power was supplied from ± 80 V battery via 5 amp fuses to the busbars, whence it was distributed to the individual positions. The circuit arrangement is indicated schematically in Fig. 15.18 and was employed for teleprinter manual switching positions.

Teleprinter Automatic Switching Positions. The cabling arrangements for these positions are radically different from point-to-point and T.M.S. working because the need for an instrument room

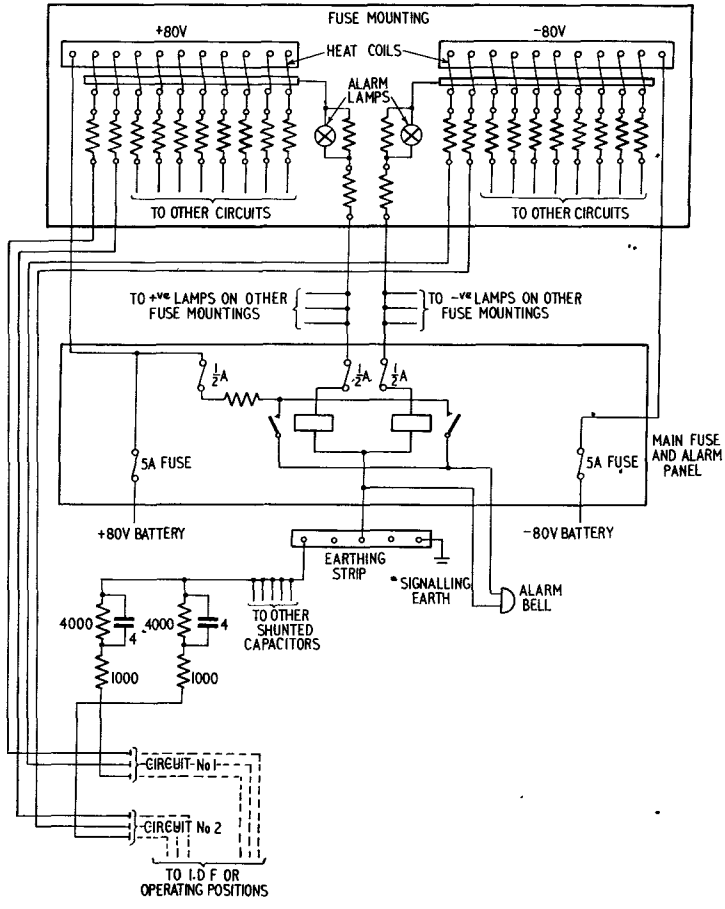


FIG. 15.17. FUSE AND POWER PANEL FOR DISTRIBUTION OF ± 80 V SIGNALLING SUPPLIES

circuits via heat coils and protective resistors of 120 Ω as indicated in Fig. 15.17. The heat coils are alarm type and when blown cause an alarm bell and lamp to be operated.

From about 1940, a slight change was made in the panel arrangements employed for new installations for the distribution of ± 80 V signalling supplies. The essential difference from the arrangements previously employed was the use of 100 Ω resistors bulb, instead of heat coils and 120 Ω resistors, in the ± 80 V feeds to individual teleprinter control board, concentrator panel and test board has been eliminated for the reasons which will be discussed later. Rack-mounted fuse and power panels are also no longer required as the necessary protective arrangements in the 80 + 80 V signalling leads are provided in the individual operator's position equipment, as also is the shunted capacitor. Cables for the lines and miscellaneous signalling purposes are terminated on a strip connexion at the end of each bench. The 80 + 80 V supply for the teleprinter motor and line signalling power is

cabled from the battery, via distribution boxes, to a distribution fuse board at the end of each suite of teleprinter benches. A signalling earth is also terminated at the end of each bench. The cabling arrangements are indicated in Fig. 15.19.

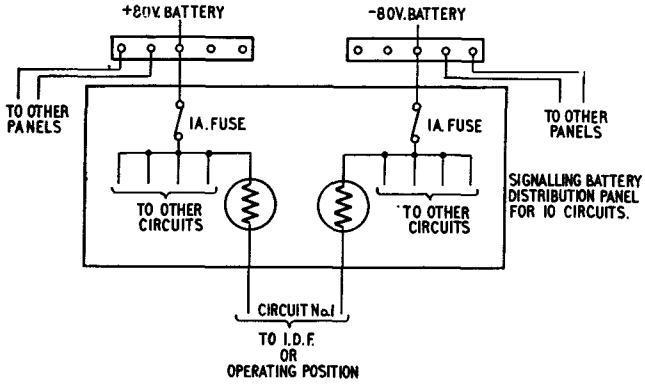


FIG. 15.18. USE OF RESISTOR BULBS IN DISTRIBUTION OF ± 80 V SIGNALLING SUPPLIES

testing work to be performed. They were usually located close to the control board and were wired to jacks on this board. By means of plugs and cords they could be connected to the TEST jacks of any circuit. Various test conditions could be set up by the operation of testing keys on the tester and the facilities provided were as follows—

1. Test into the VF channel or physical line under test.
2. Test to the local teleprinter instrument.
3. Monitor the send or receive line to observe the signals passing.
4. Speed test signals from the line or local teleprinter could be connected to a synchroscope panel to check the accuracy of the teleprinter signalling speed.

The test circuit was arranged so that under test conditions 1, 2 and 4, the office on the side of the circuit not under test received its own transmitted signals, so indicating that through-communication had been interrupted.

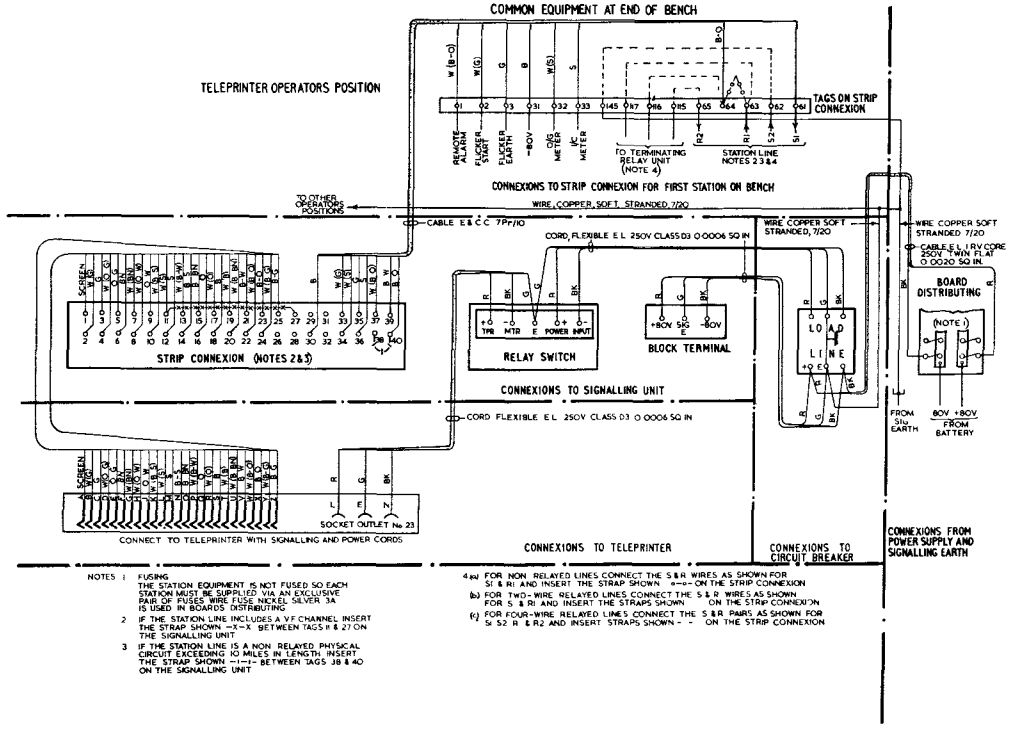


FIG. 15.19. WIRING AND CABLING ARRANGEMENTS FOR BENCH-MOUNTED TELEPRINTER AUTOMATIC SWITCHING POSITIONS

Teleprinter Test and Observation Set. One or more teleprinter test sets were provided in the instrument room depending upon the amount of Milliameters were provided on the tester to check the send and receive currents under all testing conditions.

Layout of Instrument Rooms for Teleprinter Automatic Switching Operation. When telegraph circuits are connected to an automatic switching system it enables a considerable simplification to be made in the traffic control and testing arrangements in the instrument room.

Point-to-point circuit operation entails retransmission of a considerable volume of traffic. Automatic switching largely eliminates the need for retransmission of traffic, as any teleprinter office can obtain through connexion to any other teleprinter office by dialling. Under busy or breakdown require retransmission to other offices. Such traffic will overflow into nominated instrument rooms and conditions and night working, teleprinter traffic will, however, be only a small percentage of the total.

Under automatic conditions, facilities are provided for "busying out" any position in the instrument room by operating a key on the operator's dialling unit. Thus the number of operating positions in service at any time can be controlled easily, and traffic can therefore be concentrated in any manner desired.

Individual operator's positions may be tested in local by operation of a key on the position dialling set and a test of the speed and margin of any operator's teleprinter may be made when required by dialling an engineering test number.

Full testing facilities on all lines, both physical and VF, are provided in the engineering apparatus room of the switching centre and so the need for test and control boards and teleprinter testing equipment in the instrument room is eliminated.

In small offices having only a few teleprinters all the positions are connected for both-way working, i.e. both sending and receiving. In these cases the layout of the office is a comparatively simple matter and the use of a unit type L-shaped table lends itself to a variety of layouts to suit the local accommodation conditions. The type of table used by the B.P.O. is illustrated in Fig. 15.20 whilst Fig. 15.21 shows a view of a small teleprinter office equipped with unit tables.

At these and smaller telegraph offices, of which there are several thousand in the B.P.O. system, it is usually uneconomic to provide mechanical means of circulating messages, apart from a pneumatic tube from the counter or to the delivery room, where these are not adjacent to the instrument room. Similarly, at even the larger offices of this kind, message circulation and the work of addressing and enveloping are all performed by one officer. As the size of the office declines, the duties of the staff naturally become less and less specialized until finally the point is reached where one officer not only sends and receives messages but also looks up circulation information and addresses and envelopes messages.

In larger offices the layout requires much more detailed consideration. In such cases, bench type tables are employed arranged in back-to-back suites with Vee-band conveyors between them. It is sometimes advisable to cater for a few positions being worked duplex, to deal with traffic to those offices with which it has heavy loads of both-way traffic. Positions provided for duplex working are 5 ft 6 in. wide.

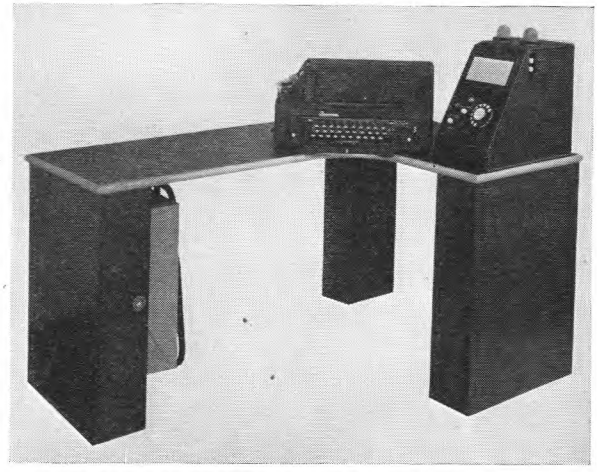


FIG. 15.20. "L" SHAPED UNIT TABLE USED FOR TELEPRINTER AUTOMATIC SWITCHING POSITIONS

(By courtesy of H.M. Postmaster-General)

Large instrument rooms fall into two main categories, namely—

(*a*) Offices at which the phonogram and TT suite is installed in a separate room and

(*b*) Offices at which the phonogram and TT suite is installed in the same room as the teleprinters.

In determining the instrument room layout for offices in category (*a*) the following principles are normally applied.

1. The circulation, segregation and addressing tables should be located between the outgoing and incoming teleprinter positions with the first choice circuits of each group adjacent to the circulation positions. If a position is provided for the night concentration of phonogram lines, this should be placed near the circulation tables.

2. Any point-to-point circuits which terminate in the office and which have traffic loads equivalent to those of early choice switching circuits should be located close to the circulation positions.

3. Messages from the incoming positions to the

circulation, segregation and addressing tables should be carried by conveyor bands.

4. If the volume of traffic and the distance involved is sufficient, then messages should also be carried by conveyor bands from the circulation table to the outgoing positions.

5. Overflow positions may be located away from the circulation positions. The overflow positions should be provided with circulation information

outgoing and incoming positions, but without separate overflow positions, the foregoing principles apply although, of course, special provision for an overflow suite, or for the diversion of overflow traffic by night, will be unnecessary.

At smaller offices, a common group of teleprinter station lines will normally be provided for both outgoing and incoming traffic and there will not be a separate suite of overflow positions. The last



FIG. 15.21. A SMALL TELEPRINTER AUTOMATIC SWITCHING OFFICE EQUIPPED WITH UNIT TABLES

(By courtesy of H.M. Postmaster-General)

in respect of offices for which the instrument room acts as the overflow centre.

Note: Facilities are provided on the engineering control board of the switching centre serving the instrument room, which enable overflow traffic to be diverted to early choice incoming positions, when desired, to facilitate night staffing arrangements.

The principles enumerated above also apply to offices in category (*b*), with the following exceptions—

1. The circulation, segregation and addressing tables should be located between the outgoing teleprinter positions and the phonogram and TT suite.

2. A small number of incoming positions, which will be sufficient to handle overflow and incoming traffic under night concentration, should take precedence in their locations over late choice outgoing circuits.

3. The remainder of the incoming positions can be located away from the circulation positions.

In instrument rooms having separate suites of

few circuits in the group of station lines, up to the number required to handle the busy hour outgoing traffic, should be located nearest to the circulation positions (i.e. positions 11–15 in Fig. 15.22 which shows a typical layout for such an office).

The early choice circuits from the selector levels, which will carry the heavier loads of incoming traffic, should be allocated the most favourable remaining table positions. The rest of the group of teleprinter station lines, which will carry a reduced load, may then be allocated to tables which are more remote from the circulation positions. Where inquiry or duplex positions are provided in an office, location of these positions will be determined largely as a matter of local expediency; wherever possible, however, the inquiry positions should be adjacent to the circuits used for outgoing traffic and near to the early choice incoming positions.

Fig. 15.23 shows a view of a large teleprinter instrument room, the operator's positions being equipped for teleprinter automatic switching.

Mechanization of Message Circulation. For many years great attention has been paid to mechanical methods for the rapid transportation of telegram message forms within telegraph offices and also over short distances between different offices, e.g. a Head Office and a Branch Office. Many ingenious principles have been employed for the purpose and many elaborate installations are now working with a high degree of traffic efficiency.

Two main methods are employed, namely, pneumatic tubes and conveyor belts and the design and construction of equipment of this type is a large and specialized mechanical engineering subject which is beyond the scope of this book to describe. It is therefore only intended here to indicate to the reader the general principles and scope of application of such devices in telegraph office practice. The pneumatic tube and conveyor engineer will readily recommend the most appropriate type of equipment to adopt in each case as much as possible and finally, it is extremely important that the cost of handling the messages should be kept to a minimum.

Messages received on the various circuits from other telegraph offices require to be passed either to the delivery room or to be retransmitted in the instrument room, the phonogram room, or the printergram section. Similarly, messages received in the instrument room from the public counter,

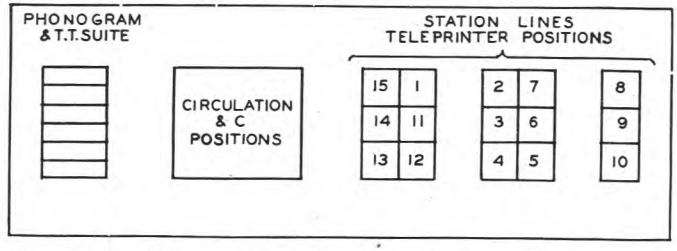


FIG. 15.22. TYPICAL SMALL OFFICE LAYOUT FOR TELEPRINTER AUTOMATIC SWITCHING



FIG. 15.23. A LARGE TELEPRINTER AUTOMATIC SWITCHING OFFICE USING BENCH TYPE TABLES

(By courtesy of H.M. Postmaster-General

In small telegraph offices, the handling of a few hundred telegrams a day does not present any great difficulty but in larger offices dealing with thousands of messages a day the transportation of the message forms presents a serious problem. The possibility of loss or damage must be guarded against, delay must be reduced to a minimum, the movement of staff about the office must be avoided from street pneumatic tubes, from the phonogram room, or from the printergram section, must be carried to the circuit from which they are to be sent.

At one time much of this message transportation was performed by juvenile labour, but rising costs and the need for greater efficiency has led to the modern practice of providing mechanical conveyors

wherever economic, for carrying the messages between the various points in the telegraph office. The general effect of the liberal use of mechanical aids has been to quicken up the process of message transference, to economize floor space and also to effect savings in the cost of handling messages. The time taken from the receipt of a message from the public counter or on a circuit, to the time at which it reaches the circuit from which it is to be sent, is termed "office drag," and in a large office it formerly amounted to many minutes.

All the messages received whether from tubes, phonogram circuits, or teleprinters, arrive at the circulation table where the next stage in the routing of the message is decided. They are then placed on conveyors which carry the message forms to the various distribution points placed as near as possible to the circuit from which the messages are to be disposed of; this may be a teleprinter circuit, the phonogram room, the printergram section or a pneumatic tube. At the circulation table, a multiple band conveyor carries the forms to the teleprinter circuits, whilst all the messages for local delivery and for the phonogram room are sorted to a conveyor to the segregation table. Here all the messages for local delivery are passed by a slow-moving band to the addressing table and after addressing and enveloping, are passed by pneumatic tube to the delivery room. In the case of firms having either registered addresses or having many messages a day, stencils are employed for addressing the envelopes.

The remainder of the messages, which are those to be sent over phonogram or TT circuits, are placed on the phonogram room conveyor. The addresses of all messages for delivery over TT circuits are examined at the segregation table to find out whether the addressees are telephone subscribers, in order that any such messages can be phoned direct and so save delivery time.

The course of a telegram will now be described from its origin to destination, under the several conditions that appertain in practice. A network of point-to-point teleprinter circuits is assumed, as this presents the most difficult case to consider.

Sending a Telegram. A telegram may originate in any of the following ways—

(*a*) Handed in at the counter of the head post office from which the message is to be signalled.

(*b*) Handed in at the counter of a branch, or sub-post office.

(*c*) Telephoned by a telephone subscriber or from a call office to a telegraph office (Phonogram).

(*d*) Transmitted by teleprinter to a telegraph office by Telex (Printergram).

(*e*) Transmitted by teleprinter to a telegraph office over a direct line between the subscriber's premises and the telegraph office (Private Wire).

In addition, certain Cable Companies are connected direct to the C.T.O. by pneumatic tubes for the purpose of handing over messages received from overseas and for receiving messages for transmission overseas.

Telegram Handed in at Counter of Head Post Office. The telegram is written on a form known as an "A" form. After checking and counting the number of words, postage stamps equal to the cost of the telegram are affixed to the form. The postage stamps are cancelled by a date stamp which also indicates the office of origin. The time of handing in, together with the number of words, is entered on the form in a space provided. The "A" form is given its consecutive number in the appropriate series by a numbering machine. In some cases, firms arrange for a credit account. At very large offices a Teltax machine is installed to obviate the fixing of stamps on the message forms. It impresses the charge and consecutive number and gives a running total of the number of messages and total charges.

After numbering, etc., the form is placed in a carrier and sent by pneumatic tube to the circulation tables.

Telegram Handed in at Branch, or Sub-Office. The "A" form is dealt with in a similar manner to that already described. Transmission to the head office to which the sub-office is connected may be by one of the following means

(*a*) Pneumatic street tube.

(*b*) Teleprinter.

(*c*) Telephone over a TT circuit.

In the case of (*a*) the tube usually terminates at or near to the circulation table, whilst in (*b*) and (*c*) at the head office the telegram is carried by band conveyors from the instrument tables to the circulation table.

Telephoned by Subscriber, or Call Office, to Telegraph Office. The subscriber obtains connexion to a position in the phonogram room either by dialling or via a manual exchange. The telegram is dictated to an operator who types the message direct on to a special form, the subscriber's number, together with the time and number of words, are entered on the form which is then placed on a belt conveyor and carried to the circulation table.

Telexed to Telegraph Office. The subscriber obtains connexion to the printergram section of the telegraph office and transmits the message. After checking and inserting the number of the telex subscriber, receipt is acknowledged and the circuit cleared. The message form is then treated in a

similar manner to a phonogram and sent by band conveyor to the circulation table.

Private Wire. The renter's teleprinter is connected permanently via a line to a teleprinter in the telegraph office. After reception, the message is checked, counted and timed and the name of the renter entered in the appropriate place. It is conveyed to the circulation table by band conveyor.

Treatment at Circulation Tables. On arrival at the circulation table, the message is sorted on to a band conveyor for transit to the distribution point for the circuit over which it has to be transmitted. On reaching the circuit, it is placed in order of its handing-in time with other messages and transmitted in turn.

Receipt of Message at Distant Office. The teleprinter slip is gummed on to a message form. After

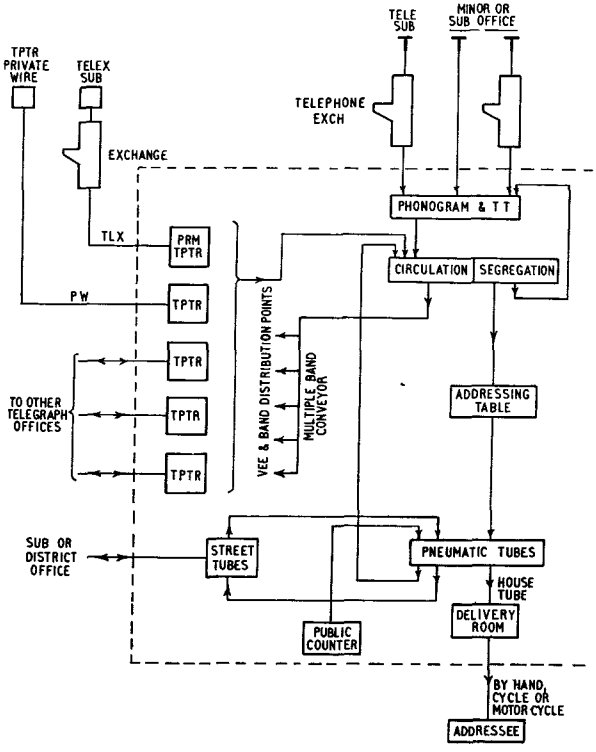


FIG. 15.24. DIAGRAM SHOWING PRINCIPLES OF MESSAGE CIRCULATION IN TELEGRAPH INSTRUMENT ROOM AND METHODS OF COLLECTION AND DELIVERY

receipt the message is timed and dated by means of a Blick timing stamp and placed on a belt conveyor which carries it to the circulation table. In the case of a retransmission, the form is sorted on to a band conveyor which will carry it to the distribution point for the particular circuit over which it has to be transmitted. Messages for delivery may be dealt with in the following ways.

Local Delivery. If the message is for an address which is in the delivery area of the office, it is sorted

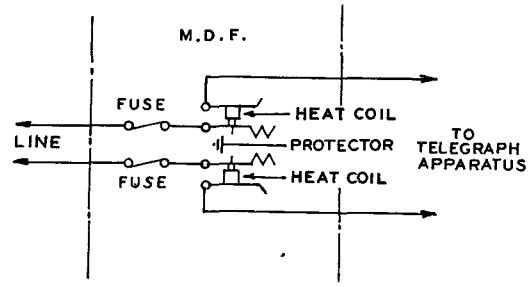


FIG. 15.25. CONNEXION OF LINE FUSES, HEAT COILS AND LIGHTNING PROTECTORS ON UNDERGROUND CABLE CIRCUITS

on to a belt conveyor which carries it to the addressing table where it is enveloped and addressed. From this point it is sent to the delivery room by pneumatic tube. Delivery is effected by a messenger boy either on foot, pedal cycle or motor cycle.

Delivery from a Sub-Office. A message for delivery from a sub-office may be forwarded by either of the following methods—

(*a*) Pneumatic tube.
(*b*) Teleprinter.
(*c*) Telephone.

If for transit by tube, it will be sorted on to a belt conveyor which will carry it to the tube terminal.

The treatment of a message for retransmission has already been described and will apply in both the case of (*b*) and (*c*). On receipt at the sub-office the message will be enveloped and delivered by messenger.

Telephone Subscriber. If the message is addressed to a telephone number it will be sorted on to the phonogram room band conveyor. On arrival, it will be given to an operator to dictate to the subscriber and a confirmatory copy of the telegram is sent by post if required.

Telex Subscriber. In the case of a message for a Telex subscriber the address will contain the word "Telex" and the Telex number. The message will be sorted on to the band conveyor to the printergram section and on arrival will be given to an operator for transmission to the subscriber.

The whole of the foregoing routing arrangements is shown schematically in Fig. 15.24.

Main and Intermediate Distribution Frames. All the underground telephone and telegraph cables which are brought into a building containing a

telegraph office enter, via ducts, into a cable chamber which is usually situated in the basement of the building. The underground paper-core cables are jointed in this cable chamber to silk and wool insulated cables which are led away and terminated on line fuse mountings on the Main Distribution Frame (M.D.F.). The M.D.F. also provides facilities for inserting heat coils and lightning protectors into each cable pair and Fig. 15.25 shows schematically how these are connected in circuit. The details of construction and design of an M.D.F. are the same as those employed for termination of underground cables in telephone exchanges and will not therefore be described here in detail.

The purpose of the fuses, heat coils and protectors is to protect the telecommunications apparatus from the effects of excessive voltage or current occurring on the line circuits as the result of contact with power feeders, etc., or lightning surges. The fuses are rated to carry 1·5 A continuously without deterioration, 2·25 A for 15 sec without operating, and to blow within 30 sec with a current of 3 A, so disconnecting the external line from the apparatus in the building.

The heat coil consists essentially of a small wire-wound heating element which carries the current in the line. The heating element surrounds a spring-loaded metal plunger which is normally held in position by a low melting point solder. Below a certain critical current value the watts dissipated in the heat coil are not sufficient to melt the solder but if the current is increased for a sufficient period it will cause the solder to melt and allow the metal plunger to be forced into contact with an earth connexion, so earthing the line concerned. A typical heat coil in use has a resistance of 4 Ω and is specified to carry 0·35 A for three hours without operating, but to be actuated by a current of 0·5 A within 210 sec.

It will thus be seen that, if a high voltage condition on the line occurs and produces an abnormal current, if it is sufficiently great and sustained it will operate the heat coil, even though it may be insufficient to blow the line fuse. In this connexion, however, it will be observed from Fig. 15.25 that when the heat coil has operated and earthed the line the increase in line current which then occurs may blow the line fuse and so disconnect the line circuit.

The lightning protector is designed to earth the line when its potential above earth exceeds a predetermined value, e.g. 500–750 V. One form consists of two carbon blocks, one earthed and the other connected to a line wire, which are held firmly together under spring pressure but whose contact faces are insulated from each other by a very thin film of special varnish. An excessive voltage produces a small puncture in the varnish where the discharge arc occurs. The heat produced by the arc causes the varnish to flow and fill the puncture when the excess voltage condition is removed. The protector is therefore self-sealing and normally lasts for many years.

If a sustained voltage overload occurs on the line and punctures the protector, then the sustained arc on the protector results in the flow of a heavy overload current and this blows the line fuse and disconnects the line from the internal apparatus. It will be seen that the combined protection given by the line fuse, heat coil and protector is considerable and of great importance, as it minimizes the danger of damage to the internal apparatus and reduces the fire risks.

The M.D.F. provides a convenient point for disconnexion and access to the line for testing and fault localizing between internal and external plant. The external underground cable pairs are usually terminated in pair order on the fuse blocks of the M.D.F. and a jumper field is provided which enables the line circuits to be through-connected or jumpered across, as required, to tag blocks from which cables are run to the Intermediate Distribution Frame. The purpose of an I.D.F. in a telegraph office is similar to that of an I.D.F. in a telephone exchange, namely, it provides facilities for interconnecting lines and apparatus in any desired manner by means of appropriate jumper wire connexions between tag blocks. The I.D.F. enables circuit re-arrangements to be made readily at any time by shifting the jumper wire connexions.

CHAPTER 16

TELEPRINTER PRIVATE WIRES AND TELEX SERVICE

MANY organizations have a need for rapid telegraph communication between two or more points and have a sufficient volume of traffic to justify leasing a circuit, or circuits, for their exclusive use. These circuits are called "private wires" and the B.P.O. has for many years leased such circuits to private renters when suitable line plant could be made available. Prior to 1930 telegraph private wires were mainly rented by telegraph cable companies for transmitting cablegrams and by newspapers and news agencies for the collection and dissemination of news. The rate of growth of private wire service was at first slow, owing to the shortage and cost of suitable lines and the specialized nature of the telegraph instruments then employed. This situation was drastically changed in the early 1930's due to various developments which gave a considerable impetus to the demand for leased telegraph circuits.

From about 1927 a large number of underground telephone cables were laid in which the conductors were arranged on the star-quad principle. As explained in Chapter 7 the phantom circuits derived from the telephone side-circuits of these cables were unsuitable for use as speech circuits but eminently suitable for direct current signalling. These phantoms were therefore suitable for use as telegraph circuits provided the voltage and amplitude of the signalling currents were limited and low-pass filters fitted to prevent interference with the speech circuits. Double-phantom circuits in multiple twin cables are also suitable for telegraph signalling provided similar safeguards are taken. From about 1930, a large number of phantom and double-phantom circuits, sometimes called by-product circuits, became available in excess of those required to meet the needs of the public telegraph service and the B.P.O. decided to offer these at low tariff rates for use as leased telegraph private wires. By this date also, the page-type teleprinter had been developed having a keyboard which only required typewriting skill for its operation and which worked on the simple start-stop signalling principle, so dispensing with the need for continuous synchronism. It was therefore ideally suited for use in business houses and undoubtedly has had a profound effect ever since upon the uses made of leased telegraph services. At the present day leased teleprinter services are being used extensively in the United Kingdom throughout industry, commerce and government service, including defence. A wide range of uses and facilities are catered for including teleprinter point-to-point simplex working, teleprinter broadcast and conference systems, concentrator working and manual and automatic switching networks.

Another form of service, which will be described later, is the "Telex Service" which provides a switching service for teleprinter subscribers similar to that provided for telephone subscribers. The Telex service when introduced in the U.K. in 1932 was in fact worked over the telephone network, using a single-tone voice frequency carrier signal which was keyed on and off by the teleprinter transmitter. This method of working has now been replaced by a switched teleprinter exchange system independent of the telephone network and employing telegraph channels. Single-tone 1,500 c/s signalling is however being retained for use on telephone private wires where alternative teleprinter working is required. The equipment employed by the renter for teleprinter working over a telephone private wire circuit is identical with that previously used for Telex service over the telephone network but is normally connected by a telephone extension circuit to the renter's P.B.X.

When teleprinter private wire service on by-product circuits was first introduced the demand for service was so great that the by-product circuits on some routes were fully absorbed within a few years and necessitated the provision and use of channels in M.C.V.F. telegraph systems to meet further expansion. By 1946, the growth of private wires had been so extensive that the great majority of long distance circuits were routed entirely on V.F. channels, apart from the local physical ends. Meanwhile increasing demands had arisen for teleprinter switching facilities which necessitated the use of telegraph transmission links having low distortion so as to permit several links, i.e. three, four or five, to be connected in tandem on a switched connexion. By-product circuits are unsuitable for this use and this factor coupled with the greater stability and ease of maintenance of V.F. channels caused the B.P.O. to standardize the use of M.C.V.F. telegraph channels for all long distance teleprinter private wire circuits. This decision enabled the provision of circuits for both the public and private wire services to be rationalized and secured considerable flexibility in the use of

the vast network of M.C.V.F. telegraph systems then existing. Nowadays modern telephone carrier circuits permit as many as 24 send and receive telegraph channels to be operated over one four-wire circuit, thus securing even greater economy in the use of line plant.

Short distance circuits are provided by means of a pair of metallic conductors in telephone cables, the renter's equipment is, however, the same as that employed on long distance circuits and employs ± 80 V signalling with local record facilities provided by means of the teleprinter send-receive switch. Chapter 7 describes the principles of operation of such circuits and also those using by-product circuits and V.F. channels.

When by-product circuits were used, the teleprinter local record was originally provided by a local record relay at a main terminal station to which the renter's teleprinter was connected by a physical pair in a telephone cable. The main terminal station also housed the other specialized equipment required for interconnecting the by-product circuit with the renter's local end, i.e. the duplex balance, and transmitting and receiving relays. Long circuits were equipped with intermediate repeaters and required a good deal of maintenance for satisfactory service. All of this equipment has now been ousted as the result of standardizing the use of V.F. channels.

Prior to 1939 teleprinter switching on telegraph circuits was in an elementary state of development. Simple extension switching on a point-to-point simplex circuit was commonly employed, as described in Chapter 8, and concentrator and broadcast switchboards were in fairly extensive use giving switching facilities for simplex working between teleprinters in a central office and selected outstations and also broadcast facilities from the central office. The principles of these arrangements are also described in Chapter 8 and were very popular with City and County Police Authorities and the Air Ministry Meteorological Service.

Nowadays, complete inter-connexion between stations in a network is more commonly required and the earlier types of switchboards are being replaced by modern teleprinter switchboards giving comprehensive switching and broadcast facilities. A great deal of development work was done during, and since, the war years 1939–1945, resulting in the production of a wide range of teleprinter switchboards. It was largely the experience of teleprinter switching in the war years which gave rise to the considerable present-day commercial and governmental use of such systems. Chapter 8 describes the principles of operation of these switchboards, including those of the latest form of teleprinter manual switchboard which conforms to the internationally agreed C.C.I.T. standards for signalling. The latter type of switchboard is used on the new B.P.O. Telex service which employs a trunk network composed entirely of V.F. telegraph channels for national and international service.

Telex service is expanding rapidly on a world-wide scale and in the U.K. it is planned to replace the manual exchanges by automatic exchanges within a few years, commencing in 1958. When this programme is completed the setting-up of any national call and some international calls will be controlled entirely automatically by dialling. The principle of operation of the U.K. exchanges will be essentially similar to those described in Chapter 9 but will also cater for local-record working and include automatic metering of local and trunk call charges.

Teleprinter Private-wire Circuits Provided over By-product Circuits. The following brief descriptions of the arrangements used for the provision of teleprinter private wire circuits using by-product circuits are given as a matter of historical interest.

A schematic circuit arrangement for a teleprinter private wire provided on a by-product circuit is shown in Fig. 16.1. Each renter is provided with a Teleprinter No. 7 and table which accommodates the necessary auxiliary equipment, and this installation is connected by means of a send and receive line to the nearest private wire terminal. The equipment at the terminal consists of a local relay panel and a line relay panel, the send and receive lines from the renter's office being connected to the local panel and the pair of wires from the by-product circuit to the line panel.

Local Panel. The circuit arrangement of the local panel is shown schematically in Fig. 16.2. It will be seen that the teleprinter transmitter is connected via a low-pass filter to the local send line, which in turn, is connected at the terminal station in series with a shunted capacitor, the line coils 1–2 of a transmitting relay and a local record relay, and thence to — 40 V battery. The resistance of the shunted capacitor is adjusted to a value which limits the steady-state local line current to 15 mA. The local record and transmit relays are biased by a permanent marking current, via coils 3–4, from the — 40 V battery. When the teleprinter transmitter is resting on its marking contact, the send wire is disconnected, with the result that no current flows in the local send wire. The transmitting and local record relays are both operated to mark by the effect of the current in the bias coils. The tongue of the transmitting relay is connected via a low-pass filter to the line relay.

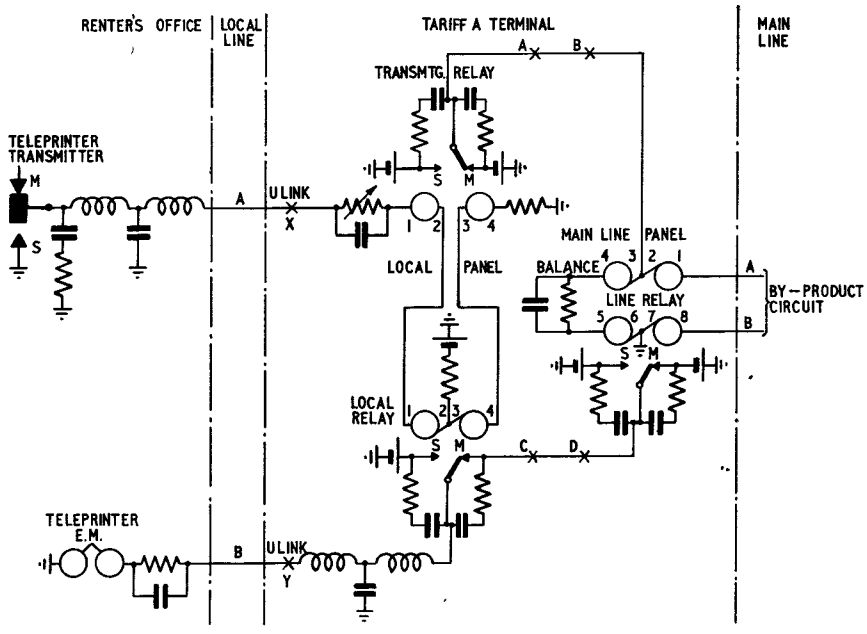


FIG. 16.1. SCHEMATIC DIAGRAM OF A TELEPRINTER PRIVATE WIRE USING A BY-PRODUCT CIRCUIT

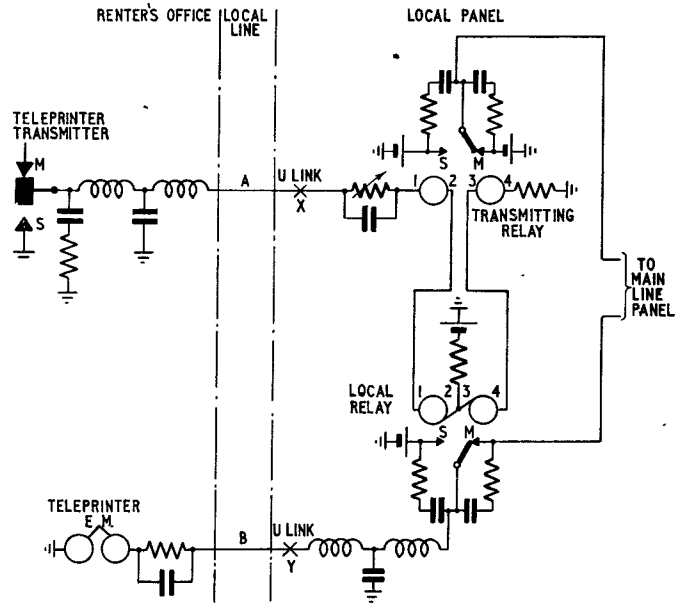


FIG. 16.2. SCHEMATIC DIAGRAM OF LOCAL PANEL USED FOR TELEPRINTER PRIVATE WIRE ON A BY-PRODUCT CIRCUIT

Main Line Circuit. The arrangement of the main line circuit is such as to permit the use of earthed batteries and at the same time afford protection against interference with adjacent telephone and telegraph circuits. Similarly, the circuit itself is afforded protection against inductive interference and earth currents. The circuit details of such an arrangement are given in Chapter 7.

Teleprinter Private-wire Circuits Provided by means of Channels in Multi-channel V.F. Systems. The standardization of V.F. telegraph channels for the dual use of private and public services has enabled an economy in maintenance costs to be achieved and a more stable and efficient service to be offered to renters. In addition it has enabled switching facilities to be provided whenever required.

Renter's Equipment and Method of Obtaining Local Record. The renter is provided with a Teleprinter No. 7 (usually a page printing model) together with a modern steel office table on which the teleprinter stands. The table is fully wired and partially equipped when issued from stores, thus enabling the equipment to be conveyed to the renter's premises as a compact unit. The teleprinter is plugged into a socket mounted on a baseboard which also carries a clearing key for use in connexion with switchboard working, a key for connecting the teleprinter in local for test purposes and a key for connecting either a lamp or bell alarm signal, the power for which can be obtained from a dry battery or via a transformer when a.c. mains are available. This arrangement reduces the installation work to a minimum. Where a.c. mains are available metal rectifiers are used to provide the line power and in the case of d.c. mains, rotary converters are employed. The metal rectifiers are bolted in position underneath the table and the rotary converters are carried on a shelf fixed underneath the table. Auxiliary apparatus is mounted on a metal base as a unit and is protected by a cover. The unit contains a shunted capacitor for connexion in series with the teleprinter electromagnet, a filter for the send line between the renter and the V.F. terminal, and spark quench circuits for the teleprinter contacts. A schematic diagram of the connexions of a renter's equipment is shown in Fig. 16.3 and a wiring diagram in Fig. 16.4.

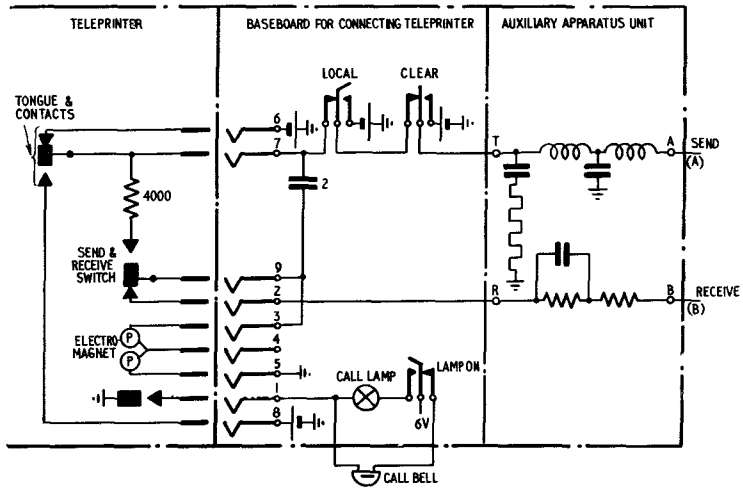


FIG. 16.3. SCHEMATIC CIRCUIT DIAGRAM OF TELEPRINTER PRIVATE WIRE RENTER'S EQUIPMENT

On teleprinters used by renters a local record of sent message is usually required. When by-product circuits were used the local record was provided by means of a relay on the local panel at the terminal equipment (see Fig. 16.2), the relay being operated by signals from the renter's teleprinter. In order to avoid complication of equipment at the V.F. terminal, to save space and to keep the terminal equipment standard for both private wire and public service circuits, no local record being required in the latter case, a means of obtaining the local record on private wires by using the send-receive switch on the teleprinter was devised. (Details of the operation of the switch are given in Chapters 7 and 9.)

The local record circuit is shown schematically in Fig. 16.5. It will be seen that the receive line between the renter's teleprinter and the V.F. terminal is connected via a shunted capacitor to the *R* contact of the send-receive switch. The

teleprinter electromagnet is connected to the tongue of the send-receive switch which, except when the teleprinter is transmitting, rests on its *R* contact and thus can receive incoming signals from the

A typical renter's equipment is shown in Fig. 16.6.

Switching Facilities Available to Renters

To permit the switching of long telegraph circuits

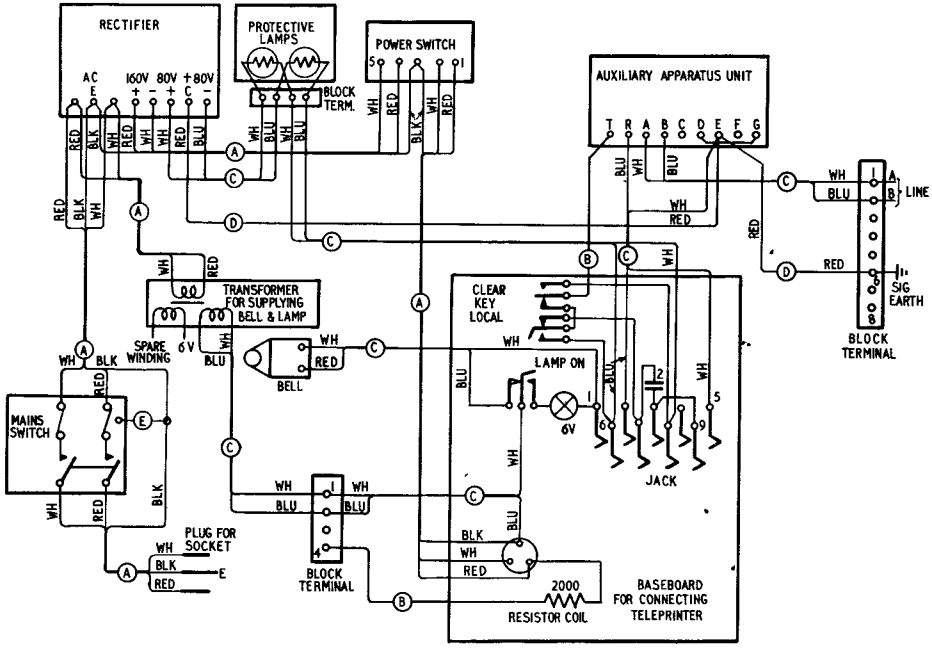


FIG. 16.4. WIRING DIAGRAM OF TELEPRINTER PRIVATE WIRE RENTER'S EQUIPMENT

V.F. terminal. The transmitting tongue is connected to the send line between the renter's teleprinter and the V.F. terminal, and also to a local record leak circuit via a resistance of 4,000 Ω to the *S* contact of the send-receive switch. A capacitor of 2 μF is permanently connected between the teleprinter tongue and electromagnet and this is shunted by the 4,000 Ω resistor when the transmitter is operated. Throughout the transmission of a character, the tongue of the send-receive switch is operated to the *S* contact thus disconnecting the electromagnet from the receive line and shunted capacitor and connecting it to the teleprinter transmitting tongue via the 4,000 Ω leak resistor. Thus, signals from the teleprinter tongue operate the electromagnet and so provide a local record of all outgoing signals. It should be noted that during reception of signals from the V.F. terminal, when the send-receive switch is on the *R* contact, an effective capacitance of 1·65 μF is connected across the electromagnet as the 2 μF capacitor is now earth connected via the 10 μF capacitor of the rectifier or rotary convertor output circuit across the *M* and *S* contacts of the teleprinter tongue.

for teleprinter working, it is essential that the various links in a connexion should be made up of stable high grade circuits such as are provided by multi-channel voice frequency telegraph systems.

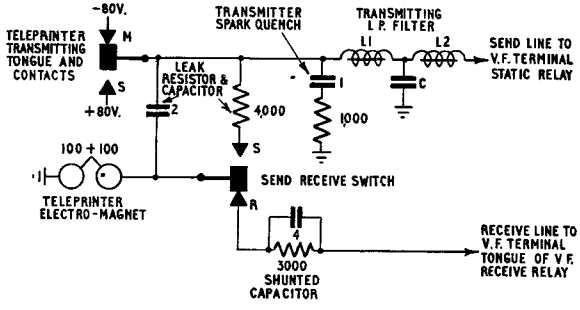


FIG. 16.5. TELEPRINTER SEND AND RECEIVE SWITCH LOCAL RECORD WORKING

By 1937 the growth of the inland voice frequency network had been considerable and between London and certain provincial centres one or more 18-circuit systems were provided entirely for teleprinter private wire services, in addition to a large number of channels appropriated in public service

systems. The availability of suitable circuits made it possible to consider the introduction of switching on teleprinter private wire circuits and for this purpose development work was commenced by the B.P.O. about 1937. This work was considerably accelerated as a result of the increased defence programmes prior to the war in 1939 which gave rise to requests from the Services and Government Departments for teleprinter intercommunication between widely separated centres.

By the end of the war a range of teleprinter switchboards was available to meet the requirements of the majority of renters and this, together with the increase that had taken place during the war years in the number of multi-channel V.F. telegraph systems available, made it possible to provide switching facilities for renters, when required.

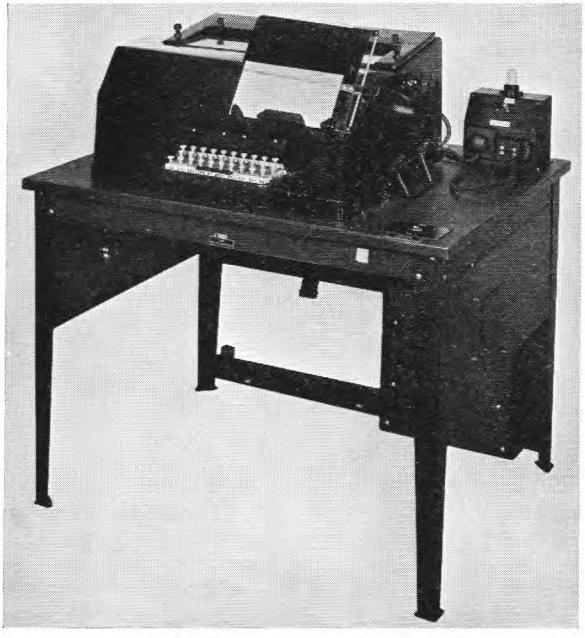


FIG. 16.6. TELEPRINTER PRIVATE WIRE RENTER'S EQUIPMENT
(By courtesy of H.M. Postmaster-General)

The type of teleprinter switchboards available for use on private wire networks will now be described. It should be remembered that in addition to these, special switchboards have been designed to meet the requirements of particular renters. The principles and circuit details of teleprinter manual switching are given in Chapter 8.

Two-line Teleprinter Switchboard. This switchboard, which is of the cordless type, is used for terminating a teleprinter private wire at a central office and an extension to a subsidiary office or works, usually not far away. Provided, however, that the link between the central office and the extension is suitable from a transmission point of view and the addition of this link does not cause the complete circuit to exceed the prescribed transmission limits, there is no reason why the subsidiary point should not be a considerable distance from the central office.

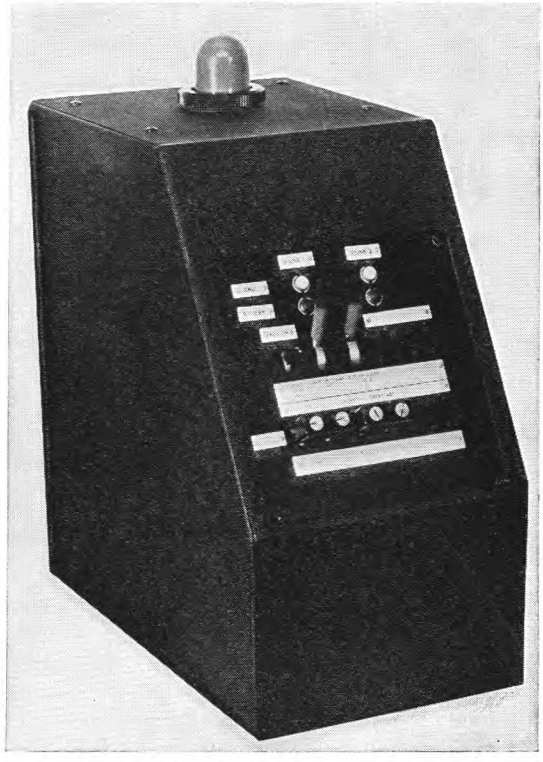


FIG. 16.7. 2-LINE TELEPRINTER SWITCHBOARD
(By courtesy of H.M. Postmaster-General)

By means of this switchboard the distant station can be connected either to the central office or subsidiary point as required or the central office can communicate with the subsidiary point. The switchboard is shown in Fig. 16.7 and its operation is described in principle in Chapter 8.

Five-line Teleprinter Switchboard. This switchboard is a cordless board and caters for five lines plus an operator's teleprinter. It is equipped with two connecting "Links" which are accessible to all lines by means of lever keys. Thus two separate connexions may be made simultaneously. The operator has direct access to each line by means of a print key, for answering calls or challenging

connexions. The operator can also monitor on either connecting link and so supervise calls in progress.

Broadcast facilities are provided so that the operator on any line can broadcast to any or all of the remaining lines. The connexion between the broadcasting subscriber and the broadcast relay is established via a connecting link. Each line is equipped with a "receive broadcast" key by means of which it can be associated with the outgoing broadcast. Lamp acknowledgment facilities are provided on lines receiving broadcast, the normal clearing relay performing the acknowledge function under these conditions.

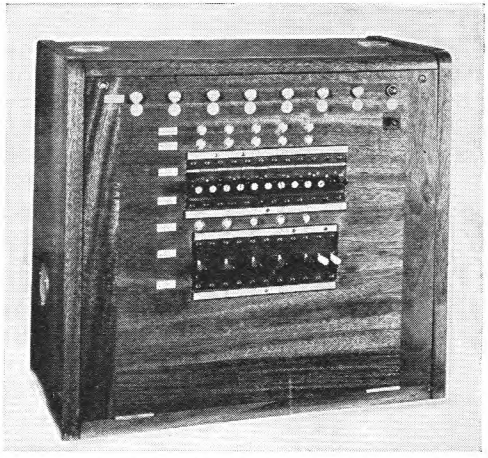


FIG. 16.8. 5-LINE TELEPRINTER SWITCHBOARD FRONT VIEW

(By courtesy of H.M. Postmaster-General)

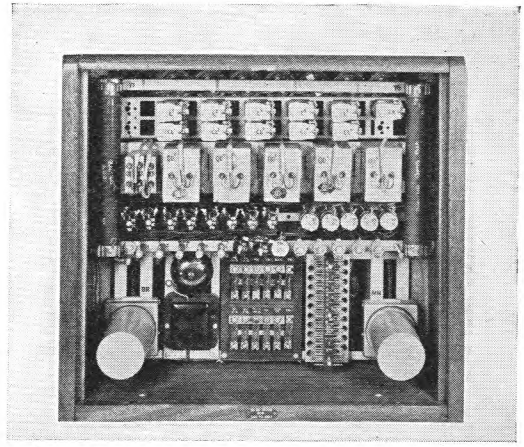


FIG. 16.9. 5-LINE TELEPRINTER SWITCHBOARD REAR VIEW

(By courtesy of H.M. Postmaster-General)

The switchboard embodies a later development of the clearing circuit in which the backward resistance of the rectifier used is stabilized by means of a shunt. A further point of interest is the method employed in the cordless switching to provide the cross-connexion between "send" and "receive" lines which is an essential requirement when switching telegraph lines. To provide for this by a system of key switching instead of cords and jacks, has added to the number of contacts which would otherwise have been necessary but, owing to the high voltages (i.e. $\pm$ 80 V) used in the circuits concerned, the fault liability is not materially affected.

Front and rear views of this switchboard are given in Figs. 16.8 and 16.9 and the circuit operation is described in Chapter 8.

Ten-line Teleprinter Switchboard. This is a switchboard which provides full inter-communication and a broadcast facility which permits any line to broadcast to all, or a selection, of the other lines on the board. The switchboard is designed for table mounting and works in association with a wall-mounted rack equipment which contains the line calling and clearing relays, the broadcast and monitoring relays, $\pm$ 80 V fuse mountings and alarms. The switchboard operator's teleprinter is a No. 7B Page or Tape and is mounted on a standard teleprinter table position adjacent to the switchboard.

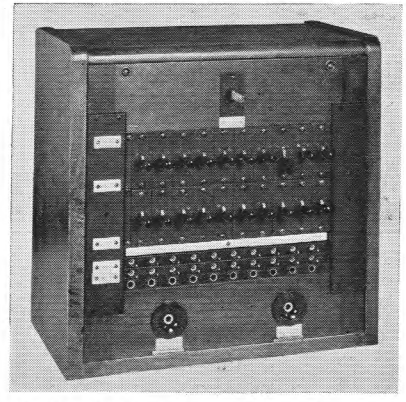


FIG. 16.10. 10-LINE TELEPRINTER SWITCHBOARD

(By courtesy of H.M. Postmaster-General)

The cord circuits are loose double-ended cords wired tip to ring and are hung on a hook at the side of the board until required for use. Fig. 16.10 shows a face view of the switchboard, the front panel of which is hinged to give access for maintenance and Fig. 16.11 shows the rack equipment.

An 80 + 80 V supply is required for operation of the switchboard and is obtained from a Westat rectifier.

The circuit operation of this switchboard is slightly different from those already described for other types, although the basic calling and clearing circuits are standard.

The lines terminate on the switchboard line jacks with an associated calling relay, but in addition a clearing relay is connected permanently to each line. The connexion of a line to its jack appearance is via the contacts of a "Print and Monitor" key and a "Broadcast" key. The position teleprinter is connected through a switchboard jack to contacts of the "Print and Monitor" key of lines 1 to 10 in series. To answer a call, the "Print and Monitor" key of the calling line is operated to "Print" and this connects the operator's teleprinter in simplex communication with the caller. Details of the required connexion are received and the call is completed by patching a double-ended cord from the line jack of the calling line to that of the required party. The operator transmits "K" to the caller and then restores the print key in readiness for the next call.

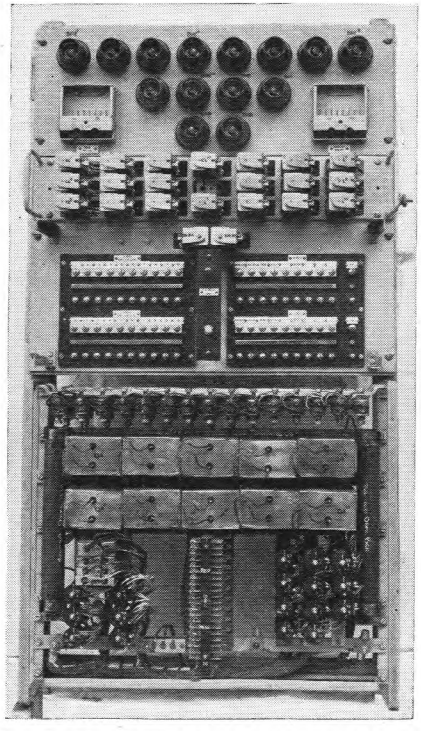


FIG. 16.11. RACK EQUIPMENT FOR 10-LINE TELEPRINTER SWITCHBOARD
(By courtesy of H.M. Postmaster-General)

To monitor an established connexion the "Print and Monitor" key of either of the connected lines is operated to "Monitor" and this connects a telegraph relay in leak from the send and receive lines and the relay repeats signals passing in the line to the operator's teleprinter.

To set up a broadcast, the calling subscriber is answered in the manner already described, the operator then operates the broadcast key for each line required and finally makes a patch, using a double-ended cord, from the calling line jack to the broadcast jack. The operator then signals "K" and restores the print and monitor key.

Clearing signals from the lines, after completion of intercommunication or broadcast calls, are obtained by each subscriber operating the clearing key in the normal manner—this lights a clear lamp associated with each line jack.

The facility is provided to enable the operator to broadcast by making a patch from the operator's position jack on the switchboard to the broadcast jack.

Thirty-line Teleprinter Switchboard. This has been designed to meet the requirements of small switching centres. This switchboard has a capacity for 30 lines (including teleprinter extensions) and one operator's position and provides full intercommunication and broadcast facilities on all lines. Only one broadcast can be made at a time, during which any line can broadcast to all or any selection of the other lines terminated on the switchboard. The switchboard is shown in Fig. 16.12. It is a floor mounted switchboard and is self-contained except for the power supply and the operator's teleprinter, which is a standard teleprinter instrument table equipped with a No. 7B page or tape machine. The switchboard installation is therefore simply and quickly installed.

The switchboard face equipment comprises a left-hand panel which accommodates the 30-line jacks in strips of ten and having a white call lamp, red engaged lamp and a designation strip above each; and a right-hand panel for broadcasting and test facilities. The right-hand panel accommodates three strips of ten broadcast keys and above each key is a green broadcast clearing lamp, a red engaged lamp and a designation label. A strip of miscellaneous jacks is mounted beneath the broadcast panel and includes a broadcast jack and three test jacks for cord circuit tests. Above the line and broadcast panels is a "broadcast failure" display panel which gives a visual indication of failure of a broadcast transmission to any line due to an earth fault.

At the top of the switchboard are mounted a Send and Receive milliameter, a 6 V a.c. to d.c. change-over switch, a fuse alarm lamp and bell-off key, and a pilot calling lamp with night alarm key.

The switchboard keyshelf is of orthodox telephone design as the operator's teleprinter is not accommodated on the switch section. It contains ten cord circuits and one test cord used for line testing. Each cord circuit consists of one answering cord and one calling cord, with a supervisory lamp associated with each cord; and one "Print and Monitor" key per cord circuit. An "Answer-Monitor-Call" key common to the position is mounted on the right-hand side of the keyshelf. All the keyshelf equipment is displaced to the left so as to be most readily accessible to the operator whose position teleprinter is fitted adjacent and to the left of the switchboard. The operator's clearing key is that fitted on the teleprinter table.

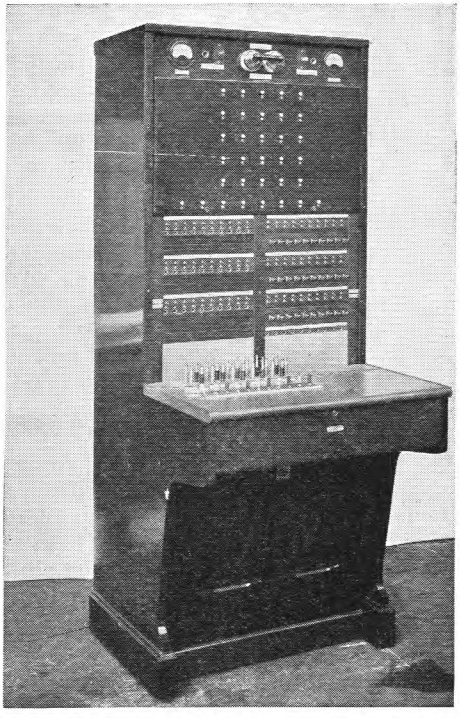


FIG. 16.12. 30-LINE TELEPRINTER SWITCHBOARD FRONT VIEW

(By courtesy of H.M. Postmaster-General)

A rear view of the switchboard is shown in Fig. 16.13 which indicates the assembly arrangements for the various lines and common equipment. It includes a 6 V mains transformer for the lamp signalling supplies and alarm type fuse mountings for the ± 80 V and 6 V supplies. All external connexions to the switchboard for incoming lines and the operator's teleprinter are terminated on a tag block.

The 80 + 80 V supply for signalling and the 160 V for the operator's teleprinter motor are derived from a Westat rectifier. If continuity of service under mains failure conditions is essential then an 80 + 80 V floating battery is used and the 6 V supply is also derived from a rectifier with a floating battery.

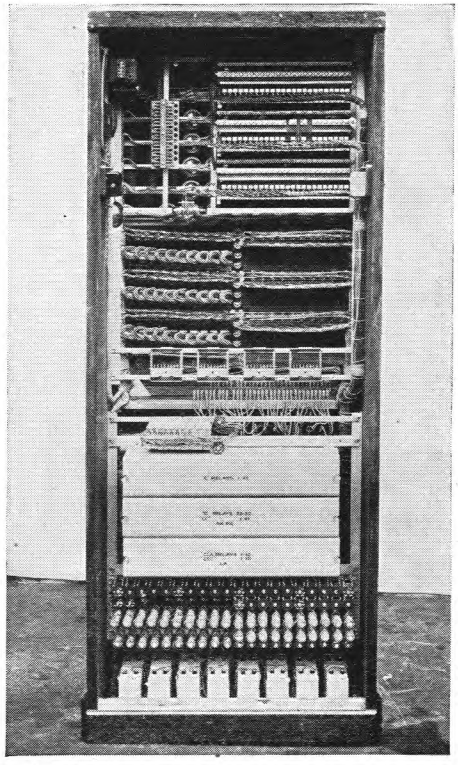


FIG. 16.13. 30-LINE TELEPRINTER SWITCHBOARD REAR VIEW

(By courtesy of H.M. Postmaster-General)

The circuit operation of the 30-line switchboard has been described in Chapter 8.

Multiple-type Teleprinter Switchboard (70 lines). This is a multiple switchboard for one or two operators' positions; it has a capacity for 70 lines and provides for full inter-communication and broadcasting by any line, with broadcast reception on a maximum of 20 lines which must be pre-selected. The broadcast arrangements cater for either a full broadcast or two simultaneous partial broadcasts to any selection of the 20 lines. Fig. 16.14 illustrates

the first operator's position of a 70-line teleprinter switchboard. A description of the circuit operation of this type of switchboard is contained in Chapter 8.

An installation consists of the following equipment—

(1) One or two switchboards teleprinter No. 8.

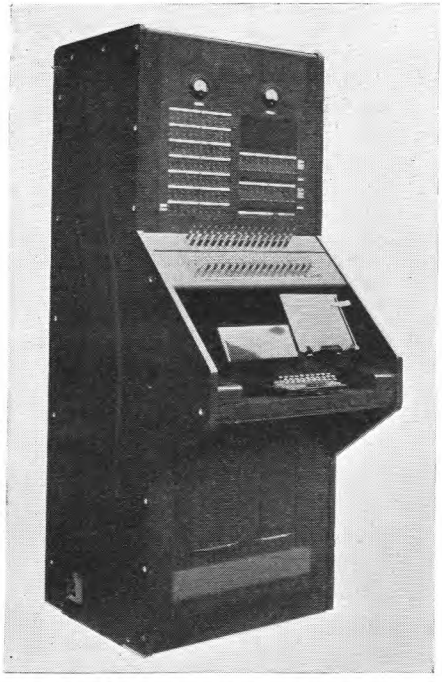


FIG. 16.14. MULTIPLE-TYPE TELEPRINTER SWITCHBOARD 70 LINES

(By courtesy of H.M. Postmaster-General)

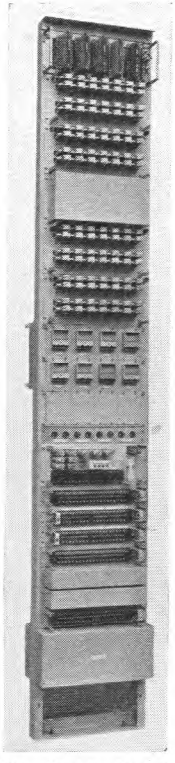


FIG. 16.15. RACK EQUIPMENT FOR 70-LINE TELEPRINTER SWITCHBOARD

(By courtesy of H.M. Postmaster-General)

(2) An equipment rack, which contains the common equipment for two operators' positions, and line relays for 70 lines.

(3) An I.D.F.

(4) A miscellaneous equipment rack.

(5) Mains operated power plant for 80 + 80 V and 6 V supplies.

The face equipment consists of two panels, of which the left hand accommodates the line appearances and the right is equipped for broadcasting. The broadcast panel is, however, only equipped on the first operator's position and is used by both operators.

The line multiple is used for both answering and calling on an ancillary basis and the lines are terminated in strips of ten arranged so that above each line jack appears a calling lamp (white), an engaged lamp (red) and a designation label. The broadcast panel is equipped with two strips of ten keys each, arranged so that above each key is an engaged lamp (red), a broadcast clearing lamp (green) and a designation label.

A miscellaneous jack strip is provided at the bottom of the panel and accommodates two broadcast jacks and test jacks, the latter for use in connexion with cord circuit tests.

The keyshelf and operator's teleprinter equipment is identical with that provided on a switchboard teleprinter No. 9 (see p. 633) except that instead of a duplicate connexion facility a test cord is fitted. The test cord is wired to two milliammeters fitted above the switchboard panels and is used to check the send and receive currents in the lines and currents in the broadcast relays. The test jacks used in conjunction with the milliammeters enable the cord circuits to be checked.

All cord circuit relay equipment is mounted in the rear of the switchboard and two tag blocks are provided for the termination of wiring from the broadcast panel and one block for miscellaneous leads. Earth bars for rack and signalling purposes and an insulated 6 V lamp return bar are provided and cabled direct to similar bars on the equipment rack.

The Equipment Rack. This is shown in Fig. 16.15 and is a standard rack 1 ft $8\frac{1}{2}$ in. wide and 10 ft 6 in. high and accommodates the following equipment—

(1) The line and cut-off relays for 70 lines mounted on five panels.

(2) Monitoring relays for two operators' positions.

(3) Four broadcast relays.

(4) Bulbs resistor for the monitoring relays and operators' teleprinters.

(5) A fuse alarm panel.

(6) $\pm$ 80 V and 6 V alarm type fuse mountings.

(7) A 6 V mains transformer for lamp signalling supplies.

All rack wiring is terminated on connexion strips at the top of the rack from which cables are run to the I.D.F. for the line circuits (five wires T, R, S, C and E per line) and to the switchboard for miscellaneous leads. The switchboard line jacks and their associated call and engaged lamps are cabled to blocks on the I.D.F. and the broadcast connexions. Thus by suitable jumpering any line may be connected to any line equipment and multiple appearance, and any selection of 20 circuits may be connected for broadcast reception facilities.

The Miscellaneous Equipment Rack. This is used for accommodating line filters and line relays which may be required for repeating signals on long physical lines.

Where the amount of miscellaneous equipment is small, however, a wall-mounted rack may be used.

Power Supplies. The 80 + 80 V and 6 V power supply and alarm arrangements are similar to those which will be described later for the 560-line type of switchboard. In some cases, however, battery stand-by is not provided and the 6 V supply is then derived from the 6 V mains transformer on the rack equipment. On earlier type installations the 6 V supply was normally taken from the transformer and under conditions of mains failure a no-volt alarm was given and mercury switches automatically changed over to a 6 V battery supply. Upon restoration of the mains supply the load was restored to the mains transformer and the battery disconnected. A 6 V change-over panel, mounted external to the rack equipment was used for this purpose.



FIG. 16.16. A SUITE OF MULTIPLE-TYPE TELEPRINTER SWITCHBOARDS
(By courtesy of H.M. Postmaster-General)

Multiple-type Switchboard (560 lines). This is a multiple type of switchboard used for large switching centres. It provides for full intercommunication for a maximum of 560 lines, while broadcasting facilities are provided for by means of special equipment associated with the Cable Turning Section, as will be described later. Fig. 16.16 shows a typical suite of switchboards. A description of the circuit operation of this type of switchboard is given in Chapter 8.

An installation consists of the following equipment, viz.—

(1) A suite of switchboards with a cable turning section (C.T.S.)

(2) A common equipment rack which contains the apparatus for 24 operators' positions.

(3) A number of line equipment racks each containing the line relays and associated apparatus for 100 lines.

(4) A miscellaneous equipment rack on which is mounted line filters and telegraph repeaters for physical circuits.

(5) An I.D.F. on which to terminate and jumper the cabling from the above equipment and lines.

(6) Mains operated power equipment for 80 + 80 V and 6 V supplies.

The design of the switchboards follows normal telephone practice, except that in order to accommodate the operator's teleprinter under the keyshelf a special frontal design has been necessary.

Each section, which is known as a Switchboard Teleprinter No. 9, comprises an operator's position and is equipped with two jack panels. The multiple is used for both calling and answering on an ancillary basis and has a capacity of 140 lines/panel, so that with a three-panel multiple the maximum number of lines is 420. A four-panel repetition can

be employed, and the multiple capacity is then 560 lines. This arrangement, however, has the disadvantage that access on the last operator's position is restricted.

Free line signalling is provided on all lines, the first free line in each group being indicated by a lamp glowing behind a green stile strip. The lines are terminated on the switchboard panels in strips

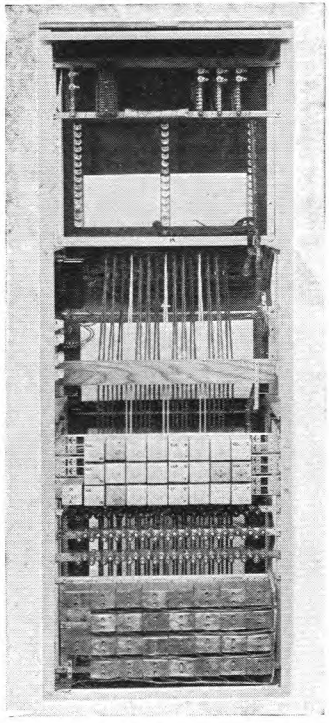


FIG. 16.17. REAR VIEW OF MULTIPLE-TYPE TELEPRINTER SWITCHBOARD
(By courtesy of H.M. Postmaster-General)

of 20 arranged with a call lamp below and an F.L.S. lamp and designation label above each strip.

The keyshelf, which is mounted immediately below the line panels, slopes downwards towards the operator and is hinged to facilitate maintenance work. The keyshelf accommodates 15 cord circuits each consisting of one answering and one calling cord with an associated supervisory clearing lamp, and one "Print and Monitor" key per cord circuit. An "Answer-Monitor-Call" key common to the position is fitted on the right hand side of the keyshelf together with a clearing press button. On the left of the keyshelf is a duplicate connexion lamp with a press button reset key.

The operator's position teleprinter is a No. 7B tape mounted on a sliding shelf below the keyshelf. The printing position is illuminated by a lamp and an "end of line" red lamp is provided to indicate, when transmitting to a subscriber, the end of a line of printing on a page machine. Both lamps are fitted below the keyshelf. The motor power socket and switch, and instrument jacks for the position teleprinter are mounted on the vertical panel behind the operator's teleprinter.

The cord circuit equipment of each position is mounted in the back of the switchboard, which also accommodates a miscellaneous tag block and bars for termination of the rack and signalling earths, as shown in Fig. 16.17. Additional blocks are provided in the C.T.S. for the termination of $\pm$ 80 V and 6 V supplies and monitoring relay wiring from the rack equipments. In addition, cables from the miscellaneous blocks in each switchboard terminate on these blocks.

Apparatus Racks. The apparatus racks which accommodate the position and line equipment are standard racks 1 ft 8½ in. wide and 10 ft 6 in. high and where possible are installed in an apparatus room. Where head-room is restricted 6 ft 6 in. racks are used and the common equipment rack then caters for 12 operators' positions and each line rack for 60 lines. The following descriptions refer only to the 10 ft 6 in. types.

The Common Equipment Rack. This is shown in Fig. 16.18 as rack 1 and contains—

(1) The monitoring relays and position apparatus for 24 operators' positions,

(2) centralized fuse alarm circuits for the whole installation,

(3) $\pm$ 80 V and 6 V fuse mountings for the common equipment, and

(4) rack and signalling earth bars from which connexions are made to the line and miscellaneous racks.

All rack wiring is terminated on connexion strips at the top of the rack from which cables run to the switchboard C.T.S.

The Line Equipment Racks. These are shown in Fig. 16.18 as racks 2, 3 and 4.

Each rack contains the line and cut-off relays with their associated circuit equipment for 100 lines. The line equipment is assembled in panel form with five circuits per panel, while alarm type fuse mountings provide supplies for — 80 V line holding currents and 6 V power for the call and F.L.S. lamps. The line panels are cabled direct to the I.D.F., a five-wire connexion, viz. *T*, *R*, *S*, *C* and *E*, being made for each line to the appropriate tags on the line panel. Rack wiring for the call and F.L.S. lamps and alarms is terminated on strips connexion at the middle of the rack from which cables are run to the I.D.F. and to the common equipment rack for the alarm circuits.

The line jacks and the call and F.L.S. lamps in the switchboard multiple are cabled to the I.D.F. and so by suitable jumpering any line may be connected to any multiple appearance and any line appearance with any line equipment. Thus full flexibility is obtained.

The F.L.S. arrangements required are obtained by making suitable straps on a connexion block at the middle of the rack. The maximum number of lines in one F.L.S. group is limited to five and where more than five lines exist on one route they are split into groups of five each for F.L.S. purposes.

The Miscellaneous Equipment Rack. This rack is fitted adjacent to the line racks and accommodates any miscellaneous items of apparatus, e.g. line filters, and telegraph repeaters, as may be required for physical lines. 80 V alarm type fuse mountings are provided and the alarms may be extended to the common equipment rack or station alarm system. All rack wiring is terminated on connexion strips at the top of the rack and is cabled from these to the I.D.F. where jumper connexions are made to the lines.

Power Supplies. The 80 + 80 V supply for the installation is derived from a single battery float scheme using either a motor generator or rectifier cubicles and the 160 V outers of this supply are used to provide current for operating the teleprinter motors on the switchboard positions. The 6 V supply is either a charge-discharge battery with a trickle charging rectifier or a single battery float scheme with a 6 V rectifier.

The battery capacites may be designed to ensure continuity of service for any reasonable period of mains failure.

Alarms. All fuse mountings on the rack equipments are fitted with bead-type fuses to give a visual indication of failure and each mounting is also fitted with a pilot lamp. The alarm from each mounting is extended to a central alarm panel on the common equipment and if desired may be connected to operate any external alarm system. "No-volt" alarms are provided in the main feeds.

Broadcast Unit. For the purpose of broadcasting a special cable turning section known as a switchboard No. 14 is provided, which gives broadcast facilities on a maximum of 80 of the lines terminated on the No. 9 switchboard.

The lines required to receive broadcasts must be pre-selected and wired accordingly via the broadcast keys of the No. 14 switchboard before terminating in the No. 9 switchboard multiple. The broadcast facilities permit any line connected to the No. 9 switchboard to broadcast, but only 80 pre-selected lines may receive. A maximum of two simultaneous partial broadcasts can be made.

The line broadcast keys are mounted together with their associated engaged and clearing lamps in a special panel fitted as an extension to the key-shelf of the C.T.S. of the No. 9 switchboards, as shown in Fig. 16.16. The wiring from the broadcast panel terminates on blocks in the C.T.S. and is then cabled to the miscellaneous equipment rack and I.D.F. for jumpering to the appropriate lines. The

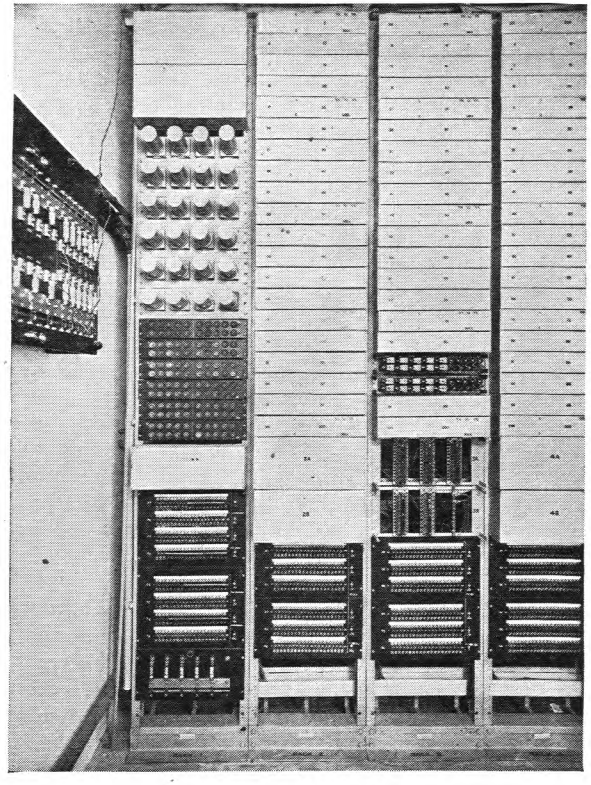


FIG. 16.18. APPARATUS RACKS FOR MULTIPLE-TYPE TELEPRINTER SWITCHBOARDS
(By courtesy of H.M. Postmaster-General)

clearing and broadcast relays and other circuit equipment is mounted on the miscellaneous equipment rack. The two broadcast jacks are fitted in a miscellaneous jack strip on the first switchboard operator's position and all requests for broadcast transmission received by other operators are passed to this operator for completion.

Conference System. Facilities are sometimes required for connecting a number of subscribers together in such a manner that any one subscriber can transmit signals simultaneously to all the remaining subscribers and at the same time receive a local record of the signals transmitted. Such an

arrangement is known as a conference system. Full details of the circuit arrangement used by the British Post Office are given in Chapter 7.

Telex Service

Telex service may be defined as "a subscriber's switched telegraph service enabling the users to communicate directly and temporarily with one another by means of start-stop apparatus." A teleprinter is normally used as the subscriber's operating instrument but provision for alternative transmission, using an automatic transmitter, is frequently made. The introduction of telex service in the U.K. was first examined about 1930 and the following three alternative methods of working were considered—

Method 1—was to provide a special telegraph exchange network in which the exchanges, whether automatic or manual, would serve the subscriber's teleprinter over a single-current physical loop circuit. The exchanges were to be interconnected by special telegraph junction and trunk circuits, worked either by direct current signalling or by using voice frequency signalling over telephone circuits.

The principal objections to this scheme were the large capital expenditure which would have been involved in the provision of the teleprinter exchanges and the unavoidable delay which would have occurred in opening the service.

Method 2—was to connect each subscriber's circuit, operating on a single-current physical loop, to the local telephone exchange at which special converter equipment would be provided to convert the d.c. teleprinter signals to alternating current of amplitude and frequency suitable for transmission over the transmission network employed for speech transmission. Converters would also be provided to convert the a.c. signals received from telephone lines into d.c. signals to the subscriber's teleprinter. These converters would have been provided either on individual telex subscribers' lines or on a traffic basis. The connexions between subscribers were to be effected over the normal telephone trunks and junctions and switching plant.

This scheme had the merit from the point of view of capital outlay and operating charges of using the existing telephone network and would have concentrated the special V.F.-d.c. conversion equipment at the telephone exchanges, so facilitating maintenance and reducing costs.

Method 3—involved equipping individual subscribers installations with a voice frequency signalling oscillator and a V.F.-d.c. converter, so that V.F. signals could be used throughout the complete line transmission path from sub to sub.

This arrangement had the great merit of enabling the whole of the existing telephone network, together with its operating and switching facilities, to be placed from the outset at the disposal of the telex subscribers. Thus any two points between which telephone communication was possible were also potentially suitable for teleprinter communication. This scheme was very attractive as the total capital outlay was small, being only proportional to the actual number of subscribers. Furthermore, the specialized telegraph equipment involved could be provided easily, so enabling the service to be opened with a minimum delay. The relatively small initial traffic could also be handled readily by the existing telephone plant.

For these reasons Method 3 was adopted and in June, 1932, the service was opened for B.P.O. administrative use followed by the opening of a public service in London on 15th August of the same year. The service was extended to provincial towns very shortly afterwards.

Similar services were also opened in several other European countries and in 1936 an international telex service, using 1,500 c/s signalling, was established between the U.K. and Amsterdam and subsequently to a number of other countries. The use of telex service over the telephone network was continued in the U.K. and a number of other European countries until recent years. The service proved very popular, especially for international communications but many problems and difficulties were encountered due to the joint use of telephone lines and switching equipment. As the result of these difficulties and their effect upon the stability of service it had become evident for many years that, with the service well established and assured of a steady expansion, the time had come to divorce the system from the telephone network and convert it to one using purely telegraph circuits and switching equipment. This policy has been followed by all European administrations and the conversion of the telex network in the U.K. was completed during 1954.

The principles which were employed in the operation of the telex system over the telephone network in the U.K. will now be described not only as a matter of historical interest but also for the reason that most of the details of the equipment used and problems involved are equally applicable to the numerous cases in which private wire telephone circuits are used alternatively for speech and teleprinter communication.

Telex Service on a Telephone Network. For telex transmission over a telephone network, teleprinter signals must be within the frequency range required for the telephone system. Single-tone voice

frequency currents are therefore utilized for transmission purposes, tone being transmitted for spacing elements and no-tone for marking elements and idle periods. At the receiving end, the voice-frequency currents are rectified to operate the electromagnet of the teleprinter and a similar process occurs, via a leak circuit, at the sending end to provide a local record.

Equipment Required. A page printing machine, the Teleprinter No. 7B, and certain auxiliary equipment is associated with each subscriber's installation. The most important item of auxiliary equipment is a voice-frequency converter, the function of which is—

(1) to provide the single-tone voice-frequency current which is modulated by the teleprinter transmitting contacts; and

(2) to convert the received voice-frequency signals into double-current impulses suitable for operating the teleprinter electromagnet.

The converter consists essentially of an oscillator and a detector-amplifier; power for the filaments and anodes of the several valves being taken from the supply mains. A telephone set is provided for the purpose of setting up calls, and also to give alternative telephonic communication when desired. A change-over switch, to enable a subscriber to connect either the telephone or the teleprinter to line as required, completes the essential features of the installation. At the telephone exchanges no additional equipment whatever is required, except for the detailed refinements described later in this chapter.

Operating Procedure. To originate a call, the subscriber lifts the telephone and, depending upon whether the installation is connected with an exchange of the automatic or the manual type, either dials or asks for the number of the wanted subscriber. The distant subscriber, on answering, is requested to "switch to teleprinter." Both parties to the connexion then move their change-over switch to the teleprinter position and replace the telephones. The result of this operation is to start the teleprinter motor and to extend the line to the teleprinter circuit at each end of the connexion. The calling party then depresses the Figures and Who are You? keys of the keyboard, thus actuating the answer-back unit of the distant teleprinter. By this means, the caller obtains verification that connexion to the correct subscriber's installation has been effected, and also that the teleprinter has been switched to line and is functioning correctly. Teleprinter messages can then be transmitted in either direction, alternately.

The circuit of a subscriber's installation is designed to give a local record of all transmitted signals. This facility provides a file copy of outgoing messages, confirms to the subscriber that signals are being transmitted correctly, thus enabling any typing errors to be immediately detected, and also indicates when depression of the Carriage Return and Line Feed Keys is required. On completion of teleprinting, both parties restore their change-over switches to the telephone position. By this means, both telephones having been previously restored to their cradles, the clearing signal



FIG. 16.19. TYPICAL TELEX INSTALLATION OF THE TYPE WHICH WAS USED FOR WORKING OVER THE TELEPHONE NETWORK

(By courtesy of H.M. Postmaster-General)

is given at each end of the connexion, and the teleprinter motors are switched off. If desired, the telephones may be lifted prior to restoring the change over switches, to afford alternative telephonic communication; clearing is then dependent upon replacing the telephones upon the cradles.

Once the call has been set up, the continuous attention of the called subscriber for the purpose of receiving a message is not essential, since attention can be called at any time by depression of the Figures and Bell keys to operate the teleprinter alarm bell of the distant installation.

Details of Equipment. Fig. 16.19 shows the standard installation which was provided for a subscriber in an area served by an automatic exchange when telex service was provided over the telephone network.

As in the case of a Private Wire Renter a modern

steel office table accommodates the whole of the equipment comprising the installation, the only installation work requiring to be done *in situ* being the connexion to the exchange line and plugging into an adjacent five amp power socket.

All equipment not required for use by the teleprinter operator is conveniently mounted beneath the table. The table top is thus left clear to give the maximum amount of space for operating purposes.

The teleprinter terminates its connexions in a nine-way instrument plug and cord and a three-way

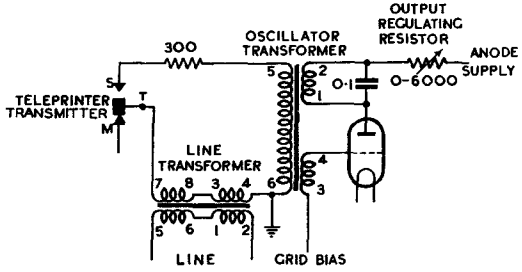


FIG. 16.20. OSCILLATOR CIRCUIT OF 1,500 c/s V.F. TELEGRAPH CONVERTER

power plug and cord. A nine-way instrument jack and a three-way power socket are suitably fitted into a metal case to form a base board which is secured to the rear right-hand position on the table. The base board also houses two 2 μF capacitors associated with the electromagnet coils of the teleprinter.

The change-over switch is fitted towards the front right-hand corner of the table. This switch comprises a tumbler switch for controlling the connexions of the teleprinter motor and the V.F. converter to the electric supply mains, coupled to a lever type telephone key which connects the exchange line either to the telephone or the teleprinter circuit. The coupled keys are secured to an engraved key mounting which is fitted flush with the table. A small metal case protects the wiring of the key.

The connexions of the V.F. converter which is mounted under the table terminate in two plugs and cords, one being for the power supply only. The permanent wiring of the table is connected to a baseboard, which is fitted under the table. This baseboard is identical with that on the top of the table for the teleprinter, except that the 2 μF capacitors are omitted.

Two types of converter are available, one suitable for operation on a.c. mains and one for use on d.c. mains. Apart from the necessary differences in adapting the power supply, the two types of converter are identical in every respect.

A six-terminal connexion strip is fitted to the table as a terminating and testing point for the exchange line.

Description of 1,500 c/s Voice-frequency Telegraph Converter. This apparatus together with the teleprinter is the essential part of the telex equipment. The converter comprises two separate panels, the valve panel and the power panel, mounted upon a common base and connected together by a short cable soldered to the connexion tags of each panel. A protective cover, fitted with a lock, encloses the whole of the apparatus. Suitably placed holes in the cover provide ventilation for cooling purposes. All electrical connexions from the V.F. converter are brought out through cords to a signalling plug and a power plug which plug into corresponding jacks fitted under the teleprinter table. The converter is thus easily removed by mechanical and electrical jacking for maintenance purposes.

The converter for use on d.c. mains is fitted with a suitable power panel; in all other respects it is identical with that for a.c. mains.

The valve panel may be considered in two portions—

(1) The transmitting circuit, comprising a valve oscillator for providing the voice-frequency current. The output from the oscillator circuit is connected to the tongue (T) and space (S) contacts of the teleprinter.

(2) The receiving circuit, comprising a rectifier valve, which responds to the received signals, followed by two amplifier valves in push-pull. The teleprinter electromagnet coils are operated from the output of this circuit.

The impedance of the receiving circuit is 1,200 Ω and in order to match this to a line of characteristic impedance 600 Ω, it is necessary that the line transformer Fig. 16.21 should have a turns ratio equal to the square root of $\frac{600}{1{,}200}$, i.e. 1 : 1·414.

During transmission, a leak path from the transmitter is connected to the receiving circuit via a suitable impedance to provide a local record of outgoing signals.

Operation of 1,500 c/s Voice-frequency Telegraph Converter. *The Oscillator Circuit.* Fig. 16.20 is a schematic diagram of the connexions of the oscillator circuit. This circuit comprises a valve with which is associated an iron-cored transformer. The primary winding (1–2) of the transformer is connected in the anode circuit of the valve, and is closely coupled to the secondary winding (3–4) which is included in the grid circuit. As a result of

this coupling, interaction between the grid and anode circuit occurs and self-oscillation of the circuits is maintained. A third coil (5–6) on the transformer is used as an output winding for supplying the oscillatory current to the teleprinter contacts.

The circuit is tuned to oscillate at a frequency of 1,500 c/s by the 0·1 μF capacitor across the primary winding; this value of capacitance in conjunction with the inductance of the primary winding (110 μH) gives the correct resonant frequency. A tapped resistor coil capable of variation between zero and 6,000 Ω, in steps of 400 Ω, is included in the anode circuit; this resistor controls the anode current for the purpose of adjusting the value of the 1,500 c/s voltage in the output winding. A series resistor of 300 Ω is included in the output circuit to limit the load on the oscillator, since serious over-loading of the circuit would result in the cessation of oscillation.

The output circuit is connected via the T and S contacts of the teleprinter transmitter to a line transformer so that when these contacts are made, the 1,500 c/s current is applied to line via the transformer. Transmission is thus on an "On-Off" basis, tone being connected to line during the spacing elements of characters and the marking elements being conditions of no tone.

Interference from the oscillator to the receiving circuit is reduced to a negligible amount by screening and making the leads from the output winding as short as possible, and spacing them well from other conductors, i.e. they are not included in the cable form. This precaution is also observed in the external cabling as described later. By this means, the capacitance between the oscillator leads and other wires, and also to earth, is kept at a low value.

The output from the oscillator circuit is adjusted to 3·0 V and assuming the line to be 600 Ω, the power at the output to line is therefore 15 mW, i.e.

$$\text{Power} = I \times V = \frac{V^2}{R}\ \text{W.}$$

$$= \left(\frac{3^2}{R}\right) \times 1{,}000\ \text{mW.}$$

$$= \left(\frac{9}{600}\right) \times 1{,}000 = 15\ \text{mW.}$$

The required adjustment is made by connecting a 600 Ω non-inductive resistor across the exchange line terminals of the converter, with the exchange lines disconnected, and varying the tapping on the 6,000 Ω resistor in the anode circuit until the desired voltage is registered upon a suitable voltmeter connected across the line terminals. It is, of course, necessary for the teleprinter tongue and space contacts and also the Send contacts of the Send and Receive switch to make during this adjustment.

Choice of Transmission Frequency. The figure of 1,500 c/s as the transmission frequency for telex working over telephone networks was agreed internationally. This value lies remote from both the upper and the lower cut-off frequencies of repeatered lines and is clear of the frequency range utilized for

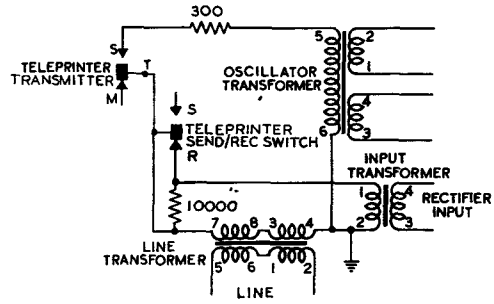


FIG. 16.21. LOCAL RECORD CIRCUIT OF 1,500 c/s V.F. TELEGRAPH CONVERTER

telephone signalling purposes, by 500 c/s ringers, and by V.F. key sending (400, 600, 750 and 900 c/s) with which mutual interference would otherwise result. With the comparatively high frequency of 1,500 c/s liability to cross-talk is greater than with a lower frequency, but the maximum sensitivity of telephone receivers occurs in the range of 100 c/s to 1,200 c/s, and it is found that no disturbance normally arises from the use of 1,500 c/s current for telex transmission. Other advantages arising from the adoption of this frequency rather than a lower one are that the effects of interference from transient disturbances such as clicks from bridging wipers in automatic switches are much reduced at this frequency; also, since a comparatively large number of cycles of alternating current (i.e. 30 per element) is obtained, the distortion which may arise depending upon the phase of the current at the moment of making T and S is reduced.

Local Record of Transmitted Signals. During transmission a portion of the 1,500 c/s current is fed via a high impedance circuit to the receiver, to provide the operator with a local record of outgoing signals. This circuit is shown in Fig. 16.21 from which it will be seen that each time the teleprinter T and S contacts make and the Send-Receive switch contacts move over to send, tone is fed to the line transformer and also to the parallel circuit formed by the input of the rectifier circuit and the 10,000 Ω leak resistor. The leak resistor is

short-circuited when the S-R switch is at receive. This arrangement attenuates any spurious signals which arrive during transmission, due to line echo, and which would thus interfere with the local record, but at the same time ensures that during reception the local record resistor causes no attenuation of the received signals.

The Rectifier Circuit. This circuit, shown

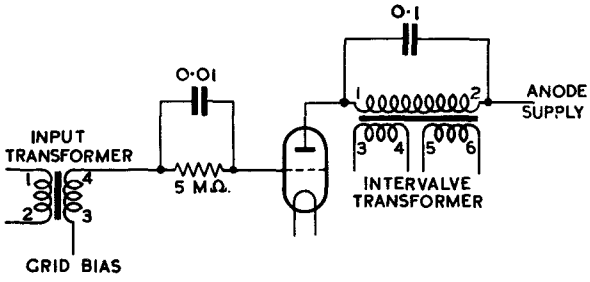


FIG. 16.22. SIGNAL RECTIFIER CIRCUIT OF 1,500 c/s V.F. TELEGRAPH CONVERTER

schematically in Fig. 16.22, combines the function of—

(*a*) a rectifier;
(*b*) a voltage limiter; and
(*c*) an echo suppressor.

The circuit comprises an input transformer, a 5 MΩ grid leak shunted by a 0·1 μF capacitor, and the valve. The input transformer has a high step-up ratio of 1:50, for the purpose of obtaining the desired grid swing from received signals. The transformer, in association with the grid-cathode capacitance of the valve, resonates at 1,500 c/s.

To minimize electrostatic and electromagnetic coupling with the oscillator circuit, the wiring of the grid circuit—i.e. that between the transformer, grid leak and capacitor, and grid of the valve—is not included in the cable form, but is well spaced from all other conductors and is made as short as possible.

Rectification. In Fig. 16.23 is plotted a characteristic curve of grid potential-anode current for the valve used. The grid of the rectifier valve is given a negative bias of some 13 V to a point on the lower bend. The arrival of a spacing signal (a condition of 1,500 c/s tone to line) across the secondary winding of the input transformer results in the application of the received signals to the grid of the valve at this biasing point. Negative half cycles of the input signals make the grid more negative and do not therefore materially affect the value of the anode current: positive half cycles make the grid less negative, to an extent depending upon the limiting action described below, and cause the anode current to increase. Owing to the action of the grid leak and capacitor, the grid potential remains sensibly constant between successive cycles of the 1,500 c/s wave, and restores to its normal biasing point on cessation of the signal. The anode current, therefore, increases at the commencement of the space signals, remains steady for the duration of the signal and decreases to normal at the termination of the signal. Rectification is thus of the half-wave type on the anode bend principle.

The 0·1 μF capacitor across the primary winding of the intervalve transformer connected in the anode circuit of the rectifying valve provides a path for the a.c. component of the rectified current. This capacitance is reduced to a minimum value in order to give a steep rise to the surges induced in the secondary windings of the transformer at the start and end of spacing signals. Its value is also critical, in conjunction with the valve impedance and the inductance and ratio of the transformer, to ensure that a surge has fully decayed before the commencement of the next signal. In an extreme case of excessive time of die-away of the surge, a subsequent marking signal would be suppressed and appear as a spacing signal.

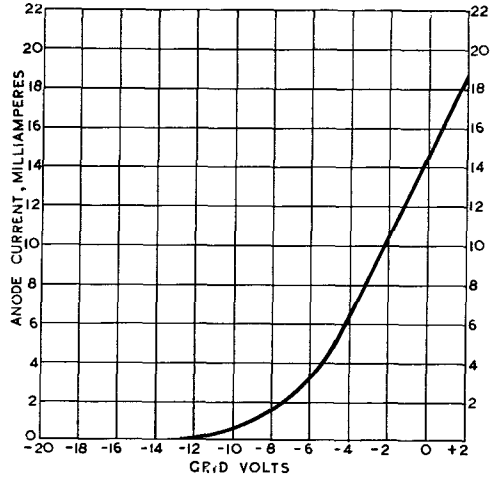


FIG. 16.23. VALVE CHARACTERISTIC

Voltage Limitation. In telex working over a telephone network, the overall attenuation of the line connecting two installations will vary between wide limits depending upon the location of the terminal instruments and the routing of the call. In practice, the converter must respond to received signal strengths which range from 3 db to 30 db below the level at the sending end for different connexions, and yet operate as far as possible independently of the value of attenuation existing

between transmitter and receiver. For satisfactory operation under all conditions it is necessary to include a compensating device, the voltage limiter, which will reduce the level (as applied to the grid of the rectifier valve) of all received signals to that obtaining in the case of the line of maximum attenuation.

This voltage limiting is effected by the grid leak and capacitor connected to the grid of the rectifying valve as follows. When strong signals are received the grid potential during positive half-cycles will become positive, to an extent depending upon the peak amplitude of the signals, and cause a flow of current in the grid-cathode circuit of the rectifier circuit. This current charges the grid capacitor and consequently the grid is made more negative to an extent depending upon the signal strength. Thereafter, only the peaks of the positive half-waves produce grid current and only the top part of the signal produces anode current. In this manner the bias upon the grid is automatically regulated by the level of the received signal so that the increase in anode current is practically constant irrespective of the line attenuation between transmitter and receiver.

Echo Suppression. When voice-frequency teleprinter signals are transmitted over repeatered lines, any unbalance of the repeater terminations results in the reflection of signals, i.e. echo, at these points. The longer repeatered circuits are equipped with echo-suppressors but, for the shorter trunk circuits, speech transmission does not necessitate the provision of suppressors: also in carrier circuits the reduced transmission time eliminates the need for them. An echo-suppressing feature is therefore necessarily included in the converter to cater for transmission over the shorter circuits where no suppressor is used. If the overall attenuation is small, as is usually the case with the general use of "zero-loss" trunk circuits, the reflected signal will arrive back at the sending end at a sufficiently high level to operate the rectifier valve.

The result of this depends upon the propagation time of the signal from the sending end to the distant repeater termination and back. If this is appreciable the reflected signal may not be completely received until after the termination of the sent signal. For instance, if a space signal is transmitted, followed by a mark signal, the reflected space signal may arrive in time to operate the rectifier during the mark signal, i.e. condition of no-tone to line. A faulty local record results, although reception at the distant end may be unimpaired. By ensuring an adequate amplitude of the local record signals, together with an increase in the value of the time constant of the grid leak and capacitor to cover the period wherein an echo may be received, the effects of such echoes are overcome. The optimum values of the grid resistor and capacitor to produce the desired echo suppression and voltage limitation, are found to be a resistance of 5 MΩ shunted by a capacitance of 0·01 μF. The attenuating network introduced into the local record circuit by the S-R. switch of the teleprinter, as previously described, also assists in eliminating the effect of echoes on the local record.

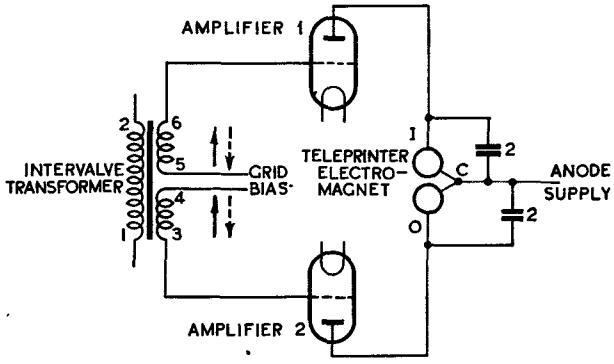


FIG. 16.24. PUSH-PULL AMPLIFIER CIRCUIT OF 1,500 c/s V.F. TELEGRAPH CONVERTER

The Push-pull Circuit. This circuit consists of the secondary winding of a transformer and two valves, with the electromagnet coils of the teleprinter connected in the anode circuits, as shown in Fig. 16.24. The secondary winding of the transformer is in two equal portions and one half of the winding is included in the manner illustrated in the grid circuit of each valve. The grid potentials of the two valves are made equal to one another and are adjusted to lie at the mid-point of the straight portion of the characteristic curve.

At the commencement of a spacing signal, the rectifier anode current rises in the primary winding of the transformer and induces an e.m.f. in each secondary winding, in the direction shown by the full arrows in the diagram. The effect of this induced e.m.f. is to increase the negative grid potential of one valve (amplifier 1) and to reduce the negative potential of the other valve (amplifier 2). The steady anode current in amplifier valve 1 therefore falls, while the anode current in the other valve rises. As a result, the magnetic flux linking the *I-C* coil of the teleprinter is reduced, while the flux of the *O-C* coil is increased.

The electromagnet is neutrally adjusted and the armature remains in the position to which it was last operated; this is, of course, the marking position when no signals are passing. The winding direction of the two coils is such that the anode

current in the *I-C* coil tends to move the armature to the marking position, and the anode current in the *O-C* winding produces a spacing tendency. In the quiescent state, these anode currents are equal, due to the equal grid, anode and filament potentials of the two valves, so that the electromagnet remains on the side to which it was last operated. The effect of the spacing signal, as described above, is to increase the current in the spacing (*O-C*) coil and to reduce the current in the marking (*I-C*) coil, and the armature accordingly moves to the spacing position.

If two or more consecutive space elements occur, the condition of the electromagnet is unchanged, due to the steady current in the anode circuit of the rectifier producing no further effect in the intervalve transformer.

On cessation of the spacing signal the rectifier anode current falls, and an e.m.f. in the secondary winding of the transformer is now induced in the direction shown by the dotted arrows of Fig. 16.24. The grid of amplifier 1 is now made less negative, and that of amplifier 2 is made more negative; the anode current in the *I-C* coil increases, and that in the *O-C* coil falls, so that the armature now moves to the marking stop.

From this it will be observed that although the transmitted signals and also rectifier anode signals are on a single-current basis, operation of the electromagnet is on a double-current impulse basis due to the action of the push-pull circuit. The capacitors connected across the coils of the electromagnet assist in providing a sharp rise in current at the commencement of each signal.

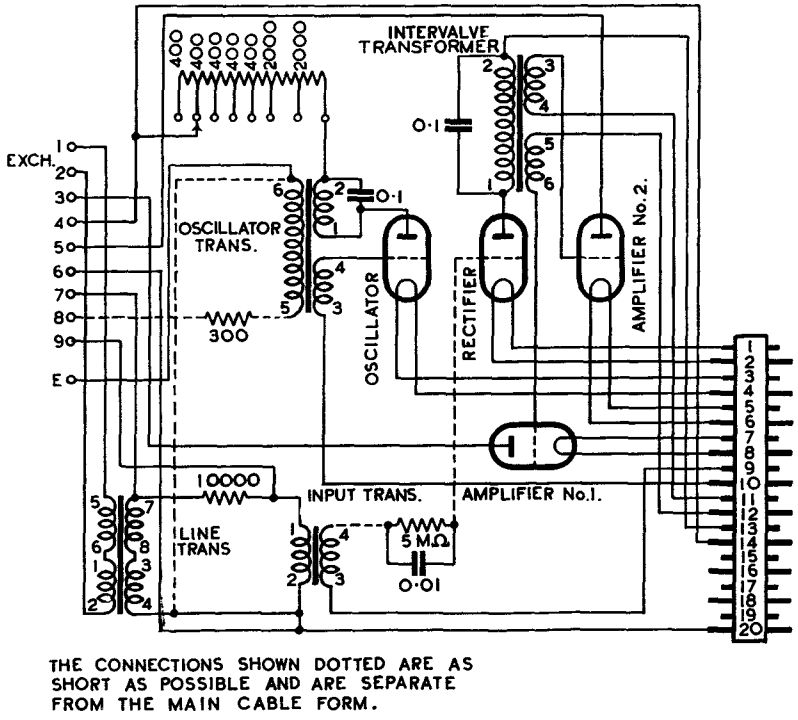


FIG. 16.25. CONNEXIONS OF VALVE PANEL OF 1,500 c/s V.F. TELEGRAPH CONVERTER

One type of valve, the V.T. 68, is used throughout for oscillator, rectifier and amplifier, irrespective of the nature of the power supply.

Fig. 16.25 shows the complete connexions of the valve panel. The connexion tags on the right are joined by a short cable to the corresponding tags of the power panel shown in Figs. 16.26 and 16.27 for a.c. and d.c. mains respectively. The nine terminals on the left are connected to the external circuit by the 9-way plug and cord.

Supply of Power to Converters. The circuit arrangements of the power panels for supplying the correct operating potentials to the filaments, grids, and anodes of the valves, when energized from a.c. or d.c. mains, are shown in Figs. 16.26 and 16.27 respectively.

A.C. Supply. (Fig. 16.26.) The power supply is connected via the cut-outs to the primary winding

of a mains transformer suitable for 50 c/s supplies. This winding is tapped at appropriate intervals to render it suitable for all normal alternating voltages likely to be encountered, i.e. 100 V to 240 V: for intermediate voltages, the supply lead is connected to the next higher voltage tapping available; e.g. a 230 V supply would be connected to the common and 240 V terminals. The transformer is provided with three secondary windings.

Filament Current. The first (*F*.1) and second (*F*.2) secondary windings each provide four volts for filament heating, the *F*.1 winding feeding the rectifier as well as both amplifier circuits in parallel, and *F*.2 providing a separate supply for the oscillator filament. The filament resistance (hot) is 9 Ω; hence each valve takes a current of approximately 0·5 A, and *F*.1 therefore provides 1·5 A. Since it is necessary for the filaments to warm up quickly, so that the converter is operative soon after switching on the supply, they are directly heated from the mains current without rectification.

Anode Potentials. The remaining secondary winding has an output voltage of 135 V. This supply is rectified by means of four copper oxide rectifiers arranged on the well-known full-wave bridge principle. The rectified current is smoothed by means of series chokes and shunting capacitors. Two stages of smoothing are employed for the rectifier valve supply and only one stage for supplying anode current to the other three valves. The resultant anode potentials will lie between 105 V and 115 V, dependent upon the actual supply voltage.

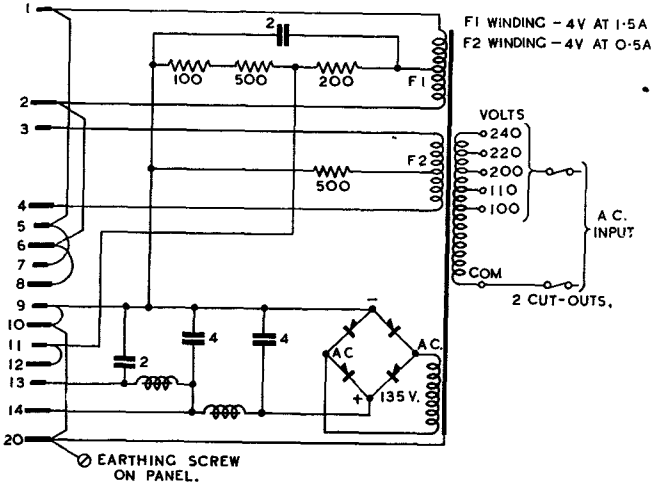


FIG. 16.26. A.C. POWER PANEL OF 1,500 c/s V.F. TELEGRAPH CONVERTER

The normal anode currents, with no signal passing, are—

Amplifiers . . .	7 to 12 mA
Rectifier . . .	Less than 0·2 mA
Oscillator . . .	5 to 7 mA

The actual value of the anode current, provided that it lies within the above limits, is not of great consequence, but the anode currents of the two push-pull valves must agree with one another closely or the electromagnet will receive a bias: these values should not differ by more than 0·5 mA, and this matching can always be effected by selecting valves of suitable internal impedance until the specified degree of balance is attained.

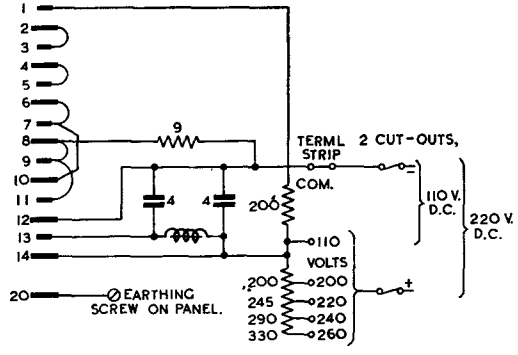


FIG. 16.27. D.C. POWER PANEL OF 1,500 c/s V.F. TELEGRAPH CONVERTER

Grid Potentials. The requisite grid potentials for all valves are obtained by the method of automatic bias. The advantage of this provision lies in the fact that any variations in the anode voltage produce similar variations in the biasing circuits. Fig. 16.28 shows the essential items of the biasing circuits and is composed of the elements of Figs. 16.25 and 16.26 for these circuits.

For the oscillator valve, the anode current flows over the circuit earth, 500 Ω resistor, both halves of the *F*.2 winding in parallel, both halves of the filament itself in parallel, the internal or cathode-anode impedance of the valve, 1–2 winding of the transformer, the 6,000 Ω variable resistor, the choke coil and from positive to negative through the bridge rectifier to earth. This anode current of 7 mA develops a p.d. of 3·5 V across the 500 Ω resistor, and is utilized to bias the grid: this grid is connected, via 4–3 winding of the transformer, to earth, and is therefore 3·5 V negative with respect to the filament.

Through the 600 Ω + 200 Ω resistors, connected

to the centre point of the *F*.1 winding, flow the joint anode currents (some 16 mA) of the rectifier and both amplifier valves. A p.d. of approximately 13 V is developed across the total 800 Ω and, the rectifier grid being returned to earth via the 5 MΩ resistor and winding 4–3 of the transformer, is biased

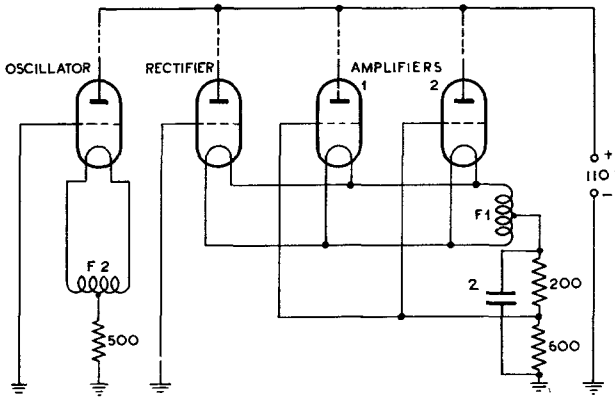


FIG. 16.28. GRID BIAS CIRCUITS (A.C. PANEL)

negatively to the extent of 13 V. The 2 μF capacitor (Fig. 16.28) across the bias resistors provides a low impedance path for the 1,500 c/s current in the grid circuit.

The grids of the amplifier valves are both connected to obtain the p.d. due to the 16 mA flowing through the 200 Ω, i.e. 3·2 V.

The foregoing relationships between grid volts and anode current are shown in the curve of Fig. 16.23.

The total consumption of the a.c. converter is roughly 15 W.

D.C. Supplies. (Fig. 16.27.) A tapped resistor of a type suitable for readily dissipating heat, provides for the accommodation of the usual range of d.c. mains voltages.

Filament Current. For d.c. supplies, the filaments are connected in series with one another and with a resistor of 200 Ω + 9 Ω, to obtain a current just under 0·5 A from the 110 V tapping on the mains resistor.

Anode Potentials. The anodes of all the valves are connected to the 110 V tapping, with the inclusion of one stage of smoothing in the supply to the rectifier valve only.

Grid Potentials. Automatic grid bias is used, the arrangement of the biasing circuits differing necessarily from that utilized in the a.c. panel.

The p.d. across the filaments is employed for obtaining the required bias values. Fig. 16.29 illustrates the need for an added 9 Ω resistor in the filament circuit to provide the amplifier 1 with a negative bias of four volts with respect to the negative end of the filament. The second amplifier and the oscillator are given a similar negative bias, but the rectifier is given a bias of just over 12 V obtained from three of the valve filaments in series.

The curve of Fig. 16.23 shows the foregoing grid voltages and relative anode currents, the latter being somewhat lower than for the corresponding circuits in the a.c. case, by reason of the slightly higher negative grid potentials of the d.c. converter.

The total consumption of the d.c. converter is 55 watts on a 110 V supply, and proportionately higher for other mains voltages.

The complete connexions for telex installations operated from a.c. and d.c. mains are shown in Figs. 16.30 and 16.31 respectively. In the change-over key for the line, make-before-break contacts are used to prevent a momentary disconnexion while changing from telephone to teleprinter, and vice versa, which might result in premature clearing of a connexion via an automatic exchange. In the "teleprint" position of the key, a loop condition is maintained by the line transformer.

Cabling and Wiring. Certain precautions are observed in wiring the telex installation, and Fig. 16.32 shows the cabling scheme in detail.

The whole of the external metal work, including the teleprinter frame and the steel table itself, are earth connected to guard against the possibility of electric shock in the event of a breakdown of insulation in the power circuit. This involves the use of a three-wire cable throughout the power

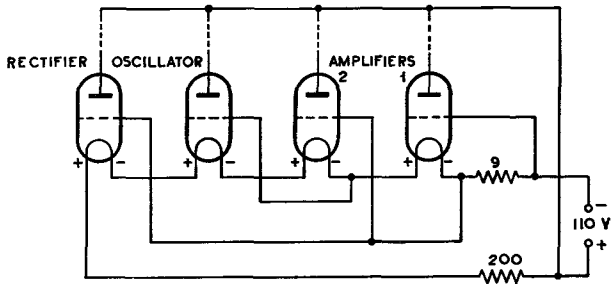


FIG. 16.29. GRID BIAS CIRCUITS (D.C. PANEL)

circuit, and a rubber-covered cable of the requisite conductor gauge is employed for this purpose.

The connexion between the space contact of the teleprinter and the oscillator output terminal is screened throughout. For this purpose, a single conductor lead sheathed cable is used, together with a specially screened conductor in the nine-way instrument cords serving the teleprinter and the converter. If this were not done, pick-up by the

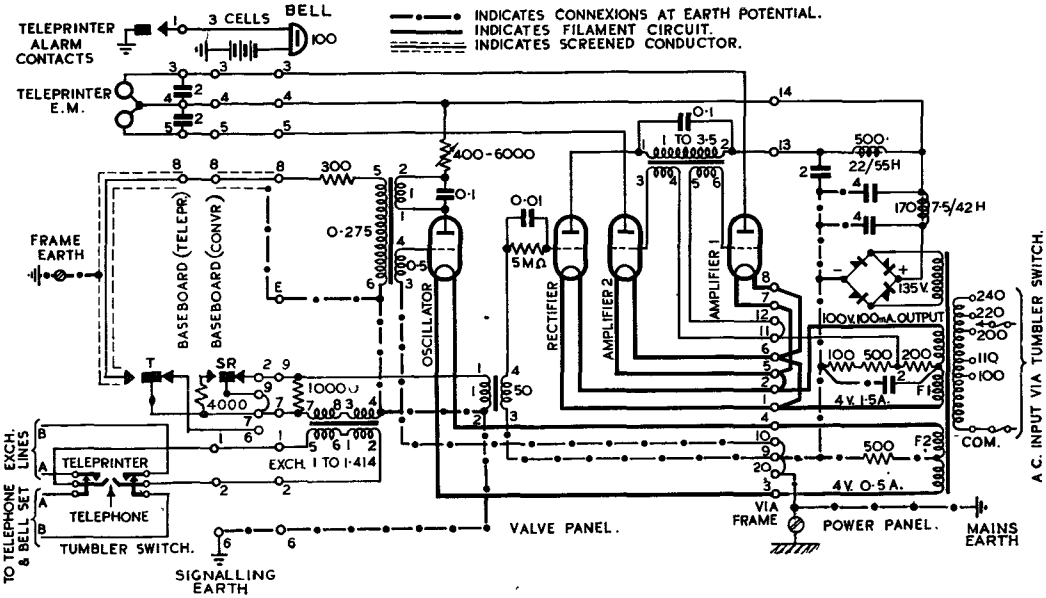


FIG. 16.30. SCHEMATIC DIAGRAM OF TELEX EQUIPMENT (A.C. MAINS) AS USED FOR WORKING OVER THE TELEPHONE NETWORK

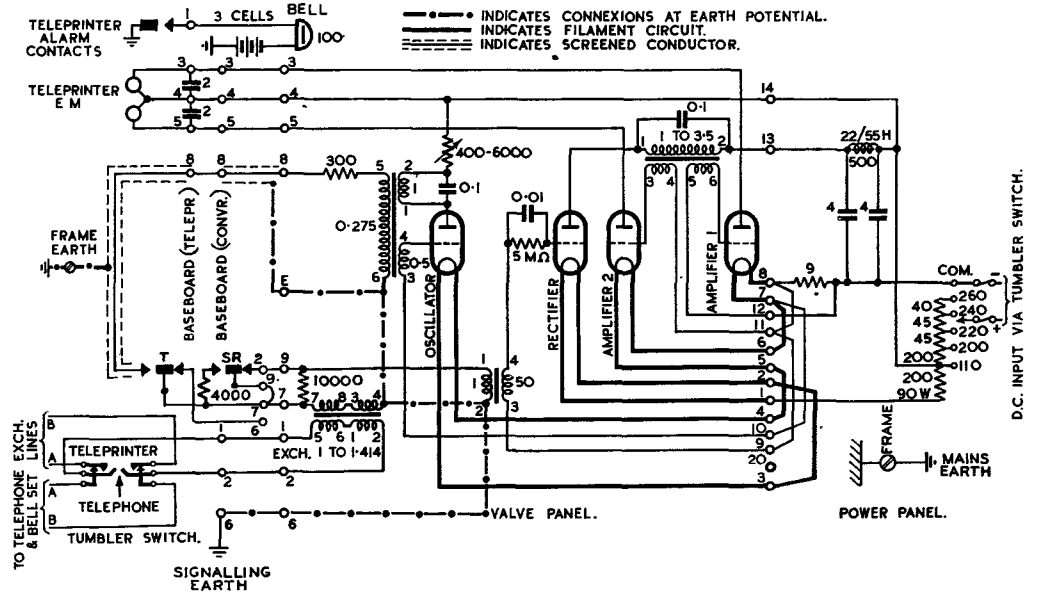


FIG. 16.31. SCHEMATIC DIAGRAM OF TELEX EQUIPMENT (D.C. MAINS) AS USED FOR WORKING OVER THE TELEPHONE NETWORK

receiver from the oscillator would result in interference with reception of weak signals which were more than 25 db below the sending level.

Lead covered cable is used throughout to prevent mechanical damage to the conductors.

The tumbler switch controls the supply of power to the converter as well as to the teleprinter motor, thus energizing the converter only when required for use.

In the event of the change of power supply from

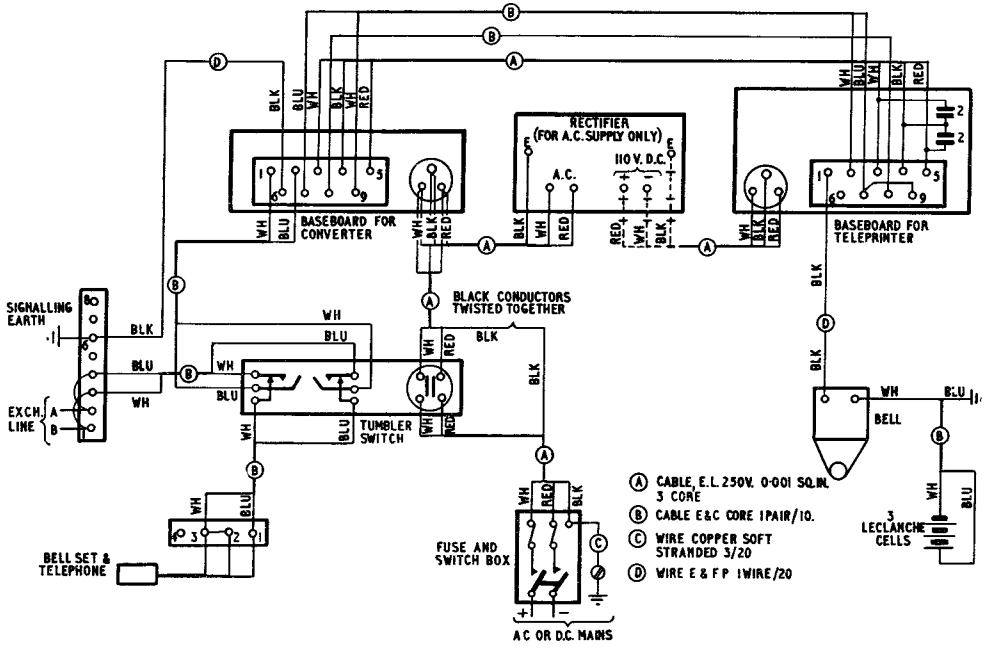


FIG. 16.32. CABLING OF TELEX EQUIPMENT OF THE TYPE WHICH WAS USED FOR WORKING OVER THE TELEPHONE NETWORK

d.c. to a.c. due to the gradual standardization of a.c. mains supplies throughout the country, it is necessary only to open the cable connecting the power sockets of the baseboards and insert at that point a rectifier for the provision of direct current to the motor; at the same time the converter must, of course, be changed from a d.c. to an a.c. model.

It may be added, that since the line is connected to the converter circuits through the line transformer, the essential condition of avoiding contact between the telephone line and either a.c. or d.c. mains supply is fulfilled.

Transmission over Trunk Circuits. On long audio-frequency telephone circuits, especially those having medium or heavy loading, echo-suppressors are necessary to prevent echoes from interfering with speech on such circuits. Modern practice, however, is to use carrier circuits more and more and the reduced transmission time on these circuits eliminates the need for echo suppressors.

The operating time and the releasing lag (or hang-over) of the echo suppressors associated with long repeatered audio frequency circuits both have an important bearing on telex transmission over trunk lines. A typical long four-wire circuit is represented in Fig. 16.33.

The suppressor operation must be sufficiently rapid to prevent any echo, caused by a signal on the "Go" channel being reflected at the distant termination, from reaching the "Return" repeater before the suppressor has operated. The propagation time of the echo, considered from the "Go" repeater to the termination and back to the "Return" repeater, will be dependent upon the length and type of the circuit concerned and the position of the suppressor along the line. If the suppressor is slow in operating, the echo will be reflected back from the distant termination along the "Return" line and tend to cause the suppressor associated with that line to suppress the signals on the "Go" line and so cut off the transmitted signals. For this reason, the operating time of the suppressor is designed to be of the order of ten milliseconds, and each suppressor is arranged to suppress the suppressor amplifier of the other channel in addition to the associated repeater. Owing to the

suppressor action of the rectifier circuit in the converter, it is immaterial whether the beginning of a reflected signal is fully suppressed at the repeater, since this will be safeguarded in the converter.

Slowness in operation of the suppressor is apparent in the mutilation of certain signals at the receiving end. Thus in the transmission of "T" (S-MMMMS-M) over the "Go" channel, if the echo from the start signal operates the "Go" suppressor, the second space signal will be suppressed.

The maximum hangover time desirable was originally governed by the operation of the answer-back signal. On early models of the Teleprinter No. 7 the answer-back unit commences to transmit at 170 milliseconds after the receipt of the "Who are you?" signal, and the suppressor must release before the answer-back signal can be transmitted over the other channel. In practice, the answer-back code was prefixed by two letter-shift signals, the first of which provided a safeguard against the hang-over of the suppressor. This first letter shift may be partially or wholly absorbed in the repeater, due to the hang-over period; since this signal consists of all marking elements apart from the start signal, the mutilation of part of this signal will not result in any operation of the receiving teleprinter. The hang-over time of the suppressor is approximately 270 milliseconds, and this is offset by the 170 milliseconds lag in operation of the answer-back, the propagation time from the suppressor to the distant instrument and back (usually comparatively small), and the first letter-shift 150 milliseconds. In this way no mutilation of the answer-back code is apparent, although the first letter shift may actually have been suppressed.

The answer-back signal naturally offers a ready means of checking the hang-over time of the suppressor. If the initial letters of the code are received as figures, it is apparent that the second letter shift has been absorbed in the suppressor, showing the hang-over time to be excessive. If the hang-over time is very great, the early characters of the code may also be mutilated.

Teleprinters No. 7B having 20 character answer-back units have now been standard for Telex Service since 1935, and because of the difficulties regarding hang-over time of echo suppressors the 20 character answer-back unit was designed so as to cause an initial delay of 540 milliseconds before the answer-back transmission commences. Thus the foregoing difficulties which were encountered in the operation of 13 character answer-back units on the earlier Teleprinters No. 7 are overcome completely.

Ringing Equipment. The ringing equipment used on trunk telephone circuits is operated by interrupted a.c. signalling tone, and when such circuits are required to be used for telex transmission it is essential to ensure that the characteristics of the ringers are such as to prevent false operation by telegraph signals.

Causes and Effects of Line Interruptions. A characteristic difficulty in telex working over a telephone network is the inherent response of the V.F. converter to any current surges which may occur in the external circuit. On a telephone connexion, electrical interruptions which may arise from various sources in the line or switching apparatus and which appear in the receiver in the form of short clicks, will not have a disturbing effect upon the listener providing their magnitude is not excessive and that they are not of frequent occurrence. In the telex system, the necessary sensitivity of the converter will permit the teleprinter to respond to those interruptions if their wave form and duration fulfil certain conditions.

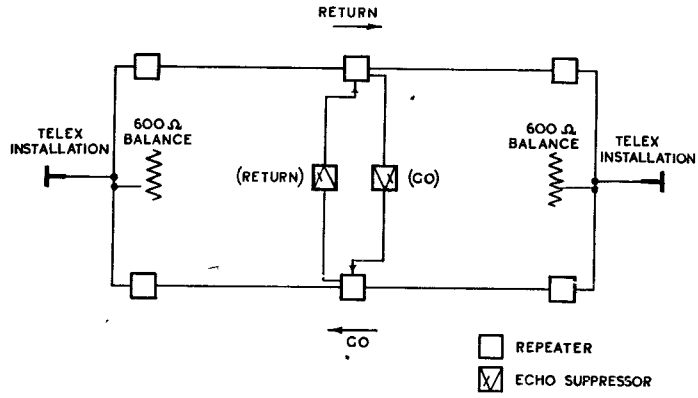


FIG. 16.33. 4-WIRE REPEATERED TELEPHONE CIRCUIT FITTED WITH ECHO SUPPRESSORS

The main sources of such interruptions include—

(1) Bridging wipers in automatic exchanges, i.e. wipers which are either worn or maladjusted and bridge across adjacent contacts during hunting and releasing of the selector. The resultant surge depends upon the initial potential difference of the bridged contacts, the circuits connected, and the time of bridging, and peak voltages of 3 or 4 V, with occasionally higher values, may be developed across the line.

(2) Overhearing of busy tone, ringing tone, impulsing, voice-frequency signals, etc., if of excessive magnitude.

(3) Loose connexions at any point, faulty plugs and cords.

(4) Entering into circuits by operators or maintenance staff. Also, when making engaged tests, the insertion of the plug so far as to make contact with a line spring of the jack.

(5) The occurrence of double connexions and contacts of any description.

(6) Microphonic action of lightly tensioned wipers due to vibration.

The duration of an interruption may be less than the period of one signal element (20 milliseconds) and, for example, if due to bridging wipers, it is usually of the order of two milliseconds. Owing to the tuned receiver circuit of the converter, such transients appear in the grid circuit of the rectifier as of an oscillatory character and persist for some six milliseconds or more, though the peak value is somewhat reduced.

The effect of such an interruption is therefore to give the equivalent of a space signal. If no signals are passing at the time, this single space acts as a start signal, thus producing a letter shift. In this case no harmful effect results unless the teleprinter combination head is in the "Figures" position when it would be changed to the "Letters" position, and any figure characters then transmitted would be printed as letters. If, however, the idle condition of the sending teleprinter is less than 150 milliseconds (the time duration of one character) the revolution of the receiving cam will not be completed before the arrival of the next character transmitted along the line and this character will consequently be mutilated.

For instance, assume the letter E (S-MSSSS-M) is about to be transmitted; if now an extra space signal, due to an interruption, occurs at about 100 milliseconds before the arrival of the E signal, the interruption (acting as a Start signal) starts the revolution of the receiving cam, and the signals set up in the teleprinter are accordingly (S-MMMM-S-MSSSS-M) plus continuous mark during the next idle period. The characters printed, therefore, are K (S-MMMMS-M) and O (S-SSSMM-M) instead of the E transmitted. Occasionally a figure shift (S-MMSMM-M) may be caused by the arrival of a double interruption (SS) during an idle period (continuous M). It will be seen therefore that the actual character printed as a result of interruptions occurring in the line depends upon the incidence of the interruptions relative to the phase of any character passing during a time period of $\pm$ 150 milliseconds with respect to the interruption.

An almost opposite effect may sometimes be caused by an interruption of big amplitude charging the rectifier grid capacitor to a point where the next transmitted space element is suppressed, giving a marking element in its place.

The energy of a d.c. impulse is distributed over a wide frequency band, and in general decreases with increase of frequency. Hence the use of a comparatively high frequency for telex operation, together with the use of a tuned circuit, itself results in some immunity.

Although the effects of such interruptions upon the telephone service have not been serious, it has been necessary to guard against the incidence of these effects whenever telex communication has to be given. Accordingly special operating procedure for telephone exchange manual positions dealing with telex calls has been designed with a view to preventing the occurrence of such interruptions. On telex calls the operator does not enter the circuit for any purpose, except on the telex service positions where high-impedance monitoring circuits are fitted, and in no case does the operator challenge or make announcements of elapsed time. In this respect, it is important that subscribers connected to magneto exchanges should "ring-off" on completion of a call, to avoid the need for the operator to enter the circuit for supervisory purposes. For the assistance of the operators, reminder rings are provided on "A" positions and on incoming trunk positions where telex traffic is handled; these rings are slipped over the cord circuit speaking key after completing the connexion, as a reminder that a telex call is concerned.

In automatic exchanges, care must be taken to remove badly worn wipers before they reach the state where they may cause interruptions.

Telex Service Positions. These are operating positions specially assigned for controlling telex calls, in trunk or group centre exchanges serving areas where telex subscribers are connected.

The equipment of these positions is generally similar to that of other positions in the exchange. The incoming circuits, however, comprise junctions of high transmission efficiency from "TLX" and "98" levels of automatic exchanges and also "telex service" junctions from manual exchanges within the area. Moreover, high impedance monitoring circuits are used and the automatic elapsed-time signal (the dot-seconds every three minutes) is omitted from the cord circuits. For the purpose of automatically timing the calls it is necessary to ensure that supervisory signals are received in the cord circuit at the telex position direct from the calling subscriber's telephone. This involves the provision of through clearing circuits at private branch exchanges if such facilities are not already in existence.

The multiple of outgoing trunk circuits is available

for the completion of telex calls on demand and the operating staff is specially trained in the handling of telex calls.

Numbering Scheme for Subscribers' Lines. A telex installation may be connected to any line in the exchange numbering scheme, the word "telex" being always included in the number, e.g. NATional Telex 2570.

For their telephone requirements, many telex subscribers have a group of lines, in numerical sequence, connected to a P.B.X. In such cases, it may be desirable for the telex line to be included in this group in order that the line may be available for telephone calls if required. To this end, the telex line is made the last line of the P.B.X. group, where it is available for telephone use in either direction should the remaining lines be all engaged at any time. This line is, however, earmarked for telex service in order that special treatment can be given at the exchange to telex calls passed over this number which is normally used for telex calls only. In order to keep a telex line as the last in the auxiliary group and at the same time to avoid frequent change in the subscriber's telex number each time that development necessitates the addition of a further line to the group, the telex line is allocated a spare number outside the numbering series of the P.B.X. group.

In the multiple of a manual exchange, a green peg is permanently inserted in the jack appropriate to the telex number, bearing a reference to that number which is the last line of the P.B.X. group, and the operator actually connects incoming calls to the number quoted on the peg. On the "A" position, a green plate is fitted behind the calling lamp to denote a telex line.

In automatic exchanges, a cross-connexion is made in the final selector multiple to tee the telex number to the last line of the group.

In the above arrangements the telex installation is connected to an extension on the P.B.X. switchboard.

Where a telex line does not form one of a P.B.X. group it is treated as a normal direct exchange line, except that the calling lamp has the green designator plate fitted, referred to above.

Alternative Access. Whenever a telex installation is worked as a direct exchange line, the subscriber is required to have available a second line giving alternative access to the telex installation. This arrangement is required so that the teleprinter will not be thrown out of use due to a line fault, or to the existence of a telephone communication on the telex line while another line is free. The additional line may take the form of a P.B.X. extension, if the subscriber has a P.B.X. as well as the direct telex line, failing which another direct line is used.

Both lines are led through a change-over switch which permits either line to be connected to the telex set, and leaves the other line terminated by the telephone set.

Fig. 16.34 shows the switching circuit. The key which is of the make-before-break type to prevent a false clearing signal (on automatic exchanges) while changing-over, normally connects the telex set to the telex line and the additional telephone

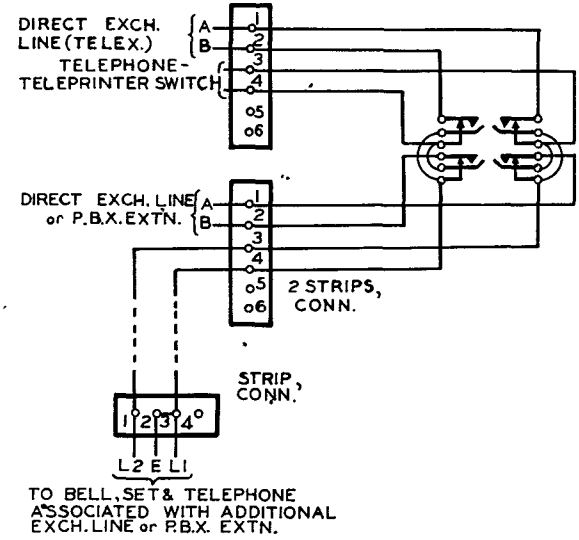


FIG. 16.34. ACCESS TO AN ALTERNATIVE LINE

set to the alternative line. Operation of the key reverses these conditions, i.e. the telephone set is connected to the telex line and the telex set to the additional line. In this way, when the telex line is engaged, access to the teleprinter operator can be obtained over the additional line, by means of the telephone connected thereto, and the call held if desired and switched to the telex set when the previous connexion is terminated: moreover should the telex line become faulty, temporary stoppage of telex service is avoided by the use of the additional line.

Procedure for Obtaining Telex Connexions. Telex subscribers are issued with a separate Directory showing the telex numbers and alternative numbers of all subscribers to the service. The Directory also includes details of the precise method of obtaining connexions from any exchange system.

For calls completed automatically, the caller dials the required number, paying no attention to the word "Telex." For all other calls, the code "TLX" (Director Areas) or "98," or in some cases

"O" (Non-director Areas) is dialled to obtain access to the telex service position. The caller then asks for the required number in full, e.g. "NATional Telex 2570."

In manual areas, for local calls the request for the desired number is passed direct to the local exchange operator. For calls to exchanges normally obtained via "Toll" or "Trunks" the local exchange operator is asked for "Telex Service" and connects the caller with the telex service position. In both cases the calling subscriber asks for the required number in full, e.g. "NATional Telex 2570."

Printergram Service. By means of the Printergram Service—the teleprinter equivalent to phonogram service—subscribers to the telex service are able to transmit and receive telegrams to and from the nearest head post office, resulting in a speeding up of the handling of subscribers' telegraph traffic. The telegraphic address of subscribers bears the indicator word "Telex" to ensure the delivery of the subscriber's inward traffic in this manner.

Special printergram operating positions for forwarding and receiving traffic to and from telex subscribers are provided in the telegraph instrument room. The equipment of these positions is essentially similar to that of the standard telex installation, except that the teleprinters used are fitted with tape printing attachments in place of the normal page printing carriages, and that special signalling facilities are provided.

The design of the signalling circuits depends upen the system of telephone working in the area concerned.

1,500 c/s Telex Service in Association with Private Wire Service. If telex service is required infrequently by a renter to a private wire teleprinter service, it may be economical to use a single teleprinter for both services. The method of switching the teleprinter to the exchange line or private wire alternatively depends upon which of two types of private wire service is in use.

(1) *Private Telephone Lines.* Where a telex subscriber rents a private telephone circuit (Tariff "D" Service), teleprinter service is available over this line using the telex equipment. Such private wires usually terminate either end upon a P.B.X. The connexion over the private wire is set up by the P.B.X. operator in the normal manner, and teleprinter transmission is effected by the use of the V.F. converter exactly as in telex working.

Telex calls are also set up via the P.B.X., hence no abnormal procedure or additional apparatus is required.

Various precautions however are necessary to avoid the incidence of interruptions on the circuit. As in main manual exchanges the P.B.X. operator is provided with "reminder" rings to prevent intrusion on the circuit.

In many cases, P.B.X.'s are provided with speaking and signalling currents by means of a power lead from the local exchange. This power supply lead usually has appreciable resistance and any changes in the P.B.X. load therefore cause a proportional fluctuation in the potential difference in the common power lead circuit. The current in each cord circuit in use, therefore, rises and falls with variations in the load, and these current surges on a teleprinter connexion cause interference with teleprinter signals. To reduce the rate of rise and fall of potential, therefore, electrolytic capacitors of 1,000 μF are fitted across the busbars whenever power is obtained from a source having appreciable resistance, e.g. a power lead or a primary cell battery. These capacitors effectively suppress interference. It may be added that care is necessary with electrolytic capacitors, to ensure that they are connected correctly as regards polarity.

A further precaution taken to avoid interruptions on cord type P.B.X. switchboards is to fit plugs with specially insulated sleeves. Were this not done, the possible occurrence of a transient earth potential on the sleeve of a plug in use on a private wire connexion, during the setting up of other calls, would result in the transient operation of the cord circuit cut-off relay with consequent interruption to teleprinter signals.

(2) *Private Teleprinter Lines Worked on a d.c. Basis.* Where a telex subscriber rents a private teleprinter circuit operated on a direct current basis over V.F. channels or physical circuits as previously described, a special switching device is necessary. This switch is required to change over the teleprinter from the direct current private wire circuit to the telex circuit and at the same time connect power to the teleprinter motor and the V.F. converter. Conversely, when the teleprinter is switched from telex to private wire the V.F. converter power is disconnected and power applied only to the teleprinter motor. An alarm circuit is required on the private wire whenever the teleprinter is disconnected therefrom. The use of such an arrangement is infrequent as in most cases the amount of traffic over the private wire precludes the use of one machine for both telex and private wire purposes.

Telex Test Position. A telex test position is provided at all zone centres for co-operative testing with subscribers' installations.

The position consists of a small test set in addition to the normal telex installation and Fig. 16.35 shows the wiring connexions of the circuit. By

operation of the test line key either of the two exchange lines provided can be extended to the testing circuit and the second is available for answering a second call. Operation of the voltmeter receive position of the voltmeter key enables the output of the test set to be checked, at the same time putting a holding condition on the exchange line.

An artificial cable, variable in steps of 1 db, is

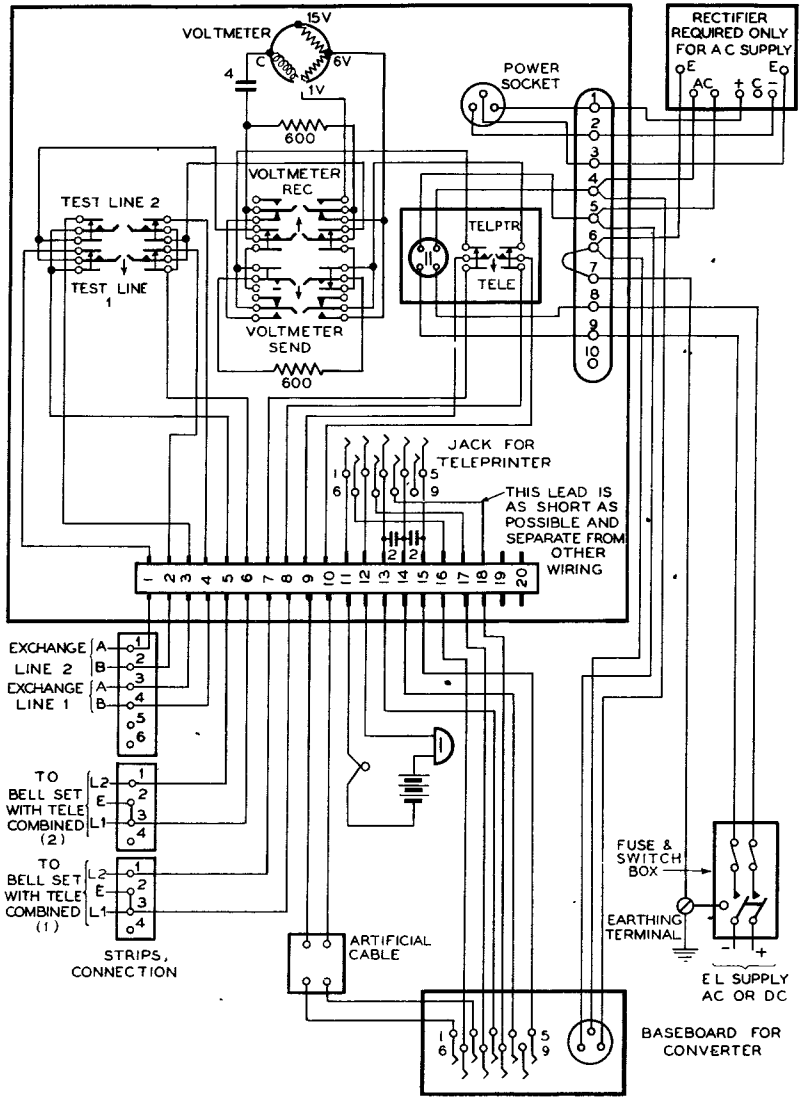


FIG. 16.35. 1,500 c/s TELEX TEST POSITION

key terminates the line with a 600 Ω resistor and connects a low range a.c. voltmeter across the termination; a 4 μF capacitor is included in series with the meter to prevent the flow of direct current from the exchange battery. In this way, with the distant teleprinter sending "tone," the magnitude of the received voltage can be measured. The other included in the testing circuit and this enables the working margin of a set to be assessed. The line attenuation into the test position can be readily determined for any connexion, from the reading of received voltage and a knowledge of the sent voltage. Tables are provided to avoid calculations. The permissible value of artificial line that

can be added to a connexion gives a useful indication of the overall performance of the subscriber's installation. Satisfactory working should be obtained with a total line attenuation, actual and artificial, of 28 to 30 db.

Valve Tester. In close association with each test position is a valve testing set. This tester is designed to check the performance of the valves under the particular operating conditions obtaining in V.F. converters, and to apply an emission

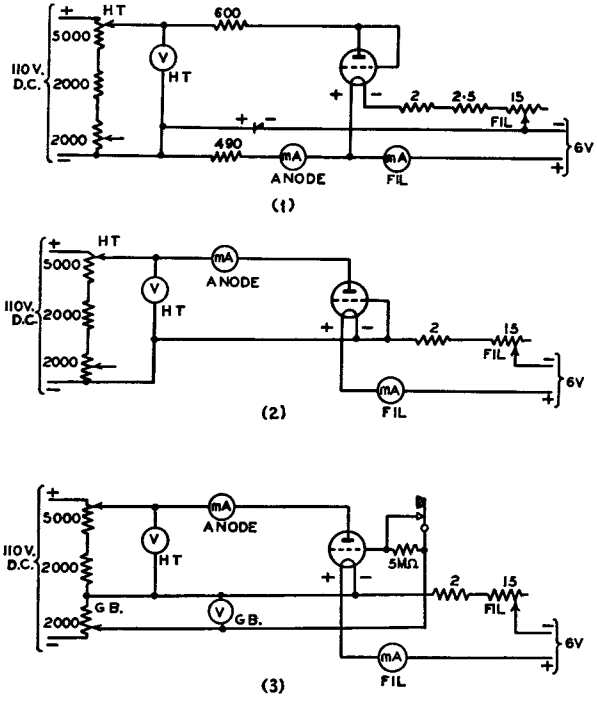


FIG. 16.36. VALVE TESTER

test to show up a valve which is nearing the end of its useful life. By changing the valves at infrequent though regular intervals and subjecting the recovered valves to these tests before re-issuing them, converter faults due to faulty valves are largely avoided.

The tester comprises two milliammeters and two voltmeters for anode current, filament current, anode potential, and grid potential measurements respectively. Three potentiometers are provided for obtaining variations of the grid and anode potentials and of the filament current (for the emission test only) and their required circuit conditions are obtained by the operation of the keys. A 110 V d.c. supply (obtained from the converter power panel if a.c. mains only are available) provides the anode and grid potentials. A six volt secondary battery is used for filament heating.

Fig. 16.36 shows the circuit condition for the following four tests, the values specified for tests three and four are apparent from the characteristic curve given in Fig. 16.23.

(1) *Emission Test.* For this test the valve is operated as a diode and a measurement is made of the filament current required to produce a given anode current. If the required filament current is excessive then the emission is low, and although the general operating efficiency may be still satisfactory, the valve is preferably discarded. The filament potentiometer is adjusted until the anode current rises to 10 mA while maintaining the anode potential between 80 V and 100 V by means of the h.t. potentiometer. In this condition, for satisfactory emission, the filament current should not exceed 340 mA.

(2) *Zero Bias.* The filament potentiometer is adjusted to give the normal filament current of 450 mA and the h.t. potentiometer to give an anode potential of 84 V. The grid is given zero bias by connexion to the negative end of the filament. The resulting anode current should be not less than 7·5 mA.

(3) *Negative Bias.* With a filament current of 450 mA and an anode potential of 80 V, the grid potentiometer is adjusted to give a bias of 10 V. The resulting anode current should not be greater than 0·5 mA. Since the grid and anode potentials are obtained from a common source, the operations of these two potentiometers are interdependent.

(4) *Insulation Test.* The grid circuit impedance of the detector valve is very high and accordingly the grid-cathode and grid-anode impedances of the valve must also be high. If the valve be biased to a point near to the bottom bend of the characteristic curve, any leakage will cause an increase in the anode current on inserting a high resistance in the grid circuit: by this means a grid cathode insulation resistance of 100 MΩ can be readily detected. The three potentiometers are adjusted to provide a filament current of 450 mA, an anode potential of 80 V to 100 V, and an anode current of 3 mA. The insertion of a 5 MΩ resistance into the grid circuit by operation of the break contact should not cause the anode current to increase by more than 0·5 mA. It is important that the break contacts should themselves possess an infinitely high resistance.

Tests 2 and 3 represent the working range of the characteristic curve used for the detector valve and together with test 4 ensure a reliable detector valve. Although the grids of the push-pull valves become momentarily positive, a satisfactory test for this cannot readily be given by simple

apparatus. Provided a valve passes tests 1, 2 and 3, however, it will be suitable for use in a push-pull stage. The oscillator valve requirements are not critical, and an oscillator valve will be satisfactory provided it passes the emission test.

It will be seen that the requirements for the detector valve are the most stringent, and that a valve which passes the four tests may be used in any stage of the converter.

It may be added that the presence of a ripple at 50 c/s in the electromagnet, sometimes found with a.c. converters, is due to a faulty detector valve. If the emission of one half of the filament becomes defective, the centre point of the transformer filament winding no longer coincides with the electrical centre of the filament, and 50 c/s current appears in the rectifier anode circuit. The ripple should not exceed two volts when measured across the electromagnet winding. Such a fault should not be present in any valve which passes the emission test.

Fault Localizing. Faulty telex transmission may be due to—

(*a*) the line;
(*b*) exchange switching equipment;
(*c*) the sending teleprinter and converter;
(*d*) the receiving teleprinter and converter.

With experience, the source of trouble may sometimes be instantly deduced from the nature of the fault: otherwise the first step is to determine which of the links (*a*) to (*d*) is responsible.

Line and Switching Equipment Faults. Under the headings "Line Interruptions," "Echo Suppressors," and "Voice-frequency Ringers," the type of transmission errors attributable to faulty lines or switching apparatus have already been indicated. Setting up a connexion over a different line may confirm this, the faulty line being subsequently tested and cleared by the exchange or repeater station in the normal manner. Excessive overall attenuation may, however, be responsible for faulty transmission and an approximate measurement may be made with a low reading a.c. voltmeter suitable for use at 1,500 c/s. Since 30 db represents the maximum attenuation which can be tolerated for reliable operation, if the sending voltage be confirmed as three volts, then the minimum received voltage (E_r) permissible is given by—

$$20 \log \left(\frac{3}{E_r}\right) = 30 \qquad \therefore \log \left(\frac{3}{E_r}\right) = 1{\cdot}5$$

whence $\frac{3}{E_r} = 31{\cdot}62$ or $E_r = \frac{3}{31{\cdot}62} = 0{\cdot}095$;

say 0·1 V.

The received voltage is measured across the converter line terminals (impedance = 600 Ω) or for greater accuracy across a 600 Ω termination.

Sending and Receiving Equipment Faults. Faults may appear as errors in—

(1) transmission;
(2) reception;
(3) local record;

and thus usually point to some definite portion of the equipment.

The passage of signals into the line may be confirmed by connecting a telephone receiver across the line; similarly the arrival of signals at the receiving end of the line is checked by switching to telephone and listening.

In case of doubt, a test with the telex test position will readily decide which terminal instrument is at fault.

The teleprinter may be checked by observation of the selections set up and of the main adjustments of the machine.

V.F. Telegraph Converter Tester. A converter tester is provided for assistance in fault finding, and also for checking the general efficiency of the converter. The circuit arrangement is illustrated in Fig. 16.37.

The tester comprises three keys, attenuator networks, a valve adapter, terminals for connexion to an external milliammeter and test clip for connexion to the earth terminal. A nine-way instrument jack is provided for connexion to the nine-way plug of the converter. The more important conditions of the oscillator, rectifier, and push-pull circuits are tested in the following manner—

Oscillator Test. The output is normally measured with an a.c. voltmeter, but if no voltage reading is obtained, the anode current can be conveniently measured by inserting the valve adapter in the valve holder and the valve into the adapter. Operation of key 1 to Detector and key 2 to No Tone will then give a direct reading of the oscillator anode current. In the absence of current, the presence of correct potentials on anode grid and filament circuit components can be confirmed with a voltmeter.

Detector Tests. These tests consist in applying 1,500 c/s current at various levels and measuring the resultant anode current, thereby showing up disconnexions and short-circuits in the circuit and confirming the operation of the voltage limiting device.

The adapter is inserted in series with the valve and the earth clip applied to the earth terminal. With key 1 thrown to Detector the following conditions should obtain—

Key 2—No Tone—Anode current less than 0·2 mA

Key 2—28 db—Anode current between 1·6 and 3·1 mA

,, —5 db—Anode current greater than the reading obtained for 28 db, but by not more than 0·5 mA.

Push-Pull Tests. The operation of key 1 to Push-Pull and key 3 to Mark and Space in turn, gives correct operation, but the test gives no check of the satisfactory transmission to line, nor of the operation of the limiting device.

Telex Service on a Telegraph Network

The disadvantages associated with the operation of telex service over the telephone network have led to separate telegraph networks consisting of

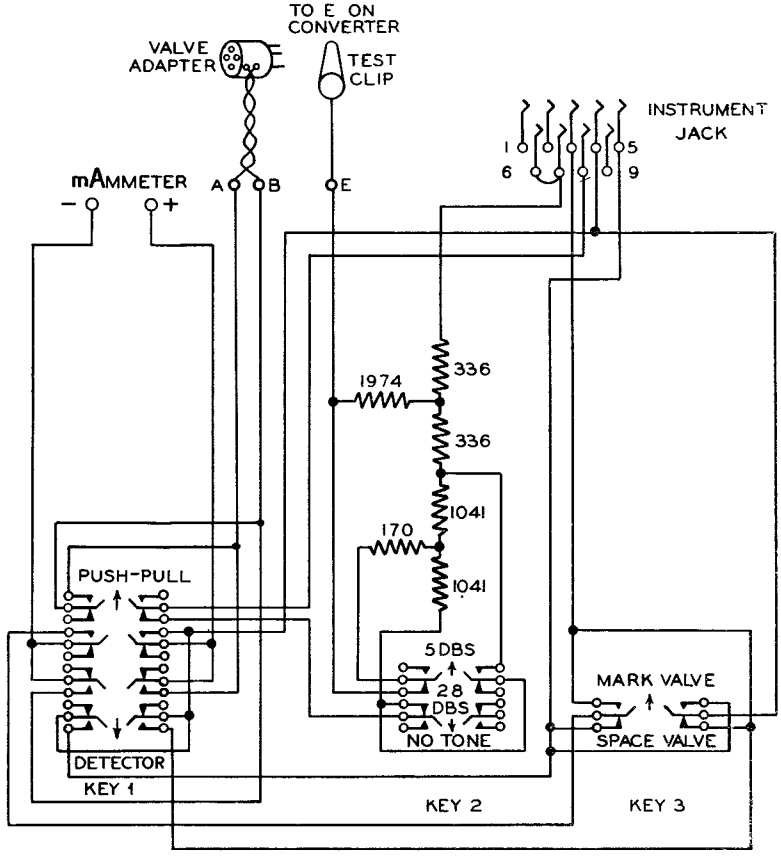


FIG. 16.37. TESTER FOR 1,500 c/s V.F. TELEGRAPH CONVERTERS

direct readings of the static anode currents of these two valves; for correct values obtainable, see p. 643.

On the existence of a fault, the variations from the figures given above will usually be considerable: the specified figures vary slightly with a.c. and d.c. converters. A full appreciation of the converter operation will enable the information gained from the above tests to suggest the particular component at fault. In practice a schedule is compiled showing the indications given by various combinations of incorrect current readings.

The local record feature of the telex system permits of testing in local to give a rough test of the V.F. channels and physical lines, with manual or automatic teleprinter exchanges being employed. The arrangements adopted in the U.K. were based initially on the use of manual exchanges at the larger centres and small automatic telex sub-centres. It is visualized, however, that conversion of the network to fully automatic operation with sub-to-sub dialling will be carried out during 1958–61 as the use of the service expands. The basic form of the present B.P.O. network in the U.K. is shown in Fig. 16.38.

It is based upon six fully interconnected zone centres, each of which controls calls from local

subscribers as well as serving as a switching centre for connecting within-zone and inter-zone calls. In addition there are other dependent, manual switching centres to which are connected all subscriber's lines in the area together with trunk circuits to the adjacent zone switching centre and to more than one, if justified by traffic. In any case, all dependent centres have direct trunk circuits to the London zone centre.

Although it is found that the majority of telex stations are situated in the main towns where zone or dependent telex exchanges are provided—in fact practically 50 per cent are in the London 10 mile circle and a further 25 per cent are in the local fee area of other switching centres—a problem is posed by the smaller number of outlying subscribers who are so remote from a telex exchange that to provide them with individual lines to their nearest switching centre would be uneconomic. A similar problem arises where a sufficient number of subscribers exists within a given area to justify a small local telex exchange but for which a 24-hour service on a manual basis would present staffing difficulties in view of the probable low night-calling rate.

The solution for both of these cases has been to employ small automatic telex sub-exchanges, each capable of serving up to 20 subscribers and giving facilities for hunting over a group of ten both-way junctions to a zone switching centre which is staffed continuously. Completion of incoming calls is achieved by dialling two digits from the parent controlling manual board; local calls necessitate the use of two junctions from the sub-exchange linked at the parent manual board, but the ratio of local calls to all other calls is small in these cases. These automatic sub-exchanges may be directly connected to their parent exchange, which may be either a zone or a dependent centre, by a single V.F. link or alternatively by a physical circuit giving not more than 10 per cent signal distortion.

With the advent of switched systems using telegraph channels a good deal of attention has of recent years been paid to the problem of overall distortion of V.F. channels when linked in tandem. The C.C.I.T., appreciating the need for administrations to agree upon the distribution of telegraph distortion circuits connecting the terminal exchanges, has provisionally recommended the following limits for the degree of rhythmic service distortion for standard text, i.e. Q9S sent continuously, caused by the trunk section of the circuit—

When one V.F. telegraph channel is used for communication . . .	10 per cent
When two V.F. telegraph channels are used for communication . . .	18 per cent
When three V.F. telegraph channels are used for communication . . .	24 per cent
When four V.F. telegraph channels are used for communication . . .	28 per cent

It will be observed that the additive distortion does not follow the simple arithmetic sum of the parts but more nearly approximates to the root mean square addition.

A supplementary C.C.I.T. recommendation states that—

"The limit of the degree of gross start-stop distortion, measured by a start-stop distortion measuring set, which can be present in signals transmitted

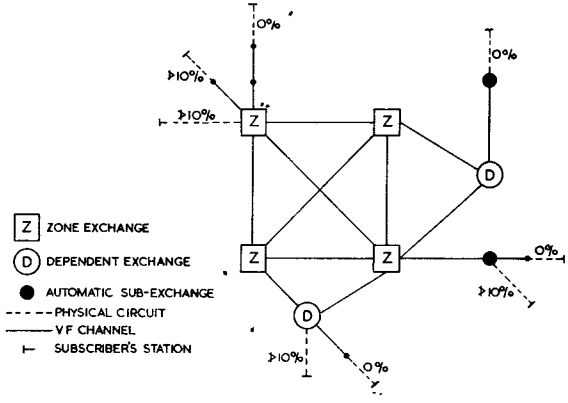


FIG. 16.38. BASIC STRUCTURE OF TELEX NETWORK IN THE UNITED KINGDOM

into the local section of the circuit without the receiving apparatus failing to translate any of the signals which it should be able to receive is 30 per cent, presupposing that the distortion introduced by the local section of the circuit is negligible."

From Fig. 16.38 it will be seen that the maximum number of V.F. links switched in tandem for any inland telex connexion is five, and under these conditions the physical ends which constitute the subscribers' lines must have negligible distortion. Physical lines which may give up to 10 per cent signal distortion are permitted for use as subscribers' lines when these terminate upon dependent or zone exchanges, or on a sub-exchange which is connected by a V.F. channel to a zone exchange: connexions with these subscribers will not involve more than three V.F. links plus the two physical lines each giving not more than 10 per cent distortion, or alternatively four V.F. links plus one such 10 per cent physical line. On sub-exchanges which have a dependent exchange as parent, the subscribers' lines must give negligible distortion. The physical extensions of V.F. channels used for subscribers' lines must also, in most cases, produce only

negligible distortion. For the initial stages of the development of inland telex service no requirement is foreseen for the inclusion of regenerative repeaters; they will however be used, when necessary, for international connexions.

Compared with the telex service which was operated on the telephone network, the average length of subscribers' lines is increased on account of the restricted number of telex exchanges. Table 16.1 shows the permissible route mileage limits of cable pairs for subscribers' lines giving negligible distortion and also not more than 10 per cent signal distortion.

Line limits for direct current circuits in underground cables are mainly determined from considerations of the fortuitous signal distortion arising from interference voltages transmitted via the capacitance couplings between conductors; these are practically independent of conductor weight.

The growth of the M.C.V.F. telegraph network has during recent years necessitated the opening of some M.C.V.F. telegraph terminal stations which are situated a few miles away from the premises in which the telex exchange is located. If the separating distance between these two points is appreciable this factor (designated "a" in Table 16.1) must be taken into account for dependent and sub-exchanges in determining the limiting lengths of subscribers' lines. If a sub-exchange is connected to its parent by a physical circuit, this forms in effect a part of the subscriber's line and the transmission limits must take account of this.

For the non-relayed circuit the limiting condition is set by the signal-to-noise ratio for which the effect of cross-talk is to modify the wave-form of the current into the teleprinter electromagnet sufficiently to change the response to cause the excessive distortion. For the two-wire relayed line the length is similarly limited by the cross-talk, but due to the increased sensitivity of the relay the operation takes place on the early steeply rising wave-front and is only delayed by relatively severe degrees of cross-talk. The two-loop circuit, unlike the two other classes of circuit, is a balanced one sensibly free from the effect of interference and the 90 miles is quoted mainly on grounds of likely practical requirements. From the point of view of sufficient line current to operate the calling relay, overriding resistance limits apply of 1,500 Ω single-wire to a main exchange, or 1,060 Ω to an automatic sub-exchange; for all relayed lines a limit of 3,500 Ω applies to the relay unit. It is unlikely that these limits will be in any way restrictive.

All subscribers on the network enjoy full and unrestricted intercommunication.

The network is designed for simplex operation

TABLE 16.1

Limiting Distances for Subscribers' Lines (Simplex Service)

1. For Negligible Distortion

Physical Separation ("a" route miles) between Telex Exchange and V.F. Terminal	Type of Circuit			Remarks
	Non-Relayed	Two wire Relayed	Two Loop Relayed	
Zero	10 miles	25 miles	90 miles	—
Up to 10 miles	(10-a) miles	(25-a) miles	90 miles	—
10 to 15 miles	No non-relayed Lines	(25-a) miles	90 miles	—

2. For 10 per cent Maximum Signal Distortion

Physical Separation ("a" route miles) between Telex Exchange and V.F. Terminal	Type of Circuit			Remarks
	Non-Relayed	Two Wire Relayed	Two Loop Relayed	
Up to 5 miles (Non-Relayed)	20 miles	45 miles	90 miles	—
5 to 10 miles (Non-Relayed)	(25-a) miles	(50-a) miles	90 miles	If "a" > 10 the section between V.F. terminal and Exchange should be relayed into the exchange.
10 to 15 miles (Relayed in one direction, i.e. into the exchange)	(20-a) miles	20 miles (Relayed into Exchange only) Or 45 miles (Relayed at both ends)	90 miles	If the subscriber's line is > (20-a) miles but < 20 miles it should be relayed into the exchange only. If > 20 it should be relayed at both ends.

but if duplex service is offered at any time in the future it will be necessary to apply lower mileage limits for the lines of these particular subscribers, due to the effects of additional fortuitous distortion.

Low-pass filters are inserted at the sending ends of all lines which enter telephone cables.

Subscribers' Numbering Scheme. To facilitate pricing call tickets in accordance with the tariff rates each subscriber's station is designated by the local telephone exchange name followed by the code TLX and a number corresponding to the multiple jack appearance on the telex switchboard to which it is connected. This procedure is advantageous for subscribers situated at a considerable distance from the telex exchange; also to a large extent it avoids number changes as the service expands and additional telex exchanges are opened.

Exceptions to this arrangement have been made in the case of London where subscribers within

the five-mile circle are designated, for example, "London TLX 2345" irrespective of their local telephone exchange name, and similarly for the two-mile circle in the larger provincial cities. A four-digit numbering scheme is in use for lines connected to the London exchange and a three-digit scheme for provincial exchanges, other than automatic sub-exchanges where a two-digit scheme is sufficient. For answer-back codes an abbreviated name designating the subscriber is used, e.g. ENGCHIEF LDN; this is a reversion to an earlier practice and corresponds with continental custom.

Signalling Principles

In the new inland telex system the adoption of C.C.I.T. recommendations for signalling simplifies the extension of the inland network to the international telex network. The recommended methods differ radically from the conditions used in the earlier public inland service teleprinter manual switching system and teleprinter private wire switching networks but are identical in principle with those used for the automatically switched public inland service, see Chapter IX and below.

C.C.I.T. Recommendation for Signalling in the Telex Service. Geneva Revision 1956. 1. *Free Line Condition.* The "free line" is characterized by a permanent signal corresponding to the start impulse in accordance with International Telegraph Alphabet No. 2 on the forward and backward signalling paths. (This is the space signal corresponding in the British system to positive polarity on physical circuits and to the no-tone condition in amplitude-modulated V.F. channels.)

2. *Call.* The "call" is characterized by the inversion of the condition specified in Paragraph 1 on the forward signalling path. (This is the stop signal, i.e. a marking signal, corresponding to negative polarity on physical circuits and tone-on in the V.F. channels.)

3. *Call-Confirmation Signal.* A "call-confirmation signal" shall be returned over the backward signalling path following the initiation of a call to prove the continuity of the line and the response of the distant terminal equipment.

4. (*a*) *Proceed-to-Select Signal.* In the case of international telex circuits terminated on distant automatic switching equipment which cannot accept the selecting information immediately after a calling signal is received, a "proceed-to-select" signal shall be returned over the backward signalling path after the call confirmation signal, to indicate that the selecting information may be transmitted.

If the interval between the transmission of the calling signal from the switching centre in the country of origin and the return of the "proceed-to-select" signal to this centre is short enough to permit the continuity of the international line to be proved by the equipment in the outgoing country, the "proceed-to-select" signal may be used to indicate the "call confirmation" and "proceed-to-select" conditions. In this case, a separate "call confirmation" signal need not be provided.

4. (*b*) *Proceed-to-Transmit Signal.* In the case of international telex circuits terminated on a distant manual switchboard a "proceed-to-transmit" signal shall be returned over the backward signalling path following the initiation of a call, to indicate that the teleprinter of the distant operator has been connected to the international circuit.

5. *Selection Signals.* (*a*) The selection signals should be in conformity with International Alphabet No. 2, or dial signals in conformity with Recommendation No. E2.

(*b*) In the case of dial selection into a system employing letters in the national numbering scheme, figures only will be used on international circuits because of the difficulty in transmitting signals other than figures from dials.

(*c*) In the case of selection from a dialling system into a system employing keyboard selection, the "prepare for digits" signal will be Combination No. 30 (Figures).

(*d*) In those cases where an "end-of-selection" signal is required, this signal shall be Combination No. 26.

(*e*) In systems which use keyboard selection and which require an "end-of-selection" signal, the subscribers' numbers shall consist of a uniform number of characters. A smaller uniform number of characters is, however, admitted for special services, but the first character must always be the same for all these special services.

6. *Call-connected Signal.* A "call-connected" signal shall be returned over the backward signalling path to indicate that the call has been extended to a called subscriber. In the case of fully automatic switching between subscribers this signal will start the equipment for determining the charge for the call.

7. *Idle Circuit Condition.* On an established connexion the "idle circuit" is characterized by a permanent signal corresponding to the stop impulse in accordance with International Telegraph Alphabet No. 2 on the forward and backward signalling paths.

8. *Clearing Signal.* A "clearing" signal is characterized by a reversion to the conditions specified in Paragraph 1 on either signalling path, maintained until the complete release of the

circuit. (In the British system the clearing signal is maintained indefinitely until the circuit is taken up by a subsequent call signal.)

Equipment terminating an international telex circuit shall be arranged to interpret such a signal as a clearing signal when it has persisted for a period of not less than 300 milliseconds.

When a clearing signal is received by equipment at one end of an international telex circuit the signal shall be returned to the other end in not less than 350 milliseconds, and maintained until the complete release of the circuit. Guard arrangements at both ends of an international telex circuit shall be such that the circuit cannot be used for a new call until the distant equipment is free to accept another call.

During this guard period the free-line condition shall be maintained on the international telex circuit.

9. *Service Signals.* If a "busy," "out-of-order," "office closed" or "number unobtainable" (i.e. not connected, service ceased or service forbidden) condition is encountered in the distant network this shall be indicated by the return of a signal to the calling end. If this is done by means of written indications the code expressions mentioned in Article 26 of Recommendation No. H1 should be used. It is desirable that in this case the code expression should be preceded by carriage-return, line-feed, letter-shift characters and be followed by the clearing signal.

10. *Characteristics of the Signals Defined in Paragraphs* 3, 4, 5, 6 *and* 9. The characteristics of these signals can be divided into two basic groups: Type A and Type B, as given in Tables 16.2(*a*), 16.2(*b*) and 16.3.

It is to be noted, however, that there is the possibility of the use of teleprinter signals as selection signals in association with Type B. For the time being, it is recommended that these signals should be used only after agreement between the administrations concerned.

The following supplementary provisions for signalling, though primarily intended for international telex service, have also been incorporated as standard facilities in the inland system of the U.K.

Supplementary Provisions for Signalling.

1. The international telex position must be equipped in such a way as to receive the clearing signal from both sides.

2. A signal to recall the operator of that position to an established connexion is not foreseen.

3. Precautions must be taken that in the event of the operator of the international telex position delaying to remove the plug on reception of the clearing signals, a new call from a subscriber on one network shall not pass to the other network.

4. When communication has been established, the answer-back signals of apparatus used at the intermediate telex positions must not be sent to line when figure-shift D is received.

5. The international telex position must be provided with equipment to determine the chargeable time of calls controlled by these positions, this timing equipment to be brought into operation in accordance with the provision of Article 25 of Recommendation No. H1, but to be stopped on receipt of the first clearing signal.

TABLE 16.2

International Telex Circuits Terminated on Distant Automatic Switching Equipment.

(*a*) Semi-Automatic Working to Subscribers.

Signal	Type A	Type B
Call-confirmation (See 3 and 4(*a*) above)	permanent stop polarity	25 mS pulse of stop polarity
Proceed-to-select (See 4(*a*) above)	(i) teleprinter signal(s) (ii) permanent stop polarity	25 mS pulse of stop polarity
Selection (See 5 above)	teleprinter signals	dial pulses
Call-connected (See 6 above)	teleprinter signals *Note.* the teleprinter signals may be preceded by a 150 mS (± 11 mS) pulse of start polarity	stop polarity for at least two seconds.
Busy (See 9 above)	teleprinter signals followed by clearing signal	(i) 200 mS pulse of stop polarity followed by start polarity for 1,200 mS. (Note 1) (ii) 200 mS of stop polarity followed by teleprinter signals and start polarity for at least 1,000 mS. (Note 1)
Out-of-order and number unobtainable (See 9 above)	clearing signal normally preceded by teleprinter signals	(i) permanent start polarity (ii) 200 mS pulse of stop polarity followed by start polarity for 1,200 mS. (Note 1) (iii) 200 mS pulse of stop polarity followed by teleprinter signals and start polarity for at least 1,000 mS. (Note 1)

Note 1: This sequence of signals may be repeated until the clearing signal is sent over the forward signalling path.

(*b*) Fully-Automatic Working between Subscribers.

Signal	Type A	Type B
Call confirmation (See 3 and 4(*a*) above)	permanent stop polarity	25 mS pulse of stop polarity
Proceed-to-select (See 4(*a*) above)	(i) 40 mS (± 5 mS) pulse of start polarity (ii) permanent stop polarity	25 mS pulse of stop polarity
Selection (See 5 above)	teleprinter signals	dial pulses
Call-connected (See 6 above)	150 mS (± 11 mS) pulse of start polarity followed by stop polarity for at least 2 seconds	stop polarity for at least 2 seconds
Busy (See 9 above)	teleprinter signals followed by clearing signal	(i) 200 mS pulse of stop polarity followed by start polarity for 1,200 mS (Note 1) (ii) 200 mS pulse of stop polarity followed by teleprinter signals and start polarity for at least 1,000 mS (Note 1)
Out-of-order and number unobtainable (See 9 above)	clearing signal normally preceded by teleprinter signals	(i) permanent start polarity (ii) 200 mS pulse of stop polarity followed by start polarity for 1,200 mS (Note 1) (iii) 200 mS pulse of stop polarity followed by teleprinter signals and start polarity for at least 1,000 mS (Note 1)

Note 1: This sequence of signals may be repeated until a clearing signal is sent over the forward signalling path.

TABLE 16.3

International Telex Circuits Terminated on Distant Manual Switching Equipment

Signal	Type A	Type B
Call-confirmation (See 3 above)	permanent stop polarity	25 mS pulse of stop polarity
Proceed to transmit (See 4(*b*) above)	teleprinter signals	stop polarity followed by teleprinter signals
Call-connected (See 6 above)	teleprinter signals	teleprinter signals
Busy, Out-of-order and number unobtainable (See 9 above)	teleprinter signals	teleprinter signals

6. The subscriber's equipment must be arranged in such a way that—

(*a*) A call can be received, the answer-back taken, the message transmitted and the connexion cleared without the intervention of the called subscriber.

(*b*) The motor of the teleprinter will rotate continuously for the duration of an established telex connexion. (For this purpose the automatic motor switch on the B.P.O. Teleprinter No. 7 is rendered inoperative for telex service.)

7. In exceptional cases, administrations may grant to subscribers the facility to free themselves from the stipulations of para. 6(*a*) for periods previously notified. In such cases means must be provided for the transmission of the code expression ABS either automatically, or in the case of manual exchanges, by the incoming switchboard operator.

8. If a subscriber's apparatus is such that he can use his teleprinter outside communication periods in order to prepare perforated tapes, for local checking of those tapes, for staff training, etc., then the taking of the answer-back may be delayed for a period not exceeding three seconds.

In applying these principles to the British system all signalling on physical circuits, including the switchboard equipment, is effected at ± 80 V. Either party to a connexion may initiate the clearing signal, which is transmitted over the forward path, giving a single clear at each switchboard on the route and clearing down the distant subscribers' equipment, upon which a clear signal is automatically applied to the return path, completing the double clear and restoring to normal the equipment of the subscriber who initiated the clearing signal.

Subscribers' Equipment. The subscriber's signalling unit Fig. 16.39 (*a*) and (*b*) is fitted with plunger type calling and clearing keys together with a red and a green supervisory lamp. The unit houses the auxiliary equipment such as relays, low-pass filter shunted capacitor, test jacks and protective resistor lamps. The page type teleprinter No. 7 is used, a rectifier being employed to provide the current for driving the motor together with a smoothed supply for line signalling.

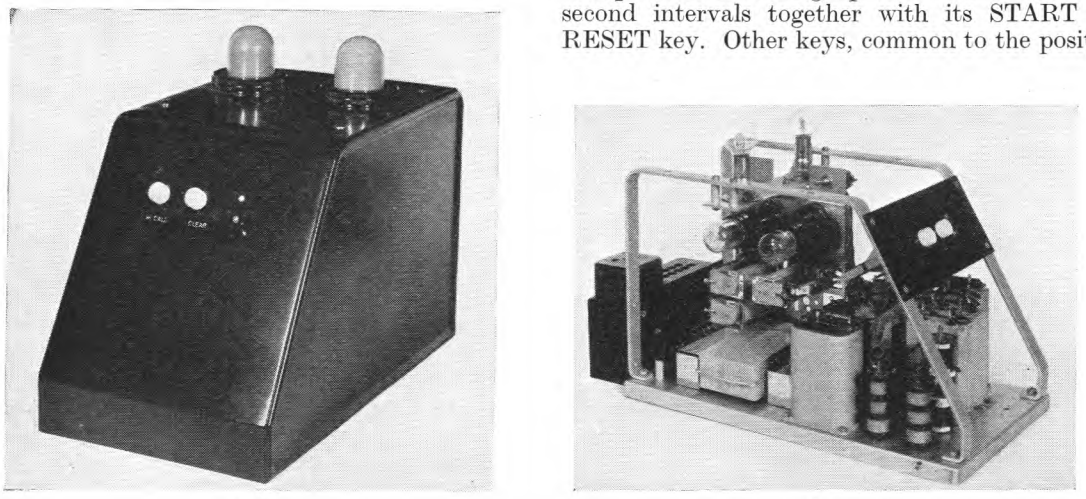
To make a call the subscriber momentarily depresses the CALL key; this action starts the teleprinter motor and gives a steady glow to the calling lamp at the teleprinter exchange. When the switchboard operator answers, the green supervisory lamp lights and the subscriber gives details of the call by teleprinter. During the progress of the call, if the secondary J signal is received, or while the home answer-back unit is off-normal, the red

alarm lamp will light, accompanied by the operation of an audible alarm. Clearing is effected by momentarily depressing the CLEAR button; this stops the motor, extinguishes the green lamp and restores the installation to normal.

On receipt of an inward call the green lamp lights, the motor is started automatically and the equipment is prepared to receive a message and subsequently to be cleared, without attention if need be.

The circuit details are given in Chapter 8.

Test jacks are provided giving access for maintenance purposes. A switch is also provided within the unit so that a faultsman after requesting the exchange operator to plug up the line, by inserting the calling cord into a HOLD jack, can maintain the calling condition and so busy the line temporarily against inward calls. Restoration of this OUT OF SERVICE switch gives a clearing signal to the exchange.



(*a*) (*b*)

FIG. 16.39. TELEX SUBSCRIBER'S SIGNALLING UNIT
(*a*) Cover on (*b*) Cover off
(*By courtesy of H.M. Postmaster-General*)

Telex Switchboards. A general view of part of a suite of telex switchboards is shown in Fig. 8.48; a closer view of the face equipment and the keyshelf is given in Fig. 16.40. The switchboard operator's teleprinter is a B.P.O. No. 11 tape machine, fitted with an end-of-line lamp for working into subscribers' page teleprinters. Sixteen cord circuits are provided, eight on either side of a central writing space for completing call tickets. On account of the large number of cord circuits in association with ticket preparation, diagonal slots are provided instead of clips, to hold tickets relating to calls in progress. Each cord circuit is equipped with a combined three positioned PRINT and MONITOR key, which leads to the common ANSWER-CALL splitting and MONITOR key of the operator's position circuit; also a clock which is capable of recording up to nine minutes in six-second intervals together with its START and RESET key. Other keys, common to the position, are a DIAL and ANSWER-BACK key and certain miscellaneous keys.

The dialling facility is required for use with automatic sub-exchanges. On account of the extensive facilities given by these cord circuits and the consequent plurality of relays, not all of the latter can be accommodated in the switchboard and for ease in maintenance most of the 3,000-type relays are separately rack-mounted. The polarized relays, which are of the plug-in type, are fitted in the rear of the switchboard.

A disadvantage inherent in this pattern of teleprinter switchboard is the amount of valuable vertical height taken up by the teleprinter. In order to accommodate the maximum number of lines within an operator's reach, two important changes in panel detail are incorporated compared with the design of previous B.P.O. teleprinter switchboards. In the first place individual engaged lamps associated with multiple jacks have been dispensed with, provision having been made for engaged testing in the classical manner adopted for telephone multiple switchboards by tapping the tip of a plug on the bush of the wanted jack. The result of encountering an engaged teleprinter

line is to flash a pair of red lamps on the pilot panel at the operator's eye level. A further safeguard is provided to nullify the effect of an accidental insertion of a second plug into any multiple jack of an engaged line. The second device to save space is the use of combined calling lamps and designation strips, the lamp lighting behind a translucent number strip; this arrangement has been used previously on certain telephone switchboards.

On the London switchboard a twelve panel (i.e. six-position) ancillary calling repetition is used for all incoming circuits, i.e. subscribers' junctions and trunks, and service circuits. On the outgoing multiples a four-panel repetition is used, putting all circuits within an operator's reach. For the junctions, trunks and service circuits, F.L.S. lamps are fitted behind the translucent designation strips. Service circuits include printergrams, multelex, inquiry positions and engineering fault reporting positions. The face equipment is completed by a row of miscellaneous routine test jacks at the top, above which is the calling pilot lamp. The maximum size for any exchange will be 1,000 lines.

For the provincial exchanges, which have fewer circuits, a combined calling and answering multiple, with a three-panel repetition, is used for all circuits.

The cord circuits are of sleeve-control type with splitting facilities, and in addition they allow for engaged testing and follow-on calls. The more important features provided are given below and the circuit arrangements, apart from those required for dialling into automatic switching equipment, are described in Chapter 8.

Cord Circuit Facilities.

1. Testing any circuit to ascertain whether it is free by tapping the bush of the jack with the plug tip; if the circuit is busy the red ENGAGED pilot lamps on the switchboard glow. If a plug should be inadvertently inserted in the jack of an engaged circuit, connexion with the circuit is prevented and the switchboard operator's teleprinter "races," i.e. it receives a continuous start signal, the red lamps remaining illuminated.

2. Gaining access and interconnecting circuits.

3. Connecting the switchboard operator's teleprinter to either the answering or calling cord as required for teleprinting. Should the operator enter an established connexion for supervisory purposes, a hold condition is maintained to the station to which the operator is not connected.

4. Preventing the operator's teleprinter from being connected to two or more cord circuits simultaneously.

5. Dialling on either cord.

6. Transmitting the who-are-you (WRU) signal from the switchboard teleprinter on either an answering or a calling cord and monitoring the subscriber's answer-back signals as they are transmitted through the cord circuit.

7. Monitoring both-way or uni-directionally, as

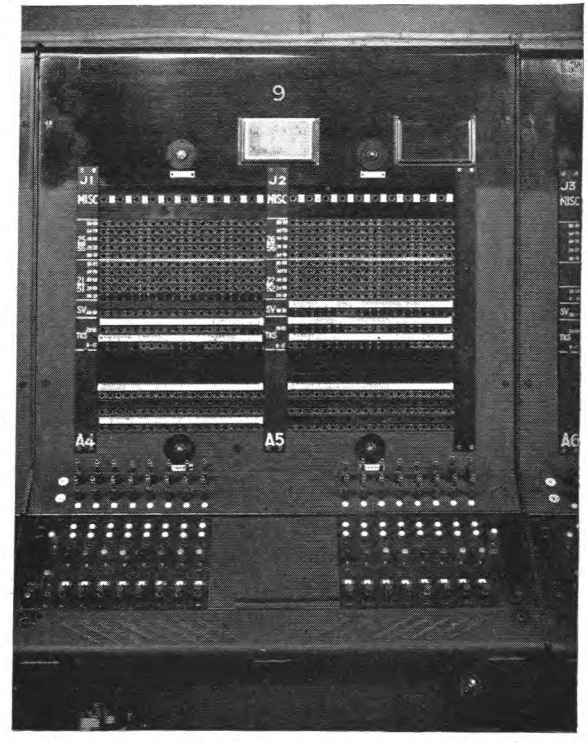


FIG. 16.40. TELEX SWITCHBOARD OPERATOR'S POSITION SHOWING FACE EQUIPMENT AND KEYSHELF LAYOUT

(By courtesy of H.M. Postmaster-General)

required, on any established connexion—the keyboard of the switchboard teleprinter is inoperative whilst monitoring.

8. Lighting the answer and call clearing supervisory lamps on the receipt of clear signals.

9. Disconnecting both sides of the cord circuit automatically when a double clearing signal is received, to allow follow-on calls even though the plugs remain in the jacks.

10. Timing calls by individual cord circuit clocks. A clock can be started manually provided that both subscribers are in circuit, and it is stopped automatically on receipt of the first clearing signal. If the clock steps to its full range of nine minutes it stops and the clock pilot alarm lamp glows.

11. Routine-testing clocks, lamps and engaged test circuit. Fig. 16.41 shows the switchboard cord

and position circuits in schematic form. For dialling, the position DIAL key (KD) is operated, relay D operates to convert the dial pulses into double-current signals for transmission to the distant automatic switching equipment and the off-normal springs of the dial hold relay DL to guard against pulse mutilation if the dial key is prematurely restored.

Direct Dialling Circuit. For dialling into automatic equipment the bothway line circuit of lamp (via its relay) disconnected up to now; the receipt of the + 80 V potential following the — 80 V pulse lights the clearing lamp in the normal manner and is the indication to the operator to commence dialling. In the event of the line or distant equipment being faulty so that the 25 mS pulse is not received, the clearing lamp will remain extinguished as a fault indication to the switchboard operator.

Relay *EE* is given a slow release to cover the

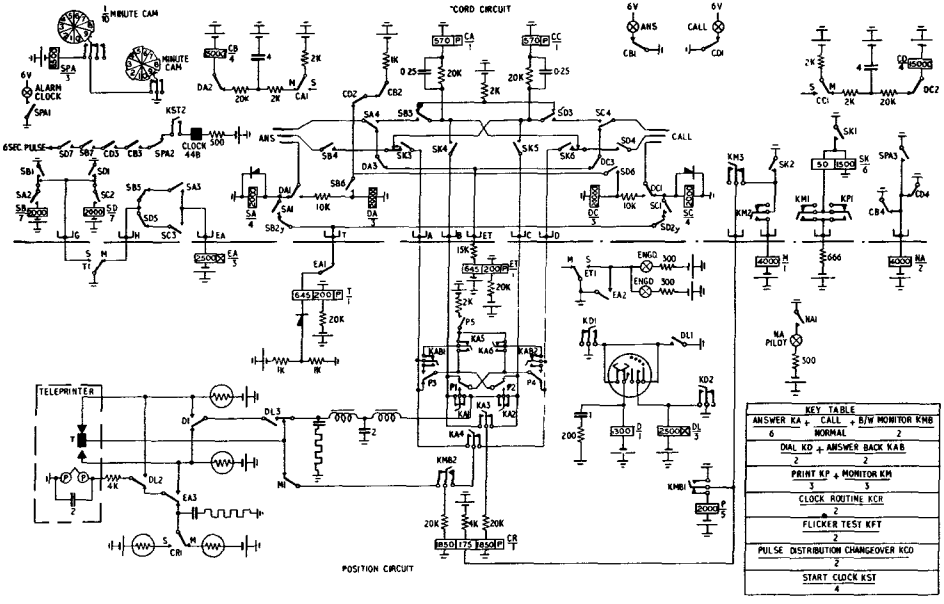


FIG. 16.41. SCHEMATIC DIAGRAM OF TELEX SWITCHBOARD CORD AND POSITION CIRCUITS

Fig. 16.42 is used. On the inland service this facility is at present restricted to traffic with automatic sub-exchanges; it is also used on the London switchboard for continental telex calls to automatic exchanges. The circuit is essentially similar to the line circuit previously described in Chapter 8 with relays *L*, *E* and *G* fulfilling the same functions. Provision is also made for follow-on calls by the automatic release of relay *E* on receipt of the double-clear signal.

When a calling plug is inserted in the outgoing jack the sleeve relays *E* and *EE* operate and a steady — 80 V calling signal is applied from the ring of the cord circuit. When a free selector is available at the distant exchange a — 80 V pulse, of nominal 25 mS duration, is received as a "proceed to dial" signal, operating relays *L*, *LA*, *LB* and *G* in sequence. The *R* wire is by this means extended through to the cord circuit, the — 80 V locally applied potential at *G* 5 having held the clearing homing of the distant selectors by delaying restoration of the *FLS* circuit. This safeguard is necessary to cover the case where a connexion is not completed and the normal double-clear will not be obtained.

On an incoming call, receipt of the — 80 V calling signal operates relays *L*, *LA*, *LB* and *EE* in sequence to light the calling lamp and step on the *FLS*. During the operating delay of relay *LB* a nominal 25 mS pulse at + 80 V, the "call confirmation" signal, is returned over the *S*-wire. When the operator answers, relays *E* and *G* operate and the line circuit is extended to the cord circuit.

Automatic Sub-exchanges. An automatic sub-exchange equipment provides facilities for up to 20 subscribers' lines to be extended, for either inward or outward traffic, to a maximum of 10 junction circuits to a parent manual board. The entire equipment, which uses only uniselectors and relays, is mounted upon a standard apparatus rack

suitable for installation in an M.C.V.F. telegraph terminal station or similar location. The equipment is designed to operate from ± 80 V.

A block schematic diagram of the arrangement of equipment is shown in Fig. 16.43. The uniselectors, provided on the basis of one per junction

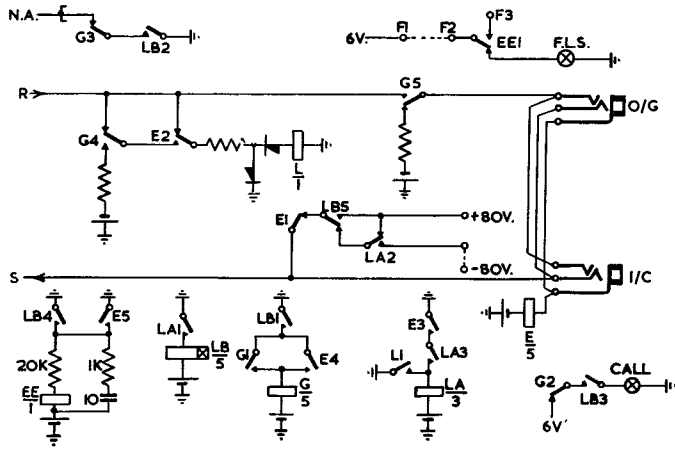


FIG. 16.42. BOTH-WAY LINE CIRCUIT FOR DIALLING INTO AUTOMATIC TELEX EXCHANGES

circuit, function as a combined subscriber's line-finder when a subscriber calls and as a two-digit selector when the junction is seized from the parent exchange. The allotter, which comprises a relay group only, selects disengaged junctions in cyclic order for extending subscribers' originated calls. The standard telex equipment is used at the subscriber's installations served by the automatic sub-exchange. At the manual exchange the junctions terminate upon the direct dialling circuit equipment shown in Fig. 16.42.

When a subscriber depresses his CALL button, a marking condition is applied to the bank of the allotted line finder, which hunts for the calling line, extending it with the calling signal to the parent manual board, provided that the 25 mS testing pulse has been returned from the direct dialling terminal equipment at the manual exchange to confirm that both junction and equipment are in order. Normal guarding facilities are provided. In the event of all junctions to the parent exchange being in use, an engaged signal is returned to the calling subscriber from the sub-exchange. Table 16.4 shows the allocation of the uniselector bank contacts to cover the subscribers' numbering range from 20–39.

When a junction is seized from the parent exchange, a "proceed to dial" pulse is returned to the main exchange provided the line and equipment are in order, and the associated selector is marked engaged at the allotter. If the first digit dialled by the operator is two, then during the inter-train pause the uniselector is caused to drive to contact 14 from which the wipers are directed by the second dialled digit to locate the required subscriber's number in the range 21–20. If the first digit dialled is three then on receipt of the units digit the wipers are stepped over the adjacent contacts among the group of lines 31–30. If a subscriber has two or more lines, P.B.X. hunting facilities are provided for all lines in a group to be tested before returning the engaged signal to the calling operator.

In the interest of simplicity and economy, modified engaged and out-of-service signals are

TABLE 16.4

Allocation of Bank Contacts at Automatic Sub-Exchanges

Bank Contact	Allocation
0	Spare
1	Test Number
2	Spare
3	Spare
4–13	Subscribers 31–30
14	Test Number
15–24	Subscribers 21–20

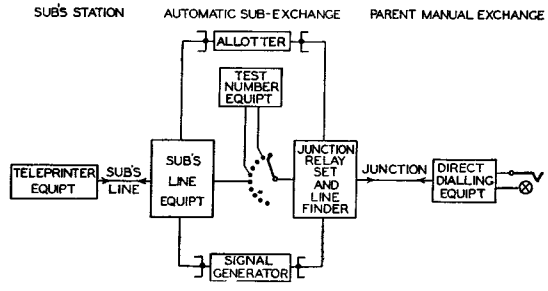


FIG. 16.43. BLOCK SCHEMATIC OF TELEX AUTOMATIC SUB-EXCHANGE

generated by simple timed relay equipment. The engaged signal consists of 20 mS pulses of + 80 V potential applied to the line every half second, producing the letter-shift signal (i.e. a non-printing signal) and giving a rhythmic signal audible at the teleprinter. The same pulse is used, but with a repetition rate of 1·5 sec, to denote connexion to a "level" or number which is spare or to a subscriber's line which is out-of-service. Low-pass filters are inserted in the distribution leads of the service signals, and as these are the only signals

generated or repeated in the sub-exchange there is no need for the inclusion of filters in the subscribers' or junction lines at this point. Normal facilities are provided for routine testing the sub-exchange equipment, which is normally unattended, by dialling test numbers from the parent manual board.

Printergram Positions. Printergram positions are equipped in the same manner as subscriber's positions with the added facility that after any incoming call the green supervisory lamp remains glowing after the call is cleared down, to enable attention to be drawn to a waiting message at an unstaffed position; the lamp can be extinguished by a RESET key fitted in the control unit.

International Telex Service. International telex service from the United Kingdom was first opened in 1936 using telephone circuits between special telex positions in the trunk suites at London and Amsterdam. Service was available between subscribers in Great Britain and in Holland, the services in both countries operating on the basis of 1,500 c/s signalling equipment with alternative speech facilities. The service was extended over the same route to the German telex network in 1937 and as the latter network was based upon an automatically switched telegraph network calls were connected from the Amsterdam manual board via a special V.F./D.C. converter equipment.

International telex service from the United Kingdom was suspended during the war years and in 1946 it was decided that the restoration of the service should be based upon the use of an exclusive telegraph network using d.c. signalling at the teleprinter and V.F. multi-channel telegraph circuits for the international trunks. Service was reopened on this basis on 24th March, 1947, for traffic initially with Holland. Six weeks later the service was extended to France and Belgium via manual telex switchboards in Paris and Brussels. In January 1948 a service was opened with the Swiss automatic teleprinter network over direct V.F. telegraph channels London–Zürich. Facilities were provided on the London switchboards for dialling direct to the subscribers in Switzerland and in the reverse direction Swiss subscribers dialled a special code to bring up a calling signal on the London switchboards where this traffic was controlled.

The growth of service has been very rapid and is available to all telex subscribers in the U.K. Calls between the U.K. and other countries are set up via London which has access to the foreign telex networks either by means of direct trunk routes or by transit switching through intermediate countries in those cases where the amount of international traffic does not justify the provision of direct trunk circuits.

By 1956, international service for telex subscribers in the U.K. was available not only to most European countries but also to the U.S.A. and Africa via radio links and to Canada via voice-frequency telegraph channels in the trans-Atlantic telephone cable. Further extension of the network to other extra-European countries can be confidently expected in the future, the ultimate objective being a world-wide service in which, in many cases, the setting up of calls will be on a fully automatic basis from subscriber to subscriber. Several European countries already have automatic telex switching systems and employ a national numbering scheme based upon a limited number of zone centres—usually between four and six—with a larger number of dependent exchanges. In some cases there is a further transmission link to a minor exchange whose subscribers gain access to a zone centre only via a dependent exchange.

Equipment. The subscriber's equipment is identical to that already described for the inland telex service except that it is found that for international service subscribers more frequently employ automatic transmitters and reperforators in conjunction with a teleprinter for handling their traffic with greater efficiency. The exchange equipment is of the same design as the inland equipment. The operating positions are divided into separate *A* and *B* suites, positions in the former suite—controlling outgoing calls—are equipped with only eight cord circuits, whilst the latter—the incoming positions—have the full 16 cord circuits. Dialling facilities are provided on all positions, the direct dialling circuit of Fig 16.42 being used on routes to the automatic networks.

For London telex subscribers connected to the inland switchboard who make only occasional international calls, a group of transfer circuits is provided between the inland and international suites in London. The subscriber's calling signal appears on the London inland switchboard and the call is extended by the inland operator to the international suite, where the connexion is completed and controlled.

From provincial exchanges separate groups of trunk circuits are available to the inland and international suites in London. This arrangement simplifies the operating procedure and facilitates the incorporation of regenerative repeaters which are necessary for the full realization of international telex service from provincial subscribers.

Telex Service over Radio Links. The operation of telegraph channels over radio links introduces many problems which do not arise on cable circuits.

The most important of these is the variable nature of the propagation path which often causes considerable changes in the received level of the signals, accompanied by corresponding changes in the signal-noise ratio at the input to the telegraph channel detector. The maximum sensitivity that can be employed in the receiver is restricted by the noise level at the detector input as during deep fades, when the signal level is very low, the noise level may exceed the signal and the detector will then operate on noise. Rapid fading is caused by multi-path propagation and under these conditions the signal received may be the resultant of two or three separate waves each propagated over a different path. Two waves arriving over paths differing in length by an odd number of half wavelengths result in a phase difference of 180° between them and if the levels are similar, maximum cancellation will occur. The difference in path lengths may result in a delay time of about two milliseconds between the times of arrival of the two waves and cause an in-phase condition at one frequency and maximum cancellation only a few hundred cycles away, i.e. selective fading occurs.

Various methods are adopted to combat these difficulties, e.g. space-diversity reception and frequency-diversity working. The use of frequency modulation is also advantageous as it enables a 6 db lower signal-noise ratio to be tolerated as compared with that permissible with amplitude modulation. Some discussion of these methods is given in Chapters 5 and 10. Nevertheless, despite the adoption of every precautionary technique to safeguard the accuracy of transmission, mutilation of telegraph signals will still occur on many radio links under unfavourable conditions. In order to provide an additional form of signal protection special error detecting codes must be used and in practice a seven-unit code is commonly employed (see Chapter 1).

A notable example of a seven-unit error detecting system which also incorporates automatic repetition and correction arrangements is that designed by a Dutch engineer Dr. Ir. Van Duuren. This system has been in use for a few years on a number of radio links and is employed for providing telex service between for example Amsterdam–New York and London–New York. In this system the detection of an incorrectly received character depends upon the conversion of every five-unit combination into a seven-unit combination so arranged that every character transmitted invariably contains the proportion of three marks to four spaces. At the receiving equipment these elements are weighed on a Wheatstone bridge circuit for their correct three–four ratio content and if this is not present an RQ signal (request for repetition) is automatically sent back to the transmission equipment which will retransmit the signal which had been mutilated—more than once if need be—until the correct mark to space ratio is obtained. With this system infallible error correction is dependent upon the probability that if one or more marking elements are transposed to spacing elements due to faulty transmission, an equal number of spacing elements will not be transposed to marking elements within the transmission of a signal character combination. Though the possibility of undetected error still exists, the probability is fairly small.

With a seven-unit code, the possible number of combinations made up from three marks and four spaces is equal to 35, so leaving three additional signals beyond the 32 of the International Alphabet No. 2 available for supervisory purposes in association with automatic error correction.

If an incorrect signal is received, i.e. one not conforming to the three–four mark/space ratio, printing does not take place. Instead, one of the three supervisory signals, an RQ signal (referred to as Signal "I") is transmitted back to the sending station: at this station the faulty signal is then automatically retransmitted, a procedure which could be repeated if necessary. It will be appreciated that, due to the double transmission time over the path including land lines and equipment, some time will elapse before this RQ signal arrives back, during which time further signals may already have been transmitted. To overcome this a four character repetition cycle is employed in which three banks of capacitors always store the last three characters transmitted, the charge on the first set being wiped out each time a new character is transmitted and at the same time stored.

The cycle of operations which results from a mutilated signal is best illustrated with the aid of Fig. 16.44. This represents a both-way radio transmission path which for the purpose of illustration is shown working duplex. In this diagram the station E is transmitting the capital letters *A*, *B*, *C* and *D* whilst the station W is transmitting the small letters *a*, *b*, *c* and *d*. The thick vertical strokes represent the operations occurring on the other channels of the time-division multiplex distributor equipment over which these transmissions are operated. The diagonal lines represent the transmission paths, allowing for the propagation time. The numbers 1, 2 and 3 relate to the capacitor groups upon which the preceding characters are still stored. It assumed that the letter "*a*" transmitted from station W is found to be mutilated upon arrival at station E, an occurrence which

results in the teleprinter being rendered inoperative for printing this character and for the three following characters also. To initiate repetition on the other channel character *D*, which would next have been transmitted in the E to W direction, is replaced by the transmission of the special RQ signal. Subsequently the three characters (*A B C*) stored on the capacitors are transmitted—indeed retransmitted, for they have already been sent out once. At the W station the receiving teleprinter is also blocked on receipt of the RQ signal as well as for the subsequent three characters, so that the *A*, *B* and *C* on their second arrival are not printed a second time.

In addition, the receipt of the RQ signal at station W causes (i) the same signal to be sent back to station E where it functions as an additional safeguard for correct reception and to reopen the teleprinter receiver, (ii) temporary stoppage of normal transmission and (iii) the subsequent retransmission from the storage capacitors of the character "*a*" previously mutilated in transmission, followed by "*b*" and "*c*" none of which was previously printed at station E. Transmission in both directions is then resumed in the normal manner.

For the sake of completeness it should be stated that the two remaining non-printing supervisory signals (known as "idle alpha" and "idle beta") are transmitted over the radio path during idle periods to maintain the three–four ratio at the receiver: these signals correspond to continuous start, i.e. spacing and continuous stop, i.e. marking signals.

It will be clear that the interpolation of the four character repetition cycle between the terminal equipments at either end of the radio link will delay the transmission of a message by an equivalent period, without of course the sending telex operator being aware of this. To act as a buffer when the signals arriving at the transmitting station overtake the signals leaving the station a unit is provided consisting essentially of a receiving perforator in conjunction with a novel automatic transmitter which is capable of reading the last character perforated.

During transmission, particularly under bad radio conditions, it is possible for a loop of tape to accumulate between the receiving perforator and automatic transmitter. This unit performs the additional function of converting the time-sequential five-unit signals from the teleprinter into "on-off" coincident signals on a five-wire local circuit: in this form the signals are more conveniently fed to the five-unit/seven-unit coder. Signals then pass to the storage capacitors and the multiplex distributor, the latter being a rotary device on the classic Baudot pattern. The receiving equipment is complementary, comprising essentially a rotary distributor, the error detecting relay group, a seven-unit to five-unit decoder, and a five-wire (on-off) simultaneous to five-unit sequential converter. There is of course no requirement for a perforated tape storage device at the receiver, the incoming signals after decoding being ready for printing. Since the multiplex equipment is itself a synchronously controlled system there is no need to transmit the usual start-stop signals over the radio link, but these signals must be applied to the decoded signals at the simultaneous-to-sequential conversion stage.

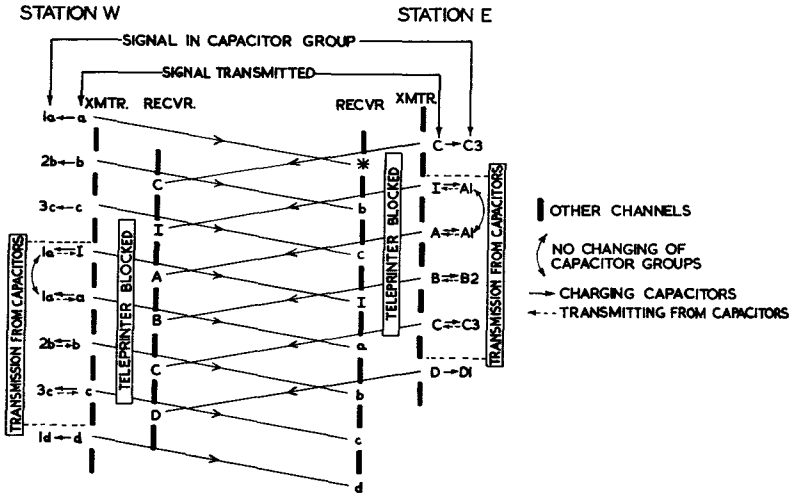


FIG. 16.44. VAN DUUREN AUTOMATIC ARQ SYSTEM: PRINCIPLE OF ERROR CORRECTION

CHAPTER 17

SUBMARINE CABLE TELEGRAPHY

It is now more than 100 years since the first submarine cable was laid across the English Channel from Dover to Cap Gris Nez on 28th August, 1850. This cable, manufactured by The Gutta Percha Co., was a primitive type and consisted simply of a single copper wire conductor of No. 14 Birmingham Wire Gauge (B.W.G.) covered with gutta percha (G.P.) as an insulant, to a diameter of $\frac{1}{2}$ in. No form of mechanical protection was provided over the main sea length of 25 nautical miles. (A nautical mile, i.e. n.m., is equal to 6,087 feet approximately.) Weights were attached to the cable at intervals to ensure that it rested firmly on the sea bed. The cable suffered from the disadvantage of having to be manufactured in lengths of 100 yd and then jointed before laying. The shore ends of the cable consisted of a copper conductor of No. 16 B.W.G. covered with cotton, soaked in indiarubber solution and encased in a thick lead tube. The whole cable only weighed five tons and was a flimsy affair to lay on a sea bed.

Nevertheless, communication over the cable was successfully accomplished employing Cooke and Wheatstone needle instruments but calamity quickly followed: a French fisherman is reported to have fouled the cable with his anchor and thinking it to be just an irritating obstruction he chopped the cable in two. This occurred on the morning following the laying of the cable and was a sad ending to a bold enterprise by the two English brothers Jacob and John Watkins Brett, who had formed the English Channel Submarine Telegraph Co.

Earlier experiments with submarine cables had been made, the most notable of these being by Charles Wheatstone during the years 1844–45. The cable laid by the Bretts was, however, the first of practical significance and is generally regarded as marking the beginning of submarine cable telegraphy. It was the foundation on which was built the submarine cable network which, in later years, bridged all the oceans of the world. The greatest contribution in this development was undoubtedly made by British enterprise and invention and the story of progress is a fascinating tale which the reader is commended to pursue in other books of reference, some of which are listed at the end of this chapter.

Following the failure of the first cross-Channel cable, the Bretts encountered great difficulties in raising funds for a second attempt. However, these were overcome largely due to the financial support and enthusiasm of Thomas Russell Crampton, an English railway engineer. He was entrusted with the design of the second cable which proved to be the basis of design for submarine cables for many years. It comprised a continuous conductor, encased in extruded gutta percha, covered with a layer of hemp yarn and finally armoured with galvanized iron wires to give mechanical protection. This cable was laid in 1851 and opened for traffic on 13th November, 1851. It is reported to have been in good working order as late as 1861.

The success of the second cross-Channel cable was quickly acclaimed and gave considerable impetus to further submarine cable enterprises. Other short submarine cables followed in rapid succession connecting Scotland with Ireland, and England with Belgium in 1853: Jersey with France, and England with Ireland in 1854: and Bulgaria with the Crimea in 1855. By 1860 cables were working also between England and Holland, and Denmark and Germany.

By 1854, serious thought was being given by engineers on both sides of the Atlantic to the possibility of a trans-Atlantic cable. This was an enormous project, the length of cable needed (about 2,000 n.m.) being far greater than any cable previously manufactured. No single ship was afloat which could carry the bulk of cable required and the depth of the Atlantic Ocean was at this time unknown and therefore had to be thoroughly charted, by deep sea soundings, over the proposed cable route. It was fortunate that at this crucial time Mr. Cyrus W. Field, a wealthy American, took an active interest in the project. His enthusiastic support, despite many disasters in the following 12 years, was a decisive factor in the successful completion of the first Atlantic cables.

The first Atlantic cable was manufactured in Great Britain; it consisted of a central conducting core, made up from stranded copper wire (weighing 107 lb per n.m.), and insulated with three layers of gutta percha to a diameter of approximately $\frac{3}{8}$ in. The insulated core was covered with a helical layer of hempen yarn, saturated with a special compound, the whole being protected by a helical "lay" of armouring consisting of 18 seven-strand iron wires of No. 22 B.W.G. The overall diameter of the cable was about $\frac{5}{8}$ in.

Experience was to prove this cable unsuitable

for deep sea use because of its low tensile strength and its high specific gravity, the latter causing it to sink rapidly and overstress the cable during laying operations, especially during rough weather. The cable broke during laying and several hundred miles of cable were lost; the project then having to be abandoned.

In the following year, on 5th August, 1858, the first successful attempt to lay a trans-Atlantic cable (between Knightstown, Southern Ireland, and Trinity Bay, Newfoundland) was completed after many difficulties and signals were exchanged. Unfortunately the cable quickly deteriorated, presumably due to insulation faults, and it finally failed completely on 20th October, 1858.

A major disaster also occurred in the failure of the Red Sea cable in 1859 and the large financial losses involved in these projects seriously impeded further progress for a few years. In 1864 the Telegraph Construction and Maintenance Co. was formed in Great Britain by the fusion of the Gutta Percha and Glass Elliott companies, who had previously engaged in the finishing, armouring and laying of cables. The T.C.M. Co designed a new trans-Atlantic cable made up of a central conducting core, consisting of a seven-strand wire weighing 300 lb per mile, which was filled with compound and insulated with four coverings of gutta percha. The gutta percha was "served" with tanned jute yarn and enclosed in armouring comprising ten ungalvanized soft iron wires of No. 13 B.W.G., each wire being compounded and served with five tarred strands of manilla hemp. The completed cable had a diameter of 1·1 in., a breaking strain of 7 tons and weighed about $1\frac{3}{4}$ tons per mile in air. In water, the cable only weighed 14 cwt per mile and thus had a better factor of mechanical safety for withstanding laying stresses.

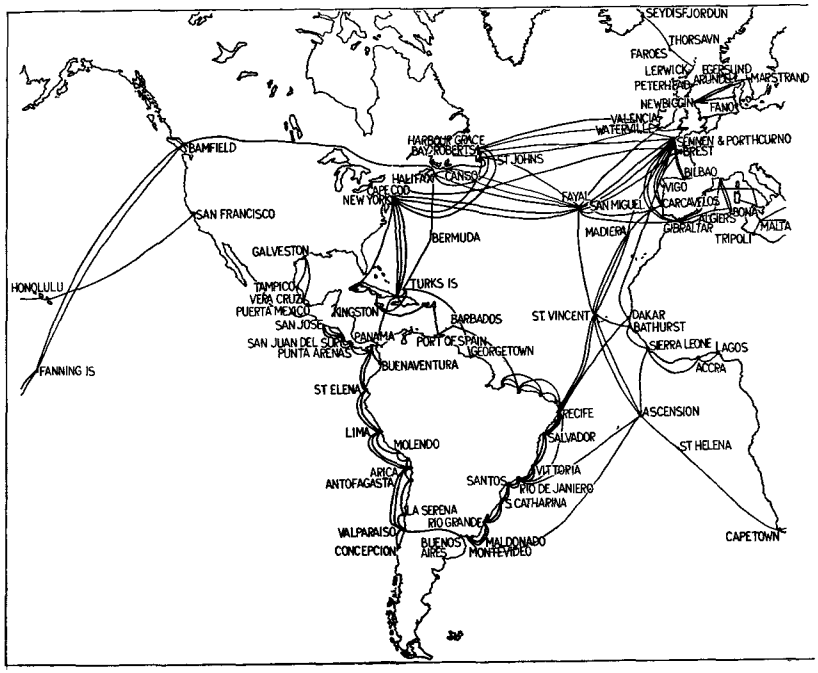
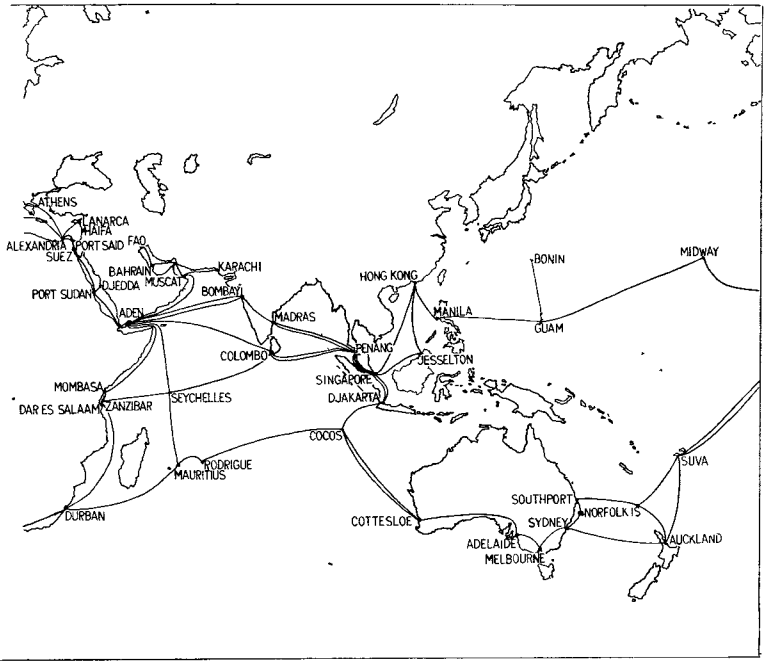


FIG. 17.1. PRINCIPAL ROUTES OF SUBMARINE

A cable of this type was manufactured in 1865 and in the same year the S.S. *Great Eastern* started the laying operation across the Atlantic from Valencia. The cable unfortunately broke in 2,000 fathoms of water (1 fathom equals 6 ft) and the expedition again had to be postponed until the following year. In 1866 a new cable was made having improved armouring; the armouring used on the previous cable had been found to be too brittle and liable to damage the core when paying out during the laying operations. The new armouring was made of a softer iron wire and was also galvanized to reduce corrosion. This new cable was laid by the S.S. *Great Eastern* between Valencia and Newfoundland between 13th July and 27th July, 1866, and was completely successful. The shore ends of the cable were made by W. T. Henley & Co., who employed solid armouring wires instead

of the three-stranded type used in the 1865 cable. The cable was reduced in size in three stages from the shore to the deep sea portion and this is still normal practice. Later in the same year, the 1865 cable was grappled and spliced to a new length and the laying of it to Newfoundland was completed on 7th September, 1866. Thus a second trans-Atlantic cable was completed and marked an historical step forward in submarine telegraphy.

The growth of the submarine cable network since



TELEGRAPH CABLES IN THE WORLD

those early days has been extensive and this can be best appreciated from study of Fig. 17.1 which shows the layout of the more important routes in the long distance submarine telegraph network in the world at the present day.

In modern times, despite considerable developments in radio telegraphy, the submarine cables still carry more than half of the world's long distance telegraph traffic. Furthermore, apart from occasional cable breakdowns, submarine cables have a much greater stability than radio circuits, the characteristics of the transmission path being much more constant. Another important factor in favour of cables is their greater privacy which is a matter of vital concern for certain messages. Furthermore, the increasing claims which are being made upon the radio frequency spectrum for various purposes impose a world need to exploit cable methods to the maximum amount practicable. It therefore seems certain that submarine cable and radio networks will continue to exist as complementary and not as competitive systems.

Laying and Repair of Cables

Submarine cables are expensive to manufacture and lay and much more difficult and costly to repair than land-line cables as they involve recovery from a sea bed. Specially equipped cable ships are required for the work of laying a cable and a notable example is H.M.T.S. *Monarch*. This vessel has a gross tonnage of 8,056 and a loaded displacement of 14,000 tons. It embodies all the latest equipment for the handling of submarine cables of all types and sizes and is capable of carrying over 3,000 miles of cable at a time. Cable repair ships are usually of much smaller tonnage, 1,000–2,000 tons, as they are not required to carry very long lengths of cable. They do however carry the latest navigational aids and testing gear, to facilitate accurate and speedy location of faults. Their smaller size makes them more easily manoeuvrable and capable of getting close inshore.

Laying. Before a cable is laid, the sea route which it will follow is carefully surveyed and charted, and in shallow waters marked by buoys, in order to secure the shortest practicable route,

consistent with a sea bed clear of sharp rocks which might injure the cable. Much information is obtained from Admiralty Charts, which enable a rough general position for the cable route to be selected prior to the detailed survey. The inequalities of the sea bed must be carefully noted so that enough slack cable may be left to allow it to be raised, when required, without undue strain. During the route survey, soundings are taken from time to time to check the suitability of the sea bed. For this purpose a cable ship is equipped with echo-sounding apparatus which enables a record to be taken showing the depth of water under the ship. In this way it is possible to avoid dangerous irregularities on the sea bed when the cable is laid. Cable is loaded in cable laying ships, in readiness for laying, coiled in large circular tanks. Great care must be taken in coiling the cable in these tanks, to ensure that it will run-out easily when it is being laid.

When a new cable is required in waters such as the North Sea and English Channel, which are comparatively crowded with cables, the utmost care must be exercised in choosing the route so that, when repairs have to be undertaken, the possibility of accidentally hooking and damaging the wrong cable is reduced to a minimum.

The ideal landing place for a cable should have a beach of a soft nature, clear of rocks and coral, sheltered from the prevailing winds and free from heavy currents. It should deepen gradually, to enable the cable ship to anchor within easy distance from shore. It should be clear of harbours and fishing grounds, and positions where ships usually anchor. A small cable hut is erected at the terminal shore points of a submarine cable for connexion of the cable to the land-lines and to provide cable testing facilities. In laying the cable one shore end is first landed from the ship standing off-shore. The cable ship then steams slowly out to sea and proceeds to pass out over large sheaves in the bow or stern just as much cable as will lie easily on the bed of the sea; too little will entail portions of cable being suspended between irregularities where it may be caught or damaged by the trawls of fishing boats; too much will involve waste and the danger of entanglement. While, therefore, the cable is being paid out, the chart calculations are carefully followed, the record made by the echo-sounding apparatus watched and continuous electrical tests of the cable are made.

The rate of paying out the cable is under continuous control by means of a cable engine and a brake and the cable passes to the bow or stern sheaves via a dynamometer which gives a continuous measure of the tension in the cable. The cable is led from the storage tanks, through guides, to the cable engine, where it is taken several times around its large diameter drum. The drum can be driven, or braked, as required.

The final operation is to land the other shore end of the cable and to connect it to the land-line, for which purpose the cable ship anchors as close inshore as possible. A sufficient length of cable is coiled from the ship's cable tanks upon a lighter, which carries it close to the landing point. The end of the cable is then hauled ashore, casks being attached to the cable to keep it afloat between the shore and the lighter. Smaller cables are usually landed by means of a raft formed by lashing timbers across ships' boats. As the raft is towed inshore, the cable is paid out until it is near enough to land to be hauled ashore.

The Repair of Cables. The first stage in effecting repair is to discover the position of the fault. By means of the instruments available in the cable hut, electrical measurements are made which enable the approximate position of the fault to be ascertained. The cable ship steams to the charted position of the fault and marks the place with a buoy. A grapnel is lowered and the ship steams, or drifts, across the line of the cable, while an experienced officer sits on the grapnel rope. When the grapnel bites, he is able to distinguish by the feel whether the cable has been caught or whether the grapnel has encountered an obstruction.

As soon as the cable is hooked the ship is stopped and the cable is hauled carefully up to the surface and secured with chains. The cable is then sawn in two and each part is tested to the cable huts, to determine on which side of the cut the fault lies. The cable end which is clear of faults is sealed and returned to the sea connected to a buoy. The faulty end remains on board and the ship steams slowly along the charted route towards the fault, the cable being hauled in and coiled in the tanks. If the cable is not completely broken the fault eventually comes aboard. The damaged portion is then cut out and replaced by a new section of cable. If, however, the fault is caused by a complete break the second broken end needs to be found and pulled up with the grapnel. When this has been done and further tests made, a new length of cable is joined on. Finally, the ship steams back and picks up the buoyed end which is joined to the repaired cable after both sides have been given a final electrical test. The armouring wires are then replaced and the cable returned to the sea.

The raising of a cable from great sea depths is usually carried out by a "cutting and holding" grapnel, which hooks the cable, holds one side and cuts away the other.

Apart from the intrinsic difficulty of submarine cable repair work, it has to be performed at the greatest possible speed and often in bad weather. The work is hard and often hazardous.

Construction of Submarine Telegraph Cables

After many early and costly failures, the problems of design and manufacture of submarine cables were satisfactorily solved nearly a century ago and the basic design has remained almost unchanged for a great many years. Fig. 17.2 shows a typical non-loaded deep sea telegraph cable and indicates the form of construction employed.

The first major development in the long history of submarine cables was the realization at the end of the 19th century, as the result of the work of Oliver Heaviside on the theory of continuous magnetic loading (see Chapter 5), that a considerable increase in the working speed of a cable could be obtained by the use of lumped or distributed line inductance. This discovery led to the application of continuous magnetic loading on some cables by winding iron wire over the core. At a later date, nickel-iron alloys, which have a high permeability at low flux density, were discovered to be much more effective than iron for loading. The conductors of the more modern telegraph cables are continuously loaded by means of a thin permalloy or mumetal tape which is wound helically around the conducting core. By this means the speed of the cable can be increased about four times compared with an unloaded cable of the same size and length.

Even with this improvement, however, the effective band-width of long telegraph cables is only about 100 c/s. It is interesting to note that the first trans-Atlantic telegraph cable operated at a speed of only about three words per minute, which is equivalent to a band-width of about 1·5 c/s. By comparison, the new trans-Atlantic telephone cable laid in 1955–56 transmits a band-width of 144,000 c/s. It is, however, of an entirely different construction from telegraph cables and consists of a solid dielectric (i.e. polyethylene) coaxial structure covered with the usual jute and armour for protection and strength. The central conductor consists of a central solid wire surrounded by a single layer of spiralling and abutting tapes carefully formed to fit closely about the wire. The return conductor is also a flexible composite structure comprising a single layer of abutting spiralling copper tapes formed into a tubular form. It is covered with overlapping spiralling copper tape for protection against teredo worm. The various spiralling layers of tape and armour are applied in the same direction of lay.

Fig. 17.3 shows the make-up of the deep sea portion of the trans-Atlantic telephone cable. A separate cable is employed for each direction of transmission over the main sea length and each is fitted with 52 submerged telephone repeaters.

The first practical applications of the principle of magnetic loading on submarine cables were made on telephone cables about 1909–12, e.g. a loading

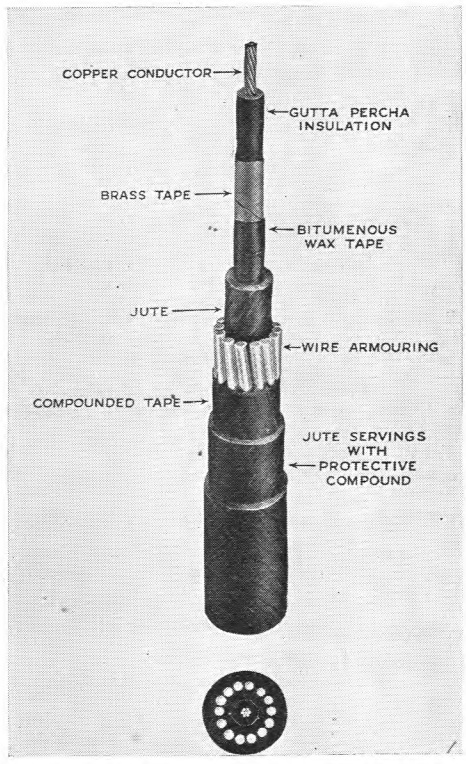


FIG. 17.2. A TYPICAL NON-LOADED DEEP SEA TELEGRAPH CABLE

of 0·012 in. iron wire was used for a four-core telephone cable from England to France in 1912. It was not until 1924 that a telegraph cable, continuously loaded with high permeability alloy wire or tape, was laid.

Much research has been carried out to find a better insulation for submarine cables than gutta percha, for although in many respects gutta percha is ideally suitable it suffers from the disadvantage that it has a high specific capacitance, viz. 3·4. Balata, *K*-Gutta (i.e. gutta percha with petroleum jelly), and Paragutta (i.e. gutta percha with rubber) were all tried, and Paragutta, which has a specific capacitance of 2·6, eventually replaced gutta percha for the insulation of more modern cables. The

capacitance of submarine telegraph cables is commonly about $\frac{1}{3}\,\mu$F per n.m.; for large cables it is higher and for the lightest cables it is lower. By way of comparison it is of interest to note that in land-line telephone cables, in which paper and air

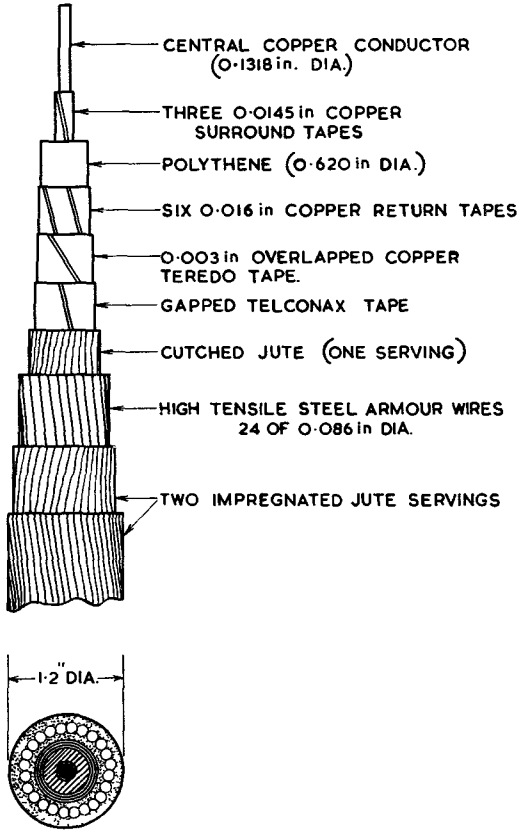


FIG. 17.3. TRANS-ATLANTIC TELEPHONE CABLE

Type used at depths greater than about 700 fathoms

space is used as the dielectric, the effective dielectric constant is of the order of 1·5.

In recent years synthetic materials have been discovered which have a much lower dielectric constant and leakage loss than Paragutta. This is an important advance, as the lower the value of the dielectric constant the less is the need for inductive loading. A great step forward was made in 1933 with the discovery, by the Imperial Chemical Industries Ltd., of polyethylene (or polythene as it is more commonly known). This material is ideal for the insulation of submarine cables as it has a dielectric constant of only 2·2–2·3, has negligible leakage losses, is non-hygroscopic and is robust, flexible and easily processed. It has been employed with notable success in a number of modern telegraph and telephone cables and has superseded the use of gutta percha types of dielectric for new cables.

The Cable Conductor. In early telegraph cables, the conductor consisted of a single copper wire but it was soon found to be preferable to use a stranded copper wire consisting of several strands twisted together, as this gives greater flexibility and reduces the liability to complete fracture. The breakage of a single strand is not serious providing it does not penetrate the insulation. For small cables, seven strands of equal diameter were used, one central strand with six twisted surrounding strands. This construction gave place to a relatively heavy central conductor surrounded by either 10 or 12 strands of much lighter gauge, or by five or six copper tapes, as these forms of construction, particularly the latter, reduce the overall diameter and surface area of the core and therefore reduce its capacitance. From the point of view of minimizing the capacitance, a solid circular conductor is best: for mechanical reasons however the stranded, or taped type, is commonly used. The conducting material is pure annealed copper so as to obtain maximum conductivity. The conductor and insulation must be able to withstand greater elongation than the armouring, otherwise during laying and repairing operations when high stresses may occur, often amounting to several tons per square inch, an internal fracture might be caused within an apparently intact cable. The core of the cable must be made solid to prevent deformation of the insulation under the pressure of the sea, which at great depths, e.g. three miles, reach three or four tons per sq in.

It is also necessary to ensure good adhesion between the conductor and the dielectric and so safeguard against the possibility of water being forced along the conductor when breaks in the cable occur in service. For these reasons the central wire of G.P. cables is heated during manufacture, so driving off any moisture, and drawn through a hot bath of Chatterton Compound, which is a mixture of G.P., tar and resin. The outer strands are then wound on and the completed core is again passed through a bath of Chatterton Compound. In the case of polythene cables a plastic filler is employed instead of Chatterton Compound.

When the cable is "loaded," either permalloy or mu-metal is spiralled round the core and the core is again sealed. This ensures that the hydrostatic pressures are equalized on the loading material when the cable is in service and so maintains uniform permeability.

The trend in long distance submarine cable telegraphy has, in recent years, been to employ

non-loaded single-core cables fitted with submerged telegraph repeaters. For shorter distances over which telephone circuits are also required, modern practice is to employ coaxial telephone cables and to provide the telegraph channels by means of multi-channel frequency-division of a carrier telephone channel.

A major advance in long distance submarine cable telegraphy has been made possible in recent years by the successful introduction of submerged repeaters on telephone cables which enables the distance limitation previously imposed on the operation of such cables to be overcome. The new trans-Atlantic telephone cable (see Bibliography) which is of coaxial construction provides initially 36 telephone circuits of 3·4 kc/s band-width and any of these circuits are capable of carrying a 24-channel telegraph system. Thus the possibility of a new era in submarine telegraphy has been opened.

The Cable Dielectric. The dielectric which has been used exclusively until recent years has been gutta percha, indeed it still forms the main constituent of all but the most modern dielectrics which are now synthetic plastics based on polyethylene. Gutta percha is the coagulated latex of certain trees which grow in the Malay Peninsula and East Indian Islands. It resembles rubber in chemical composition but is hard at ordinary temperatures and becomes soft and plastic in hot water. It has excellent properties as an insulator and is extremely suitable for submarine use as its dielectric properties actually improve under water pressure. It must not be allowed however to become thoroughly dry otherwise it deteriorates: strong sunlight also has deleterious effects and for these reasons the raw material and manufactured cables are stored under water. Before use, the natural gum from the trees has to be processed to remove impurities and then mechanically manipulated to produce an homogeneous mass, free from air bubbles, which is rolled into sheets ready for use.

The gutta percha is applied to the conducting core of the cable by heating it to a uniform temperature until it is plastic, then forcing it through the die of an extrusion machine over the conductor which is drawn centrally through the die at a uniform speed. The insulated core is cooled and hardened in a bath of cold water as it emerges from the extrusion machine. The gutta percha is applied in two or more layers according to the size of the core.

Indiarubber is sometimes used for insulating the shore end of cables in very hot climates where there would be a risk of the conductor becoming decentralized in the warm and consequently softened gutta percha. Each core of the beach section of a cable is lead-covered in order to exclude air. Lead-covering is discontinued when a sea depth is reached and there is therefore no risk of the cable being uncovered for long periods to the atmosphere, nor submitted to temperatures at which gutta percha softens.

For new cables gutta percha types of dielectric have been superseded in recent years by the thermoplastic polythene. This material is formed of solid polymers of ethylene and is prepared by subjecting ethylene gas ($CH_2{:}CH_2$) to very high pressure, thereby producing long chain molecules having the chemical formula—CH_2—CH_2—CH_2—CH_2—. The chains are of variable length but are of the order of 1,000 units long; the individual unit is called the *monomer*, and the large number of units forming the chain is the *polymer*.

Polythene is similar in appearance to paraffin wax but has much higher mechanical strength and softens at a much higher temperature. It is tough, flexible, translucent, non-hygroscopic and has negligible leakage loss and a low dielectric constant, i.e. 2·2–2·3.

For cable manufacture it is supplied in the form of small rough chips. These are softened by heating and may be mixed with a plasticizing agent, usually polyisobutylene, to increase the flexibility and ease of processing the product. Polyisobutylene is another polymer of hydrocarbons which has excellent elastic qualities and possesses electrical characteristics similar to those of polythene. For cable manufacture up to 12½ per cent polyisobutylene may be used. The heated mixture is rolled into thin strips which are subsequently cut up into convenient sizes and ground to a granular form in readiness for use. The plastic granules are loaded into the hopper and fed into the cable extrusion machine which forces the softened plastic through a die over the conducting core of the cable, which is drawn centrally through the die at a uniform speed. The insulated core passes from the extrusion machine through a long water trough in which it is slowly cooled.

The insulated core is now ready for sheathing and the methods employed for this purpose will now be described briefly: the methods used for polythene and gutta percha types of cables are generally similar.

Cable Sheathing. Except in deep water, it is necessary to provide protection in tropical waters against the "teredo worm" which causes failure of the cable by boring into the dielectric. Protection consists in wrapping the dielectric with a brass tape and is effective so long as the tape lasts.

Corrosion of the tape is liable to occur, however, due to electrolytic action between the galvanized armouring wires and the brass tape, which can be mitigated to a large extent by surrounding the brass tape with an impervious cotton tape heavily coated with a bituminous compound.

To provide mechanical protection for the cable during and after laying the cable is armoured. The armouring varies according to the depth in which the cable is to be laid and the nature of the sea bed and strength of sea currents in the locality concerned. It must be strongest over the shore-end section as it is here most subject to damage from the hazards of chafing on rocks and other obstructions by sea motion, and damage by ships' anchors and fishing gear. Mild steel armouring is generally used for all except the deep-sea type, in which high tensile steel is used.

The first consideration in the design of armouring for the shore-ends is protection from coastal causes of damage. On the other hand, the principal consideration in the case of the deep-sea portion is the stresses to be withstood during laying and subsequent repair operations, when the strain has to be taken off the long length of cable supported from the bow sheaves of the ship to the sea bottom.

Because of these hazards there are, broadly speaking, four types of armoured telegraph cable to meet the various conditions of the route, viz. the "Deep-sea type," having an overall diameter of about 1 in., which is used for depths exceeding 500 fathoms; a "Medium type," of larger diameter, which is used for depths between 30 and 500 fathoms; a "Heavy type," having a diameter of 2 in.–3 in., which is used in depths up to 30 fathoms; and a "Shore-end type," having double-sheath armouring, which is used for 1–2 miles at the beach end. The armouring of the cable affects its size and weight considerably as may be seen from the following table which gives certain details for the types of cable used on various sections of the Cable & Wireless Ltd., Fanning-Suva (1926) cable.

To armour a submarine cable a jute serving is first lapped over the already protected teredo tape, to form a cushion on which to bed the armouring wires. The armouring wires of galvanized iron or steel, covered with protective compound, are then wound over the jute serving. (In some cases, due to the acidity of the sea bed, it is necessary to provide additional protection for the armouring wires to resist corrosion. This is done by applying a protective tape to the individual armouring wires which are subsequently compounded and covered with jute.) More preserving compound is then applied, then another layer of compounded jute serving and, for double armoured cable, a further layer of armouring wires. Very rarely a third layer of armouring is applied. The cable is completed by applying as an outer serving two coatings of heavily tarred jute yarn twist, laid in opposite directions over the sheathing wires. The final serving reduces corrosion of the armouring wires by protecting them from abrasion. The cable is finally whitewashed to prevent contiguous layers, i.e. "flakes" of the cable from adhering to one another when stored in the cable tanks prior to laying.

Type	Approx. Diameter of Cable	No. of Armouring Wires	Diameter of Armouring Wires	Weight per Nautical Mile
Deep Sea	1 in.	17	0 083 in.	1·73 tons
Heavy Deep Sea	1·1 in.	17	0·120 in.	3 0 tons
Twin-Core Heavy Deep Sea	1·5 in.	35	0 095 in.	4·9 tons
Tri-Core Intermediate	1·8 in.	19	0 2 in.	9 tons
Tri-Core Shore End	2·2 in.	15	0·3 in.	14 3 tons
Tri-Core Rock	3 in.	15 and 22 Two Layers	0·244 in. 0·3 in.	30·8 tons

Fig. 17.4 shows schematically the make-up of a heavily armoured twin-core shore end cable.

The Sea Earth. Submarine telegraph cables use earth return signalling and therefore require good earth connexions at each end of the cable. Furthermore, as the signals received over a long cable are extremely weak and often of the order of only a few microamps, it is essential that the earth should be as free as possible from electrical noise in order to secure a satisfactory signal/noise ratio. Similarly, it is necessary to minimize the effects on the telegraph signals of other sources of noise which may be produced in the cable by induction from atmospheric disturbances and crossfire from other cables.

The extent of crossfire can be reduced by keeping the paths of different cables as widely spaced as possible, particularly where they follow similar routes, and making any unavoidable crossings at right angles if possible. Where, however, the cables converge upon the same cable station and sufficient separation cannot be maintained between them as they approach close inshore, appreciable crossfire may occur unless preventive measures are taken as described later. The inductive effect of atmospheric disturbances occur most in shallow water and thus arise in the shore ends of cables. At depths exceeding 100 fathoms or so, the attenuation of such disturbances caused by their downward passage through the sea reduces their effect considerably and at depths exceeding 300 fathoms their effect is negligible. At such depths also the changes of potential due to a.c. and other power sources on shore are also negligible.

For the foregoing reasons it is usual to make the earth connexions of a submarine cable out at sea in fairly deep water. Such an earth connexion is therefore called a "sea earth."

For simplex circuits only one earth connexion is required at each end whereas for duplex circuits two earth connexions are necessary, viz. one for the artificial line and one for the transmitter. These two points may be connected to a common earth, either by connexion to the cable sheath at the example, at Bay Roberts, Newfoundland. On the other hand, for example, at the Azores, deep water is reached quickly and the sea earth only extends for $2\frac{1}{2}$ n.m. A common distance for more recently laid cables is between 20 and 30 n.m.

It will be evident that the advantages gained by the use of sea earths are (*a*) the effect of induced voltages in the shore ends of cables is neutralized, (*b*) crossfire into other cables due to the shore ends is practically eliminated,

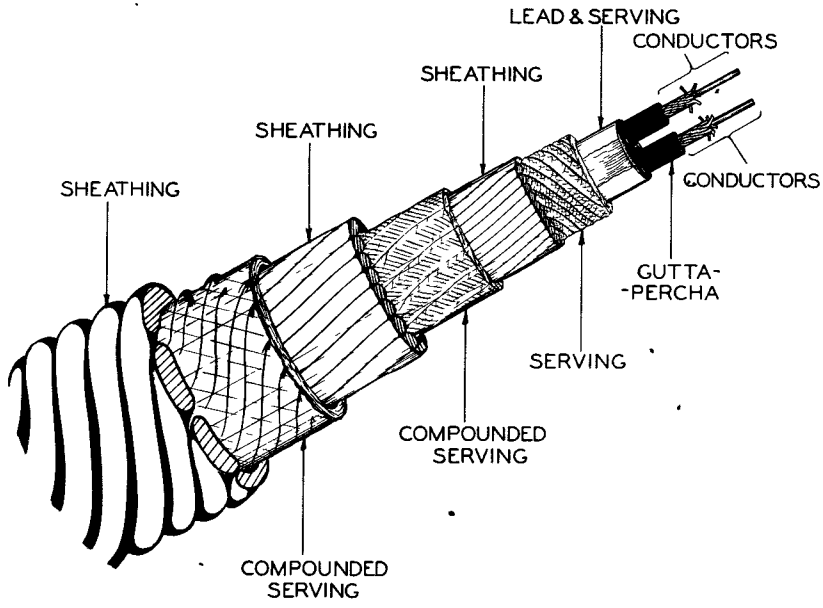


FIG. 17.4. HEAVILY ARMOURED TWIN-CORE SHORE END TELEGRAPH CABLE

submarine cable station or, for reasons of noise reduction, to a sea earth. It is preferable to use a sea earth for both simplex and duplex circuits and on duplex circuits it is common practice to provide two separate sea earths. Depending on whether one or two sea earths are employed the shore end cable is either a twin-core or tri-core type and the earth cores are bonded to the cable sheathing at a distance from the shore where a sufficient depth of water is reached.

To ensure a reliable earth it is usual to make the bonding for each sea earth from the earth core to the cable sheath over a distance of some 10 fathoms. Where two sea earths are employed for duplex circuits, that for the transmitter is made closest to the shore and is known as the "short sea earth," whilst the sea earth connexion for the duplex balance is made further out to sea, and is known as the "long sea earth." The short sea earth is usually about 1 n.m. from shore but the long sea earth may be 50 n.m. or more from shore as, for

and (*c*) direct injection of noise arising from variation of earth potential is reduced.

Submarine Cable Signalling

The theory of transmission of direct current telegraph signals is dealt with in Chapter 5 in which it is shown that the transmission quality of a line is dependent upon its four primary constants, namely, resistance R, inductance L, capacitance C and leakance G. The shape of the signal arrival curve can be greatly improved by inductive loading and this enables higher speeds to be employed so increasing the traffic carrying capacity of the cable.

The principal difference between landline and submarine telegraph cables is the very much higher capacitance of the latter which, in conjunction with the great length of many cables, imposes severe restrictions on their maximum signalling speed. The majority of cables in service to-day are old and unloaded as the practical use of loading was only introduced about 30 years ago. When

continuous loading was first introduced it rendered the cable unsuitable for duplex working owing to the critical nature of the balance required. This difficulty was overcome by the use of "tapered loading" in which the amount of loading is increased in several stages from zero at each end of the cable to a maximum over the middle section.

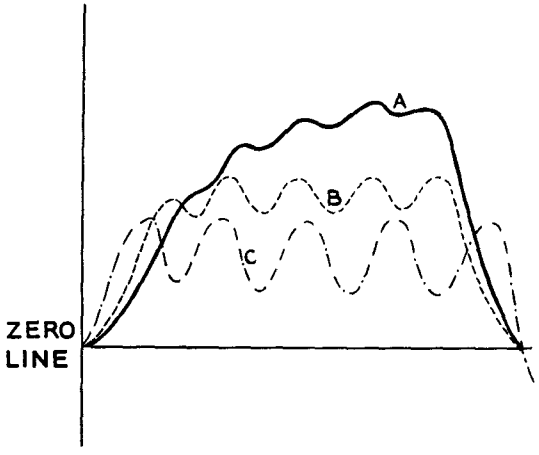


FIG. 17.5. SIGNAL SHAPE FOR FIGURE FIVE ON LONG, MEDIUM AND SHORT CABLES

In recent years much development work has been done on submerged repeaters and their use on telegraph cables enables much higher signalling speeds to be obtained without the need for loading. The Western Union Telegraph Co. were the first to install a submerged telegraph repeater and fitted one in an unloaded trans-Atlantic cable in 1950. The repeater enabled the speed of signalling on the cable to be approximately trebled and served as a striking practical demonstration of the important advance in submarine telegraph cable transmission methods which is made possible by the use of such repeaters.

The use of high signalling voltages on submarine telegraph cables has to be avoided owing to the risk of insulation breakdowns and for this reason not more than 120 V is normally employed. The received signalling currents on long cables are extremely small and often considerably distorted; it is therefore necessary to use extremely sensitive apparatus and also to employ every possible artifice to improve the shape of the received signals.

In this connexion, the value of inductive shunts and shunted capacitors at the sending and receiving ends of a circuit, as a means of improving signal shape, has already been discussed in principle in Chapter 5.

Zero Wander. As the speed of signalling is increased on a long cable, the signal elements begin to merge into one another and ultimately become unreadable. This effect is illustrated in Fig. 17.5. Curve A shows the shape of the arrival curve for figure 5 signalled in cable code and received over a long submarine cable, whilst curves *B* and *C* show similar signals received over a medium and short cable respectively. In curve *A* the dots are still distinguishable by the humps in the curve, but it will be observed that the value of current increases above zero with each succeeding dot. The same effect, though less marked, is also evident in curve *B*. A succession of dash signals in cable code would show a similar effect, except that the curve would be below the zero line. A succession of dots followed by a single dash would, in an extreme case, only be interpreted by the recognition that each signal element ended when the current curve fell downwards. In other words, the signals are read from a new zero line formed by the lowest part of each dot. This new zero continually changes in accordance with the preponderance of positive or negative signalling elements. This effect is called "zero wander."

The letter *L* signalled in cable code at the same speed on these three cables is contrasted in Fig. 17.6. The last two dots in curve *A* could be recognized by a skilled telegraphist from the greater length of the curve as compared with that of the first dot.

Signal Curbing. Signal curbing is the term used to denote the effects produced by various signalling

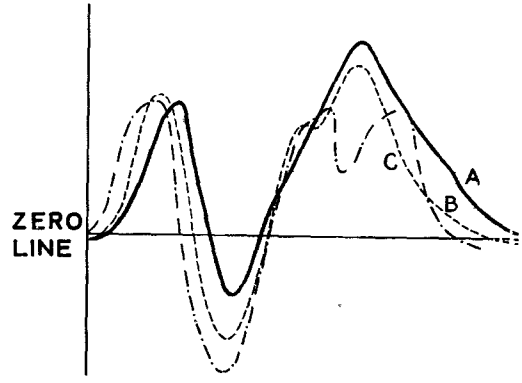


FIG. 17.6. SIGNAL SHAPE FOR LETTER L ON LONG, MEDIUM AND SHORT CABLES

arrangements designed to improve the wave shape, i.e. sharpen the signals at the receiving end of a cable by hastening the discharge of the cable at signal transitions and preventing zero wander. One method consists of sending a current of reverse polarity for a short period at the end of each signal element. Another method used at one time consisted of sending after each dot or dash signal a

current of shorter duration in the reverse direction followed by a short period during which the cable was earthed.

The duration of the curbing required depends upon the speed of working, being greater for higher signalling speeds, e.g. when using automatic transmitters: for low speed hand-keyed signals curbing is not required.

Modern practice is to employ an earthing period at the end of each signal element, the earthing period being adjusted as required. For unloaded cables a period from 5 per cent to 25 per cent of the duration of the signal element is employed whereas on loaded cables, earthing for a period as high as 40 per cent is used to advantage. The optimum earthing period for each cable is determined by observation of the signal shape at the receiving end under working conditions, the transmitting station being requested to increase or decrease the earthing period as necessary until the best results are obtained.

Signalling Capacitors. The use of sea earths on submarine cables to reduce the effects of interference caused by industrial earth currents has already been described. Another source of interference arises from the fact that the potential of the earth's surface at different parts of the world varies, so that a cable connected to earth at each end is acted upon by the potential difference between the two earth connexions. The current which flows is superimposed upon the telegraph signalling currents and is thus a source of interference.

The earth potential at any part of the world is continually varying and changes in a cyclic manner, due to the rotation of the earth, twice in every 24 hours. The rate of change is normally slow but at certain times violent magnetic storms occur, due to sun spots, which produce extremely large and rapid changes of the earth potential. At such times the resulting changes in p.d. between the two ends of a cable may produce such serious interference as to render the circuit unworkable. Fortunately, such changes are exceptional.

As the normal daily changes occur slowly they can be largely excluded from the cable by fitting a series capacitor at each end. The capacitors permit the transmission of telegraph signals, as these are produced by rapid changes of signal voltage and thus contain alternating current components: the steady direct earth current is however blocked and the magnitude of the alternating component of the earth current is normally too small to have any appreciable effect upon the operation of the circuit. The series capacitors were originally fitted to submarine cables purely for the purpose of blocking earth currents but it was soon discovered that they had a marked curbing effect upon the transmitted signals and improved the shape of the received signals; they reduced zero wander and enabled cables to be operated at higher speeds. These capacitors, known as "signalling capacitors" are therefore invariably used in the operation of submarine telegraph circuits and when fitted in series with the line at both the transmitting and receiving ends the method is known as double-block working.

In practice, a signalling capacitor of the smallest value to give adequate amplitude of the received signals is employed. Raising the value increases amplitude at the expense of deterioration in signal shape but the value employed is not critical. Typical values employed in the Cable & Wireless system for cable code signalling are 40 μF on cables having a CR of from 1–3 sec and 60 μF for cables having a CR of over 3 sec. When the CR is as high as 5 or 6 sec, some benefit may result from the use of 80 μF.

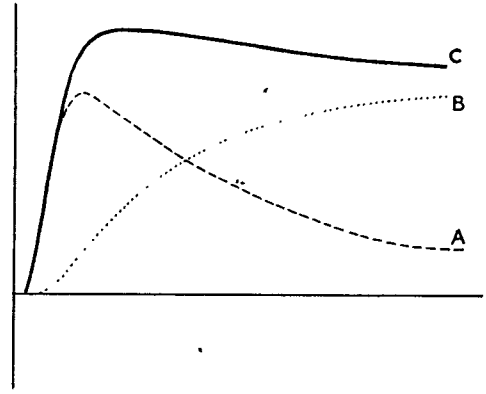


FIG. 17.7. EFFECT OF SHUNTED SIGNALLING CAPACITOR ON RECEIVED SIGNAL SHAPE

Shunted Signalling Capacitors. The use of signalling capacitors alone results in operating the circuit on an impulse basis and improved signal shape can be obtained by shunting the capacitor with resistance. The effect is illustrated in Fig. 17.7 in which A represents the received current due to the action of the capacitor, B represents the received current due to the effect of the resistor, and C, which is the sum of A and B, shows the total received current.

In general, a shunt resistance of 10,000 Ω per sec of the CR of the cable is employed, but this is often reduced to 6,000 Ω per sec in the presence of other signal shaping devices mentioned later. The actual values employed in any given case are determined by trial.

The use of shunted signalling capacitors readmits the direct earth current in the circuit and consequently necessitates the use of a device for

balancing out the biasing effect of the direct current. This is the function of the bias correction devices described later.

Signalling Codes

The great majority of submarine telegraph cables in the world to-day use either cable code or five-unit code for transmission of signals.

Morse Code. It is in use in a few cases but its retention seems only justified when the amount of traffic to be carried is well within the signalling capacity of the cable. Morse is very uneconomical in its utilization of line time as compared with cable code or five-unit code and either of the latter must therefore be used if it is essential to derive the maximum traffic capacity from a cable. When Morse is used, Wheatstone automatic equipment is usually employed using double-current signalling. Morse keyboard perforators are employed for converting the messages to be transmitted into perforated tape, which is then used to control a Wheatstone transmitter which automatically transmits into the cable the appropriate double-current signals corresponding to the characters of the message. The received signals, after amplification, are recorded on a Morse reperforator which reproduces a perforated Wheatstone tape from which a printed copy of the message is obtained using a Creed Morse Printer. The principles of operation of these instruments have already been described in Chapter 12; they are robust and reliable in operation, and as their speed of working can be varied readily within wide limits, they provide good traffic flexibility as the speed of operation can be increased, during busy periods, up to the maximum signalling speed permitted by the cable.

On cables carrying very light traffic loads, double-current hand-Morse may be used, but this is rare.

Cable Code. As already explained in Chapter 1 this is based upon the Morse code but utilizes a three condition signalling system which enables considerable economy to be effected in the duration of the signal elements required for the transmission of each character. Dot, dash and space are each signified by a distinct signalling condition but the time duration is the same for each; the need for a space between dot and dash elements in a character is eliminated, and spaces are only required to separate characters and words. In the result, the average duration of a character in cable code is equivalent to approximately 3·7 signal elements (i.e. dots), as compared with 8·6 signal elements (i.e. dots) for Morse code.

Cable & Wireless Ltd., and the British Commonwealth Administrations utilize cable code exclusively in their extensive submarine cable network which provides a very reliable and efficient service. Cable code, like Morse code, is suitable for hand keying and is so used on a few short lightly worked cables. On most cables, however, it is operated using automatic transmitting equipment and the received signals, after amplification and automatic regeneration, are used to operate an ingenious Direct Cable Code Printer which provides a printed record of the message on a tape without the need for reperforating, as is required in the case of the Wheatstone automatic system. In cable code operation the message to be transmitted is perforated on a normal Morse keyboard perforator and the tape is then fed into a special automatic transmitter. These transmitters will handle either Wheatstone Morse perforated tape or cable code perforated tape and convert the perforation into corresponding cable code signals for transmission into the cable. The appropriate earthing period at the end of each dot and dash element is automatically applied by the transmitter. The cable code transmitter and receiving direct printer are operated synchronously and the signals are automatically regenerated at intermediate stations which interconnect different cables.

Cable code is adaptable to time-division multiplex operation and is extensively used in this manner in the Cable & Wireless Ltd. and Commonwealth network. The multiplex arrangements may be varied to suit requirements, e.g. a cable may be used to provide two time-division channels operating at the same speed or alternatively, two channels operating at different speeds. The latter facility is very useful in cases where it is required to interconnect the two channels in one cable to two other cables having different signalling speeds, e.g. in the ratio of 2:1. In such a case, the time-division system in the first cable is arranged to allocate the line time between the two channels in the ratio 2:1 and so exploit the traffic-carrying capacities of the cables as fully as possible. This principle of working is called "uneven channel working" as distinct from "even channel working" in which the line time is divided equally between the channels in the time-division multiplex system.

The speed of working cable code may be varied readily over a wide range by making changes in the gear ratios of the phonic motor drives of the transmitting, receiving and regenerative repeater equipment. The cable code direct printer is capable of speeds of operation up to 90 w.p.m.

Five-unit Code is also used extensively on submarine cables by some cable companies, especially those having cables which are capable of higher signalling speeds, e.g. The Western Union Telegraph Co. The five-unit code is always used in

conjunction with synchronous terminal equipment as start-stop signalling over the cable would be very wasteful of line time on account of the need to transmit start and stop signals. Five-unit code only requires two basic signalling conditions, viz. marking and spacing, and thus permits the use of Gulstad methods of reception, whereas cable code does not. Furthermore, as double-current signalling is used with five-unit code, it is less affected by noise than is cable code as the latter employs three significant signalling conditions, including a no-current condition, i.e. earth.

In practical use it is found that five-unit signals may be transmitted up to a speed at which all isolated single code elements of marking or spacing are almost completely suppressed by the cable and such elements are then reinserted at the receiving end by synchronous Gulstad equipment. This method of working is therefore often called "five-unit suppressed singles operation."

It is perhaps worth noting that the statement sometimes made that interpolation of single element signals at the receiving end reduces the fundamental signalling speed by half, as only those signals having a duration equal to two or more code elements have to be transmitted satisfactorily, are unsound because some information at the baud speed of the original code is always necessary in the receiver to enable accurate detection to take place. The essential advantage of synchronous Gulstad working is that with synchronous interpolation greater distortion at the higher frequencies in the signal spectrum can be tolerated, partly because discrimination is possible at the receiver with smaller changes in signal amplitude and partly because of the regenerative properties of the interpolation method. Some cable companies employing synchronous five-unit systems nevertheless claim that use of the synchronous Gulstad method of reception has had the effect in practice of increasing the traffic-carrying capacity of the cables concerned by approximately 40 per cent more than is possible when using cable code signalling.

Future Trends. Whilst a comparison of the relative efficiencies of cable code and five-unit code is not easy to make from the point of view of the overall operation of a system, there is nevertheless a tendency for administrations to favour the greater use of five-unit code as it offers attractions from the following points of view—

(*a*) Securing greater integration of methods between submarine cable and land-line circuits. This arises from the fact that land-line circuits are nowadays operated almost exclusively on a five-unit (usually start-stop) basis and thus the transference of messages from one circuit to another is facilitated if a uniform code is used throughout. Training of operators and maintenance staff is also simplified as a result.

(*b*) The design of instruments, e.g. printers, using five-unit code is simpler than those used in cable code, as five-unit code involves a constant number of elements for each character whereas in cable code the number of elements is variable.

(*c*) Perforated tapes in five-unit systems are only about a third of the length of corresponding cable code tapes, although wider. They can therefore be handled more readily and at the same time economize in the amount of paper used.

As explained in Chapter 1 cable code has some advantage over five-unit code from the point of view of detectability of errors arising from certain forms of distortion. This advantage is due to the fact that a five-unit code has no redundancy and requires the use of shift signals, whereas in cable code certain mutilations produce redundant code combinations which can be recognized; furthermore shift signals are not necessary.

It has to be remembered that the capital costs invested in the terminal and repeater station equipments at present employed in submarine cable networks is very large and many highly skilled personnel trained in the operation and maintenance of cable code systems exist; thus it is not to be expected that a general conversion to five-unit working will take place rapidly. The problem is made more complex by the need, in many cases, to transfer traffic from submarine cable circuits to radio circuits and vice versa. Many radio circuits still employ Morse or double-current cable code signalling and although increasing use is being made of radio systems using synchronous error detecting and correcting codes, e.g. the Van Duuren system (see Chapters 1 and 16), to ensure that five-unit code signals are transmitted with a high degree of accuracy it will be some years before all main routes are converted. This state of affairs tends to support the continued use of Morse and cable code signalling methods and gives rise to the need for code converters during the interim period in which Morse code, five-unit code and cable code are all being employed. Code converters have been developed which enable conversion to be effected automatically from five-unit code to either Morse or cable code, and vice versa, and these are finding increasing use. One example of converters of this type which have been developed by the B.P.O. is briefly described in Chapter 12.

Methods of Working

The economical exploitation of submarine telegraph cables is an extremely important matter in

view of the high capital and maintenance costs of the plant involved. Many cables in service are very old and being unloaded, are only capable of slow signalling speed, in some cases as low as 10 bauds. The traffic requirements on many routes have changed considerably since the early cables were laid and in many cases the increase in traffic has necessitated the laying of more modern high speed loaded cables to supplement existing capacity. The resulting complex network of cables of various terminal equipment and maintenance and enables a higher speed of transmission to be used in one or other direction than would be possible in either direction under duplex working. (*Note.* The total traffic-carrying capacity for duplex working is always less than twice the simplex speed due to the effects of inaccuracies in the duplex balances.)

Nevertheless, in a great many cases the volume and incidence of traffic in the two directions on a cable is such that simultaneous transmission is

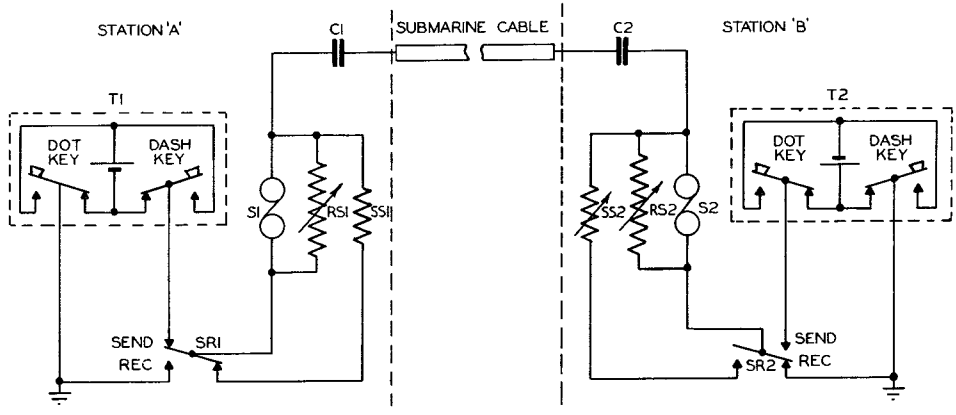


FIG. 17.8. MANUAL SIMPLEX WORKING USING A CABLE CODE KEY

speeds involves consideration of many factors in the planning of new cables to ensure efficient overall integration and use. The importance of the signalling code has already been discussed and consideration will now be given to the choice of the method of working. One important factor in submarine cable telegraphy which often influences the traffic requirements is the large difference in longitude, and hence difference in local time, between the two ends of a cable, e.g. between London and New York there is a time difference of roughly five hours. These differences normally result in a difference in the time of business activity between the terminal countries served by the cable and cause the peak traffic from East to West to occur at a time which is appreciably different from that of traffic from West to East. The greater the difference in longitude the more marked usually is its effect upon the peak periods of traffic flow in the two directions.

As a result it is often possible to operate a cable on a switched simplex basis according to a pre-arranged schedule, the cable being connected for transmission in one direction during certain hours and switched at other times for transmission in the reverse direction. This avoids the need for duplex operation, with consequent simplification of the essential and the cable therefore has to be worked duplex. Using duplex methods it is possible to operate simultaneously in each direction either a single channel or a time-division multiplex system, depending upon the signalling speed permitted by the cable and the traffic requirements to be met.

Manual Transmission. In the early days of submarine cable telegraphy manual signalling was employed and such methods are still sometimes used on short cables carrying light traffic. Cable code signalling is usually employed and is transmitted by means of a manually operated cable code key or two-key commutator as it is often termed. It consists essentially of two single current keys mounted side by side on a common insulated base. Fig. 17.8 shows the schematic connexions of a simplex circuit using such a key and the circuit operation is as follows.

$C1$ and $C2$ are the signalling capacitors, $T1$ and $T2$ the transmitting keys, $S1$ and $S2$ the siphon recorders, and $SR1$ and $SR2$ the "send and receive" switches for connecting the sending or receiving apparatus to the cable at will. $SS1$ and $SS2$ are adjustable low resistance sending shunts and $RS1$ and $RS2$ are high resistance inductive receiving shunts.

The receiving shunts are adjusted to secure the

optimum value of received current for operation of the siphon recorders whilst the sending shunts, which shunt the recorder coils when the send-receive switch is at send, are adjusted so that the current permitted to flow through the recorder at the sending station is equal in magnitude to that which flows when receiving. It should be noted that the battery connexions are reversed at one end of the circuit, in order that each recorder may also be used to provide a local record when sending. It will be observed that only a single battery is employed at each end of the circuit, transmission of dots and dashes being effected by reversing the battery thus securing the advantage that dot and dash signals employ precisely the same voltage.

When the circuit is idle, both send-receive switches are placed in the receive position so as to be in readiness for receiving a call. Earth potential is therefore connected to the signalling capacitors via the send-receive switches. When a station wishes to transmit, it first operates its send-receive switch to send, earth potential is thereby extended via the dot and dash keys and the send-receive switch to the signalling capacitor. During signalling at station *A*, the depression of the dot key earths the positive pole of the signalling battery and causes negative polarity to be extended to the cable signalling capacitor via the back stop of the dash key and the send-receive switch. When the dot key is restored and the dash key depressed, the negative pole of the battery is earthed via the back stop of the dot key, whilst the positive pole is connected via the dash key and send-receive switch to the cable signalling capacitor.

During space signals, the dot and dash keys are both at rest on their back stops and earth potential is thereby extended to the signalling capacitor via the send-receive switch. Thus cable code signals, i.e. three condition signals, are transmitted to line via the siphon recorder and its shunts, *SS*1 and *RS*1, so resulting in impulse working to the distant receiver, where the signals flow through the siphon recorder coils and high resistance inductive shunt *RS*2, to earth via the send-receive switch *SR*2.

Automatic Transmission Methods. The use of automatic transmission enables the speed of signalling over a cable to be made independent of the sending speed of an operator, as not only can the messages be prepared in the form of perforated tapes in advance of transmission but, if necessary, several operators may be used in the preparation of tapes for one circuit.

Automatic transmitters not only enable the duration of the signal elements to be controlled precisely and transmitted without pause but they also facilitate the use of signal curbing techniques and so improve signal transmission and reception.

The type of automatic transmitter employed depends primarily upon the signalling code to be used. A typical automatic transmitter which is used extensively for transmission of cable code signals is the Judd and Fraser transmitter. This instrument is designed so that either Wheatstone Morse or cable code perforated tape may be passed through it; the perforations in the tape determining the cable code signals transmitted into the cable.

Synchronous five-unit systems are commonly employed on submarine cables and for this purpose a five-unit perforated tape is used in conjunction with a five-unit automatic transmitter. The Murray automatic transmitter described in Chapter 2 is typical of an instrument employed for this purpose and, although there is a number of modern variants, their principle of operation is generally similar. The transmitter usually operates in association with a channel in a time-division multiplex system, the distributor of which connects each channel transmitter, in turn, to the appropriate five segments of the distributor, so controlling the sequential transmission of the five code elements of each character. The tape is then stepped one centre hole, under the control of the distributor, in readiness for transmission of the code signals of the next character.

On long cables the received signals are greatly attenuated and distorted and therefore not easy to recognize with accuracy, a problem which is accentuated with hand-keyed signals owing to their irregular nature. Automatic transmission enables signals to be automatically regenerated by means of regenerative repeaters, so extending the distance over which signals may be relayed and avoiding the need for manual retransmission at intermediate stations.

It is desirable that the signals received from a cable should operate either a direct printing instrument, a retransmitter, or a reperforator, and this is only possible by the use of automatic transmitting and receiving machines. Thus from many points of view automatic transmission methods are to be preferred to manual methods and they are therefore almost universally employed in modern submarine telegraph cable practice.

Automatic Wheatstone Morse was extensively used at one time but systems using cable code or five-unit code, with synchronous transmitting and receiving apparatus, are now almost universally employed. It is also found preferable to operate channels at a speed which is related to the working speed of a sending and receiving operator, i.e. about 60 w.p.m., and in those cases where a cable

is capable of a higher signalling speed multi-channel methods are used to derive a number of slower speed channels from the cable. Multi-channel methods facilitate the interconnexion of channels in cables having different speeds and enable through-circuits to be set up more efficiently

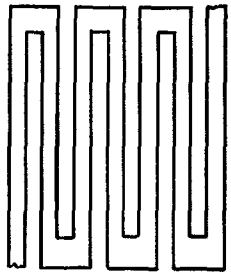


FIG. 17.9 ELEMENT OF A ZIG-ZAG TIN FOIL CAPACITOR

in a chain of cables. The channels from one cable can be branched off, if required, at intermediate points and interconnected to channels in a series of different cables to form through-circuits to different destination points. This is a very useful facility which saves time and labour as it would otherwise be necessary to retransmit the traffic at intermediate offices.

The principles employed in typical modern systems of synchronous cable code and five-unit working and the multi-channelling methods employed will be described later.

Duplex Working. For economic reasons the duplexing of submarine cable circuits is usually desired and bridge duplex is always used. The use of duplex methods enables the traffic capacity of the cable to be almost doubled, providing the duplex balance is accurately made and maintained.

The principles of bridge duplex have already been described in Chapter 7 and the reader is recommended to re-examine the principles therein described. For a long submarine cable, the bridge duplex circuit must be very refined for optimum results and this necessitates the use of high quality electrical apparatus and a very high degree of skill in initially setting up the circuit and in subsequent maintenance.

The duplex balance network, termed the "artificial line," must simulate the distributed capacitance and resistance very closely. Dr. Muirhead solved this problem by using zig-zag sheets of tin-foil, having a resistance equal to that of the cable, interleaved with paraffined paper and full sheets of tin-foil, and so proportioned as to have capacitance corresponding to that of the cable. Figs. 17.9 and 17.10 illustrate the arrangement in principle. In the first sections of the artificial line the values are much more critical than in the later sections, and the first few balance boxes are divided, in a typical case, into 10 sections each having a capacitance of 1 μF and a resistance equal to that of a length of cable having a capacitance of 1 μF. In later sections the boxes have seven 3 μF subdivisions.

The high variation of resistance of tin foil with temperature causes difficulty and arrangements have to be made to keep a fairly uniform temperature as the resistance of a cable immersed in deep water is almost invariable. The boxes are placed in asbestos-lined cupboards and careful attention is given to constancy of room temperature and low humidity. The capacitance of a paraffin-waxed paper capacitor decreases by about 0·06 per cent per °C rise of temperature.

A composite dielectric formed by treating the paper with shellac or gum damar and wax in the correct proportion produces a capacitor with a temperature coefficient of only 0·1 per cent per °C. The ideal dielectric is mica, but unfortunately its cost is prohibitive for general use. In recent years synthetic dielectrics such as styroflex have been used. Despite the advances made in the construction of artificial lines, temperature and humidity

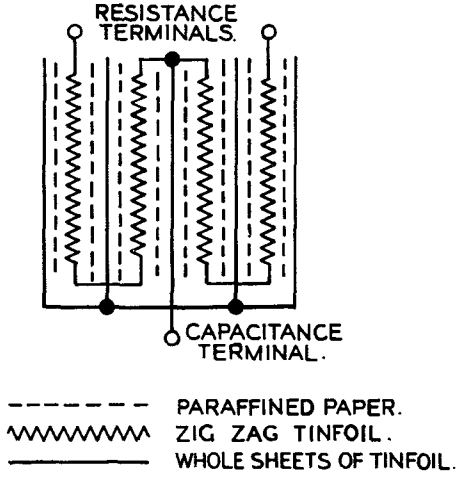


FIG. 17.10. MUIRHEAD ARTIFICIAL LINE: PRINCIPLE OF CONSTRUCTION

control of the room containing the duplex-balance is still desirable.

Until about 1942 a common method of constructing the artificial line was that known as the "clothes line" type (Fig. 17.11) and consists in using Eureka strip to the centre of which is attached a tin foil plate. A slit is cut in the top of the paper and the strip bent back upon itself. Thus a lumped

capacitance is added to the resistance strip in the centre of every 18 in. of its length. This subdivision offers, for all practical purposes, the equivalent of the uniform distribution of the Muirhead arrangement. The use of Eureka con-

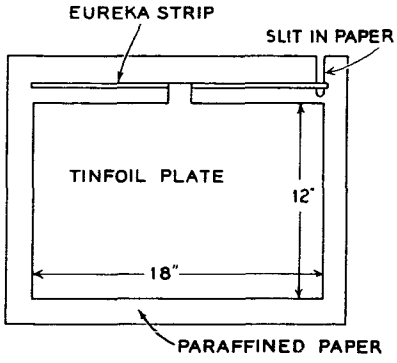


FIG. 17.11. "CLOTHES LINE" TYPE OF ARTIFICIAL LINE

siderably reduces the variation of resistance due to temperature changes.

Artificial lines have been constructed by using constantan or manganin wire wound either on bobbins, or on sheets of mica, with connected capacitance values built up in the manner of ordinary capacitors and in modern times this method using rolled capacitors has superseded the earlier methods. A fairly fine subdivision of capacitance is obtainable, but at the expense of a very large number of wired connexions. In the late sections of an artificial line, where a lower degree of subdivision is possible, this plan possesses some advantages.

Double Block Duplex. When submarine telegraph cables are duplexed the bridge duplex system is employed with capacitors in the ratio arms as illustrated in principle in Fig. 17.12. An apex resistor of a few ohms, subdivided into steps of 0·1 Ω, is sometimes employed in the manner indicated as a vernier adjustment for making slight ratio changes of balance.

The use of capacitors in the ratio arms and in series with the receiving relay produces a considerable improvement in the wave-form of the received signals but causes a marked reduction in signal amplitude. Their inclusion, however, has the great advantage that they block the passage of parasitic earth currents, which usually vary in a slow manner, through the receiving relay. Due to this blocking action, the method is called "double block duplex working."

The reduction in the amplitude of the received currents, which occur as a result of the various methods adopted to improve the signal shape, necessitate very accurate adjustment of the balance and the employment of sea earths in the manner already described, in order to reduce noise and crosstalk and thus secure a satisfactory signal/noise ratio and the highest practicable signalling speed.

The difficulty in obtaining the balance of a new cable has increased progressively as the resistance and capacitance per n.m. of cable has been reduced to obtain higher working speeds. Later researches have however tended to improve the duplex balance position. Methods used involve closer representation of the cable impedance, especially that of the sea return path, which varies with frequency. Tuned filters are used to minimize peak balance errors and the use of oscilloscopes having a slow time base and persistent image screens has helped materially in balancing by enabling the wave-form of the out-of-balance signals across the receiver to be continuously observed in detail during balancing.

Sending End Inductance. An inductance is usually included at the apex of duplex circuits. Its effect is to increase the magnitude of the received currents corresponding to those signals which suffer maximum attenuation during transmission, i.e. signal reversals. It also modifies the wave-form of the current entering the cable from a peaky shaped wave, due to the capacitor, into a rounded impulse. Hence the potentials applied across the receiving apparatus at the sending end change less abruptly, so that the effects of slight difference between the cable and the artificial line are minimized. At the commencement of a signal, the current rises very rapidly in the cable and in the artificial line and interference with the receiving apparatus will therefore occur unless very close agreement exists between the rates of rise of current in the cable and the balance: this is why the accuracy of the first sections of the artificial line balance is very critical. Where this equality

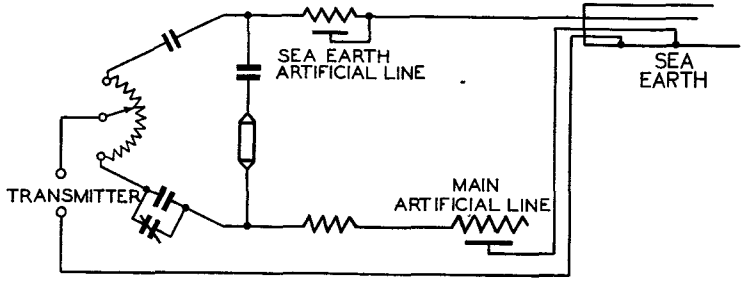


FIG. 17.12. PRINCIPLE OF DOUBLE BLOCK DUPLEX

of current rise does not exist, interference is caused in the local receiving circuit by the transmitted current.

The precise value of the inductance is obtained by trial but a first approximation can be determined by calculation. In general, its value is such that its reactance more or less cancels that of the signalling capacitor. The inductance is usually shunted to avoid sparking at the transmitter contacts and the values used in a particular case are shown in Fig. 17.13.

at the head of the cable. This takes the same form as the artificial line. In the case of the cable balance which is described in detail below, the sea earth is so short that no compensation is provided.

Details of a Typical Artificial Line. The values and arrangement of the balanced duplex circuit of a typical Cable & Wireless Co.'s unloaded cable having the following characteristics are shown in Fig. 17.13. The artificial line is shown in Fig. 17.14.

The artificial line comprises 30 boxes the first three of which have ten divisions, each of 1 μF.

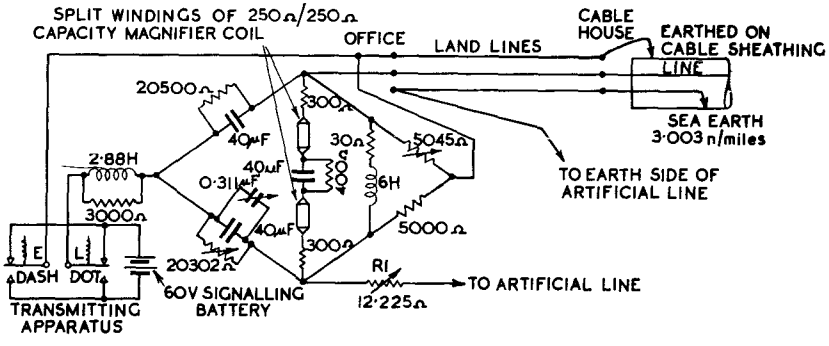


FIG. 17.13. DETAILS OF A TYPICAL CABLE AND WIRELESS LTD. DUPLEX CABLE TERMINATION
(By courtesy of Cable and Wireless Ltd.)

Extra Apex Arms. These arms, as used on duplex circuits of Cable & Wireless Ltd., are usually 5,000 Ω each (see Fig. 17.13, which illustrates a typical case). Their purpose is to reduce the effect of any small day-to-day change in the terminating resistance of the artificial line on the balance at the distant station. They also have the effect of making the terminal capacitor of the artificial line give better balance conditions at every instant during signalling.

The apex arms reduce the amplitude of the received signal, firstly as a shunt on the sending circuit, and secondly as a shunt on the receiving circuit. These losses can, however, be largely compensated by raising the e.m.f. of the signalling battery so that the p.d. applied to the head of the cable is the maximum permissible stress, i.e. the battery e.m.f. used before the addition of apexes.

The apex arms, as leaks to earth, produce overcurbing and this necessitates the use of lower resistance shunts on the signalling capacitors and increasing the resistance of the circuit of the magnetic shunt.

When the CR is 4 sec, 7,500 Ω apexes with block shunts of 20,000 to 30,000 Ω are required.

Sea Earth Compensation. When the earth is carried far out to sea it is necessary to insert equivalent distributed capacitance and resistance

The remainder have only seven 3 μF divisions between the terminals. It will be observed that a resistance of 8 Ω is inserted between the first and second division of the first box. Similarly, resistances of 19·5 Ω and 20 Ω are inserted in the third and fourteenth boxes. Shunting resistances in the positions shown are included around the third and fourth, and around the fourth and fifth boxes.

Cable Characteristics

Length of cable	1,843·754 n.m.
Conductor resistance of cable	3,406 Ω
Conductor resistance of artificial line	2,876 Ω
Capacitance of cable	707·5 μF
Capacitance of artificial line	603·3 μF
Core ratio of cable, i.e. resistance/capacitance	4·8
Core ratio of artificial line, i.e. resistance/capacitance	4·7
Capacitance added to end of artificial line	147 μF
CR of cable	2·4 sec
Length of sea earth core	3·003 n.m.
Resistance of sea earth core	10·670 Ω
Capacitance of sea earth core	1·099 μF
Length of land lines (each wire)	0·091 n.m.
Resistance of land lines (each wire)	0·9 Ω

The earthed plate of the capacitors of the first two boxes and of boxes five to thirty are connected to the sea earth. The first six divisions of box three are connected to the sea earth via a resistance of

33·75 Ω. The remainder of this box, box four, and the first division of box five, are earthed through 14·25 Ω. Neither the precise value nor the position along the artificial line of any of these resistances, determined by experiments, can be changed without adversely affecting the balance. On some cables, the arrangements are much more complex but this example suffices to illustrate the complexity of

The signal shaping circuit is arranged as shown in Fig. 17.13. The reason for splitting the magnifier coil into two sections and placing the receiving capacitor between them is that it gives a symmetrical circuit and avoids ill effects due to capacitances to earth being unequal.

Resistance at Head of Artificial Line. This resistance *R*1 (Fig. 17.13 refers) is exceedingly

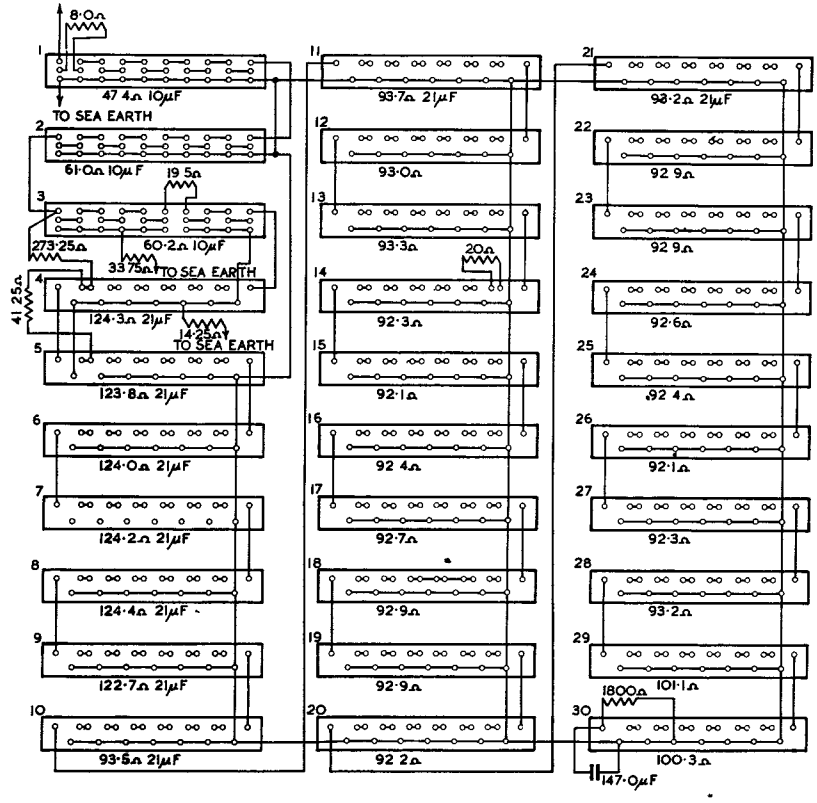


FIG. 17.14. TYPICAL MAKE-UP OF AN ARTIFICIAL LINE FOR AN UNLOADED TELEGRAPH CABLE

balancing a new cable. Fortunately, when once done, major alterations are only required after cable repairs involving the substitution of a long length of new cable.

At the end of the artificial line a mesh is required to represent the impedance of the distant terminal apparatus. In the case of this cable a capacitor of 147 μF with 1,800 Ω as a shunt is employed.

The very small balance adjustments required from day to day due to temperature changes are provided by making the artificial line signalling capacitor and its shunt adjustable, the former by the addition of a finely divided small capacitor. In this way, any change in the resistance or in the capacitance of the cable is balanced out separately.

critical and is adjustable by steps of not more than 0·025 Ω from 0–40 Ω. Its principal function is to balance, in an approximate manner, the natural inductance of the cable, which is of the order of 3 mH per n.m., and to follow head-of-cable changes due to temperature.

Apparatus Insulation. The problem of apparatus insulation is extremely important, particularly in humid climates, as it is essential to maintain a fairly high degree of insulation resistance even under the most adverse humidity conditions.

Taper Loaded Cable Balance. It is impractical to duplex a cable which is uniformly loaded from end to end owing to the critical balance conditions to be satisfied. By tapering the loading at each end

from zero to fully loaded conditions for a considerable distance out to sea duplex working becomes possible. The artificial line is as shown schematically in Fig. 17.15; it is complex and costly. The capacitances, resistances and inductances are contained in separate boxes. Valves are used for reception and day-to-day balance changes are made with the aid of an oscilloscope. In a typical case, a cable having a length of 1,200 n.m. is unloaded at each end for the first 150 n.m. and for the next 150 n.m. the loading is tapered from 65 mH to the full loading of 175 mH, thus giving 600 n.m. of fully loaded cable in the centre.

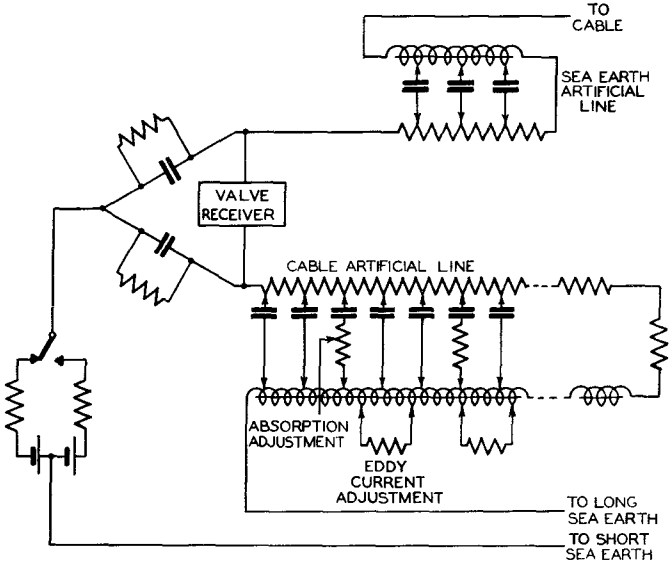


FIG. 17.15. DUPLEX NETWORK FOR A TAPER LOADED CABLE

Methods of Reception

In the early days of submarine cable telegraphy, transmission of signals was effected by means of a manually operated key and a mirror galvanometer, directly operated by the received cable signals, was used as the receiving instrument. The receiving operator read the signals by noting the deflections of a spot of light reflected from a small mirror attached to the moving coil. This method involved the constant attention of a receiving operator and the work, over long periods, was very tiring. It was obvious that a permanent record of the received signals would be advantageous and this became possible with the invention of the siphon recorder by Lord Kelvin. The principle of operation of a siphon recorder is described in Chapter 2 and this type of instrument was for many years the principal one employed in submarine cable telegraphy. It is a very sensitive instrument and can be made to operate by currents as low as 50 microamps. However, on long cables, owing to the attenuation of the signals caused by the cable characteristics and by the signal shaping devices employed, the received signals are too weak to operate a recorder directly and need to be amplified.

The use of siphon recorders has long since been abandoned, except in the case of a few local cables and for monitoring purposes; modern practice is to use direct printing and reperforating instruments which are operated synchronously and use either cable code or five-unit code. The operating currents required for instruments of these types are considerably greater than those required for siphon recorders and the received signals from the cable therefore need even greater amplification before they can be used to operate a recording instrument. In many cases the signals received from one cable have to be automatically repeated for retransmission over another submarine cable, or land line cable, to a terminal telegraph office. The weak signals received from the cable must therefore be amplified and the relay employed for this purpose is called a "cable relay" or "cable magnifier." It is important to realize that the function of a cable relay, or magnifier, is purely to reproduce the signals received from the cable with greater amplitude in a secondary or local circuit and although the magnifier tends to restore the original abrupt nature of the signal changes it does not correct the time distortion which is present in the received signals. The signals from the magnifier are used to operate a secondary relay, the signals from which are then used for retransmission, or for operation of a receiving instrument, as required.

In many cases, e.g. in synchronous systems, the signals after amplification are regenerated by means of a regenerative repeater. The distortion of the received signals is thereby almost completely eliminated and thus retransmission of the signals over another long cable is facilitated; alternatively, if the signals are used to operate a direct printer or reperforator, regeneration of the signals greatly improves the stability of working and eliminates the need for a high degree of margin in the receiving instruments.

Cable Relays and Magnifiers. Many ingenious forms of cable relays and magnifiers have been developed in the past and some of the most successful of these will now be described to indicate the principal methods employed.

The Brown Drum Relay. This was one of the earliest forms of submarine cable relay used and has been employed on some cables until quite recent years. Its principle of operation is indicated in Fig. 17.16 which illustrates its use for repeating signals from one cable (No. 1) into another cable (No. 2) and at the same time operating a local recorder at the repeater station. The signals received from cable No. 1 pass through the lightly suspended coil *MC* of a very sensitive galvanometer and the resulting movements of this coil are conveyed by fine control threads to a light cradle *A* which can turn about *O*. *A* carries a light metallic tongue *T*, the end of which rests, with extremely light pressure, on the periphery of a rotating drum *D*. The drum is rotated slowly so as to reduce the frictional resistance between the tongue *T* and the drum surface. The drum consists of three adjacent silver rings and the central ring, on which *T* normally rests, is insulated from the outer rings *W* and *Z* by thin mica discs. Polarized relays *R*1 and *R*2 are connected by brushes to the outer rings *W* and *Z* respectively. When the current received from the cable causes the moving coil *MC* to rotate clockwise, the extremity of tongue *T* slides from the central ring across to ring *W* which completes a circuit for operation of relay *R*1. Conversely, when *MC* is caused by the received current to move anti-clockwise, the extremity of *T* will slide to *Z* and thus complete a circuit for the operation of *R*2. Relays *R*1 and *R*2 have a spacing bias and when operated to spacing their tongues

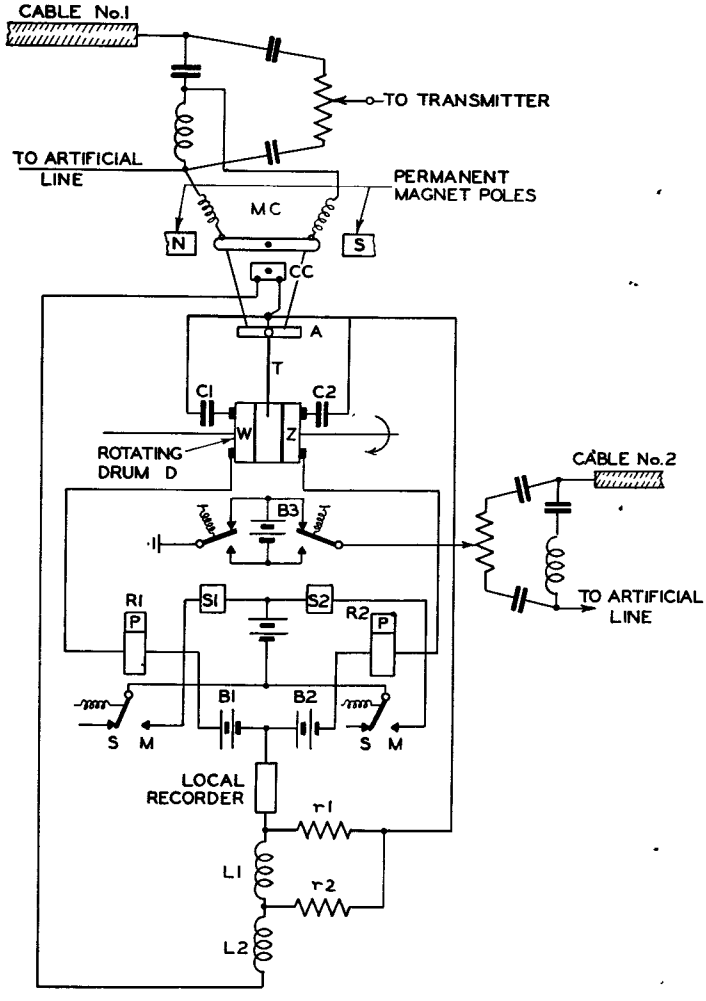


FIG. 17.16. PRINCIPLE OF BROWN DRUM RELAY

disconnect the circuits of relays $S1$ and $S2$ respectively. In this condition, the back contacts of $S1$ and $S2$ connect cable No. 2 to earth. When tongue T is moved to make contact with W, a local circuit is completed from battery $B1$, through $R1$, ring W, tongue T, and thence through $r1$ in parallel with $r2$ and $L1$, to the local recorder. The tongue of $R1$ therefore operates to its marking contact (M) which then actuates $S1$, the tongue of which earths the negative pole of the cable signalling

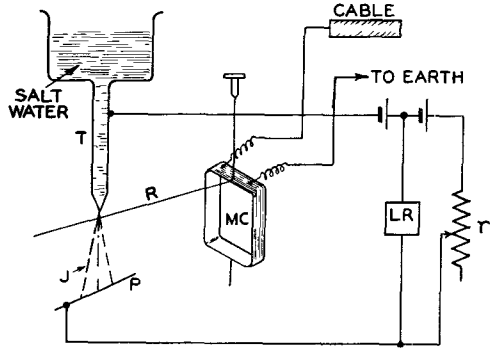


FIG. 17.17. PRINCIPLE OF ORLING JET RELAY

battery $B3$, thus causing positive polarity to be extended to cable No. 2 via the back contact of $S2$. Similarly, when T moves across to make contact with ring Z, the resulting operation of $R2$ and $S2$ connects the negative pole of the line signalling battery to cable No. 2 and the positive pole is earthed via the back contacts of $S1$. $C1$ and $C2$ are spark quench capacitors to reduce sparking when T breaks contact with the outer drum rings.

On long cables, the received current for a succession of dots or dashes does not fall to zero, thus MC and hence T remain continuously deflected for the duration of the dots or dashes. The signals retransmitted by the relay are therefore of "block" formation as the earthing period following each signal element is omitted. Earth is only retransmitted for spaces. Arrangements can be made for re-insertion of the earthing periods, following each signal element, by the use of an "Interpolator."

When unshunted block capacitors are employed in the bridge arms of a duplex circuit, the amplitude of a succession of signal elements of the same sign gradually falls and if uncorrected, the coil MC would allow T to move back to the central ring of D and so terminate the retransmitted signal prematurely.

This trouble is counteracted to some extent by shunting the blocking capacitors with high resistance, but the difficulty can be eliminated by means of the correcting coil CC which is wound on the same frame as MC. When MC is deflected and causes T to make contact with one or other outer ring of D, a local circuit is at the same time completed for coil CC causing the latter to be energized in a direction tending to maintain MC in its operated position. The time constant of the circuit for CC is adjusted by $L1$, $L2$, $r1$ and $r2$, so that the combined effect of MC and CC maintains T deflected for the duration of a succession of dots or dashes.

The Orling Jet Relay. The principle of this relay is illustrated in Fig. 17.17. The received current from the cable actuates a moving coil MC which carries a fine quartz rod R which projects into the path of a jet of salt water J which falls from the nozzle of a tube T. The water jet falls on to an inclined plane P and the movement of the moving coil causes the rod R to deflect the salt water jet so that it strikes the inclined plane at a higher or lower point depending upon the direction and extent of the deflection of the moving coil. This action either reduces or increases the resistance of the jet and results in a comparatively large current flowing in one direction or the other through the circuit of the local recorder, or secondary relay, LR. The resistance r is adjusted so that when rod R is not deflected, no current flows in LR. The Orling jet relay could be made to have a sensitivity of approximately 0·01 micro-amps and was used very successfully at one time.

The Muirhead Gold Wire Relay. This relay is shown schematically in Fig. 17.18. The received signals from the cable operate a moving coil MC, and the resulting deflections control the movement of a lightly suspended cradle C via fine threads $T1$ and $T2$. C carries a light arm A, attached to which is a gold wire W which normally lies between two platinum contact butts M and S. According to the direction of deflection of MC and hence that of A, the gold wire W will be caused to make contact with M or S, thus operating the secondary relay SR to marking or spacing respectively. Operation of SR controls the operation of relays $S1$ and $S2$ which in turn cause the signals received from cable No. 1 to be automatically retransmitted into cable No. 2 and/or a local recorder as required. To ensure good electrical contact between the gold wire W and contacts M and S, the gold wire is attached to a vibrator V. A correcting coil CC is provided for the same purpose as that already described in the case of the Brown Drum relay.

The three principal methods of signal magnification in use at present are—

1. The Heurtley hot wire magnifier.
2. The Capacitance magnifier, and
3. Valve magnifiers.

The Heurtley Magnifier. In its original form, a heated wire was deflected in its relation to a blast of cold air by the action of a moving coil receiver. In this way the resistance of the heated wire was varied by change of temperature. The modern instrument (Fig. 17.19) dispenses with the air blast

The relation of the heated wires is shown in Fig. 17.20. When the wire *ab* is moved outwards, the distance between *a* and *d* is reduced and that between *b* and *c* is increased. The temperature of *a* and *d* therefore rises, whilst the temperatures of *b* and *c* fall. Hence, an outward movement raises

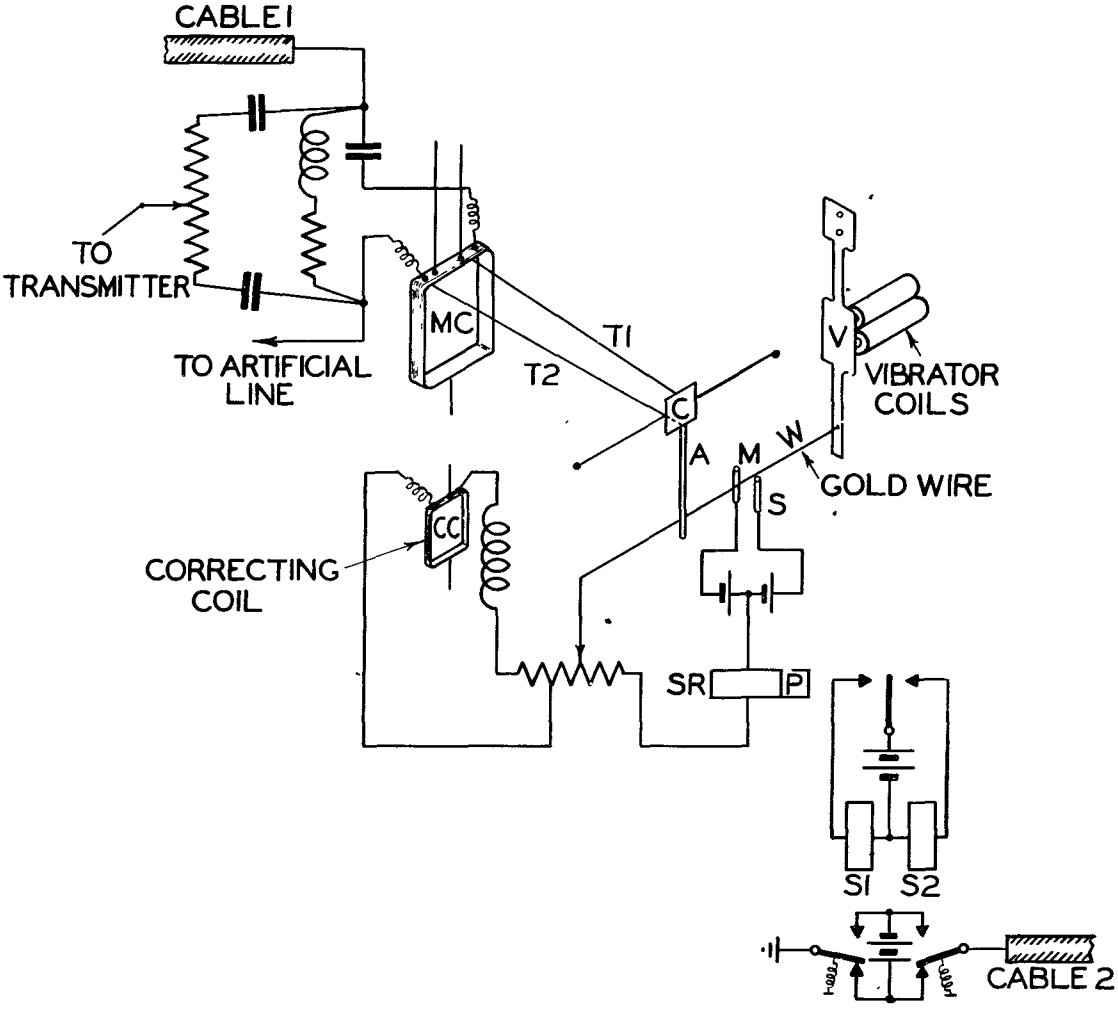


FIG. 17.18. PRINCIPLE OF MUIRHEAD GOLD WIRE RELAY

by moving the heated wire in relation to fixed heated wires. Platinum wires (0·25 mm diameter) are used because they are not subject to oxidization, have a fairly high temperature variation of resistance and can be made in extremely thin diameters so giving appreciable resistance in a short length, and having small heat capacity give quick temperature changes when moved into or away from the heat field of the fixed wires.

the resistance of *a* and *d* and decreases that of *b* and *c*. Conversely, an inward movement raises the temperature of *b* and *c* and lowers that of *a* and *d*. The four wires are connected to form a Wheatstone bridge (Fig. 17.21) with the result that the current which flows in the receiver, or secondary relay, varies in direction as indicated in Fig. 17.21 according to whether the wires are moved outwards or inwards. The stationary wires *c* and *d* are

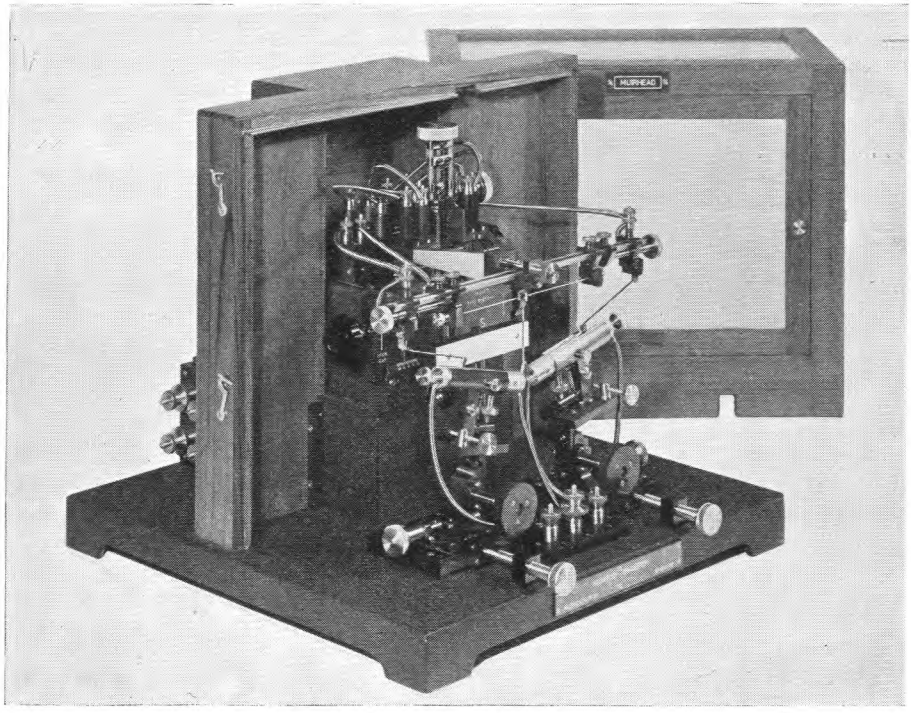


FIG. 17.19. HEURTLEY MAGNIFIER
(By courtesy of Messrs. Muirhead & Co., Ltd.)

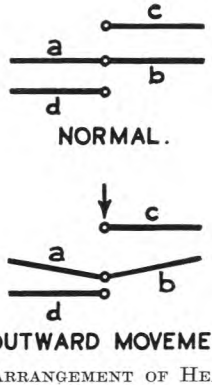


FIG. 17.20. ARRANGEMENT OF HEATED WIRES IN HEURTLEY MAGNIFIER

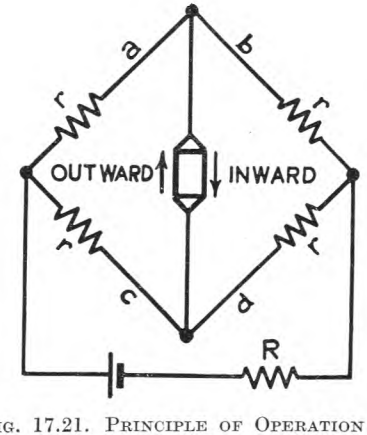


FIG. 17.21. PRINCIPLE OF OPERATION OF HEURTLEY MAGNIFIER

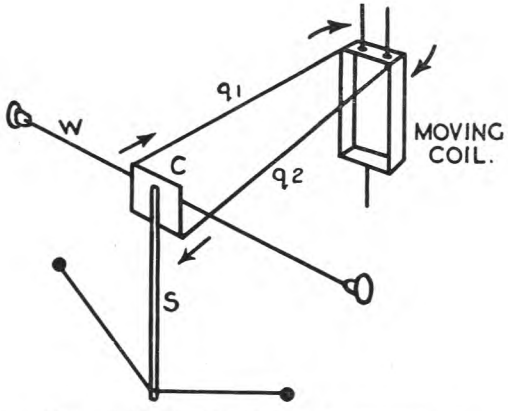


FIG. 17.22. PRINCIPLE OF OPERATION OF HEURTLEY MAGNIFIER

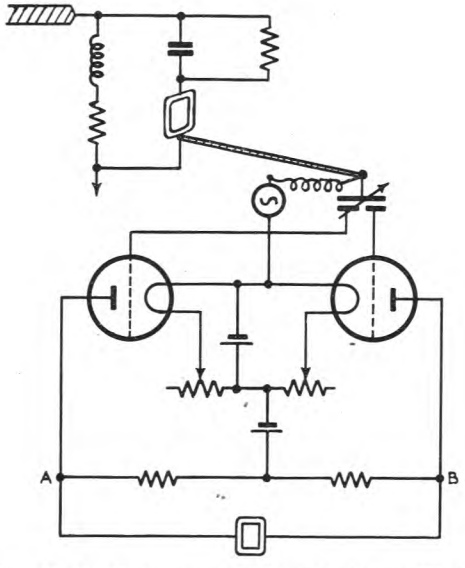


FIG. 17.23. PRINCIPLE OF OPERATION OF WOOD CAPACITANCE MAGNIFIER

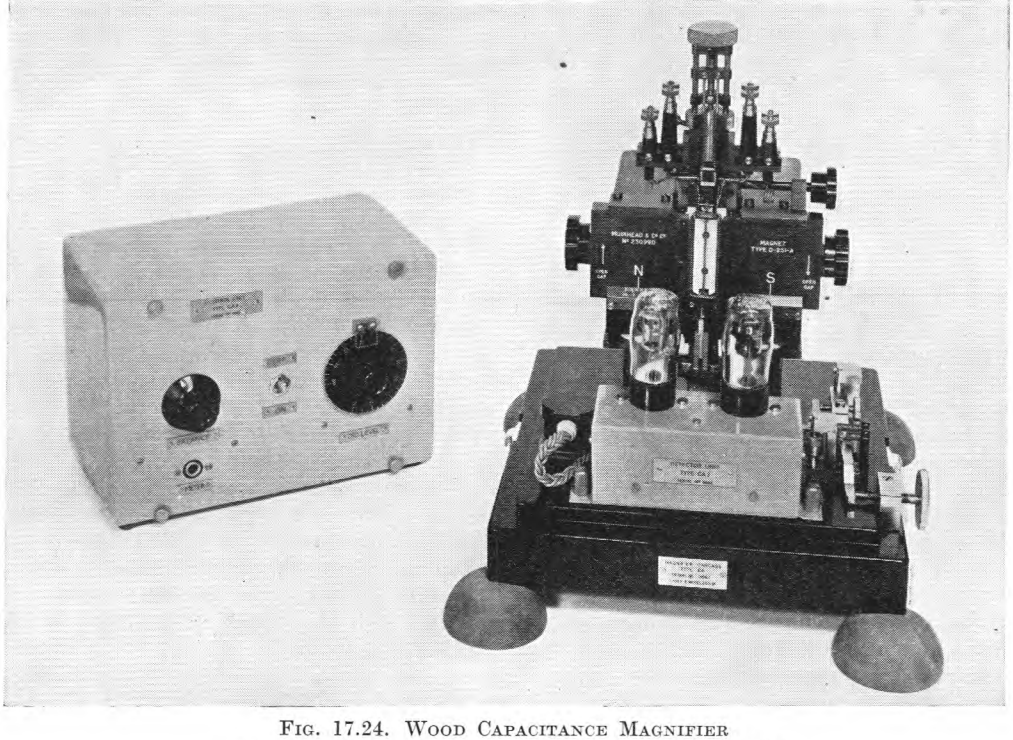


FIG. 17.24. WOOD CAPACITANCE MAGNIFIER

By courtesy of Cable & Wireless, Ltd., and H.M. Postmaster-General)

mounted on adjustable stands so that their precise relation to *ab* may be varied. Small adjustable resistances are connected in series with each wire so that an accurate balance may be obtained in the normal position of *ab*. The heating current is also adjustable by the resistance *R*.

An aluminium cradle *C* (Fig. 17.22) carried on a spring-tensioned cross-wire *W*, is tethered to the moving coil by quartz fibre reins *q*1 and *q*2, so that a deflection of the coil in the direction of the arrows

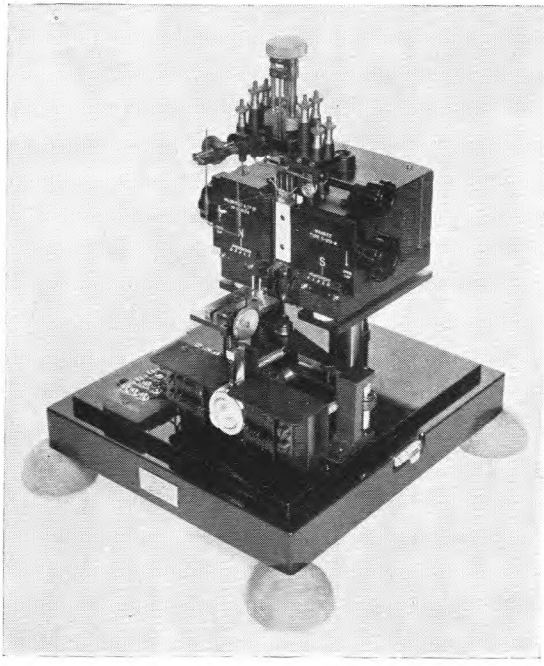


FIG. 17.25. FORK RELAY
(By courtesy of Cable & Wireless, Ltd., and H.M. Postmaster-General)

causes a corresponding movement of the cradle. A straight glass siphon tube is fixed on the face of the cradle and by its movement deflects the moving wires and also conveys current to their junction by means of a conductor placed inside the tube. A deflection of the coil in the sense indicated by the arrows moves the junction of the wires outwards.

The Wood Capacitance Magnifier. In this magnifier the moving coil through which the signals are received is used to operate a differential capacitor, consisting of two small fixed electrodes with a central vane moveable between them. In the normal condition, the vane is central and there is equal capacitance between the vane and each electrode. When the vane is moved by the coil the capacitance balance is upset, the capacitance being increased towards the nearer and decreased from the farther electrode. The fixed electrodes are taken to the grids of two rectifier valves and a source of alternating current having a frequency of approximately 30,000 c/s is applied between the moving vane and the cathodes of both valves (Fig. 17.23).

High tension is applied to both anodes via the centre of a resistance placed across the recording instrument. When the vane is central, the potentials applied to the grids are equal; therefore the anode currents and thence the potential of points *A* and *B* are equal. Movement of the vane to one side causes an increased alternating voltage to be applied to one grid and a correspondingly reduced voltage to the other. Hence the mean anode current of one valve is reduced and that of the other increased so causing a potential difference across the two resistances *A*–*B* and so operating the recording instrument in one direction or the other in accordance with the movement of the vane.

A view of a Wood capacitance magnifier is shown in Fig. 17.24.

Fork Relay. The capacity magnifier is employed extensively in the Cable & Wireless Ltd., and Commonwealth submarine cable network. In this case the amplified signals received from the magnifier are passed through the suspended coil of a fork relay (see Fig. 17.25). The coil of this relay carries a pair of gold wires, see Fig. 17.26, which make and break contact with silver butts. Each gold wire is in contact with its butt when no signals are received so that a current flows from the positive of the battery via the silver butts and the gold antennae to polarized relays *R*1 and *R*2, to negative battery via the 1,500 Ω resistors. Relays *R*1 and *R*2 are thus operated to spacing, so energizing the non-polarized relays *S*1 and *S*2, the tongues of which disconnect the circuits to the selectors of the retransmitting apparatus.

When a dot impulse is received, the fork relay coil moves in a direction such that the right hand antenna breaks contact with its butt, so disconnecting relay *R*2, which operates to marking under the action of its bias. Directly the tongue of *R*2 leaves the *S* contact, the current through the dot relay *S*2 is broken, its armature is released and moves to its back contact under the action of its spring, thus making a circuit through the dot selector electromagnet of the retransmitting apparatus. Should the next impulse be a dash the antenna will be moved in the opposite direction, so that the left hand antenna breaks contact with its butt almost immediately after the right hand antenna and butt remake contact. This causes the dot relay *R*2 to operate to spacing, thus completing the circuit of *S*2 which in turn breaks the circuit to

the dot selector electromagnet of the retransmitting apparatus. The restoration of the dot circuit having been effected, the left hand antenna breaks

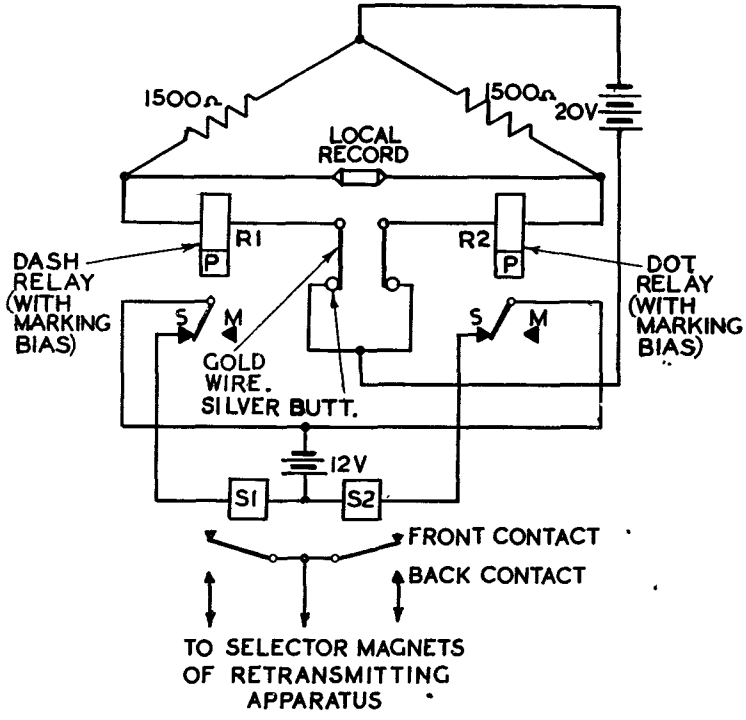


FIG. 17.26. LOCAL CIRCUIT OF FORK RELAY (BIAS CORRECTION CIRCUIT NOT SHOWN)

its butt contact and a similar breaking and making of circuits, as occurred on the dot side, now takes place on the dash circuits.

Equality in the length of time of break between antennae and their butts for dots and dashes is desirable and this is obtained automatically by a bias corrector which moves a platform carrying the butts in the desired direction to effect equality.

In order that the duplex balance may be checked immediately an opportunity offers, a light beam attachment is fitted to all fork relays.

The fork relay coil (Fig. 17.27) carries an aluminium cross arm which moves a lightly suspended cradle carrying a mirror. A beam of light is reflected by the mirror on to a scale and therefore any movement of the fork relay coil is shown on the scale considerably magnified. The device also provides a valuable means of observing the shape of the incoming signals.

The magnifier will function with a current of 1 μA through its coils but in practice the operating current is from 5–10 μA. The fork relay is operated at 50–100 μA and its local circuit containing relays $R1$ and $R2$ works with 8 mA. The latter control non-polarized relays $S1$ and $S2$ which operate at 100 mA. Their contacts are robust since they are required to make and break local circuits carrying operating currents of 0·75 A.

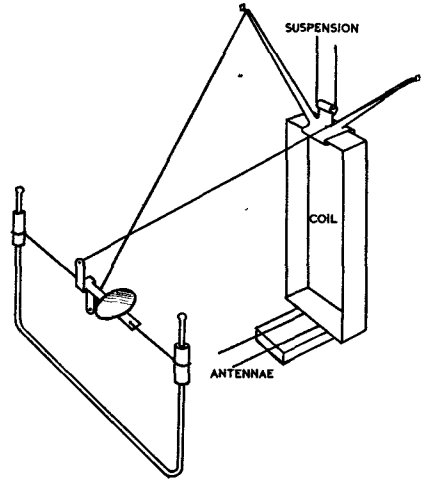


FIG. 17.27. MIRROR ATTACHMENT TO FORK RELAY

Correction of Signal Bias. Automatic correction of bias in the signals from a capacity magnifier, due to earth currents and other causes, is effected in the following manner. The principle of the method employed relies upon the use of synchronous methods of working which are described later and compares the time of arrival of the successive signal changeovers with the time at which the changeovers would occur if the signals were perfect. When a difference in these times occurs a 'corrector' is caused to function and eliminate the bias. The effect of bias on the received signals is illustrated in Fig. 17.28.

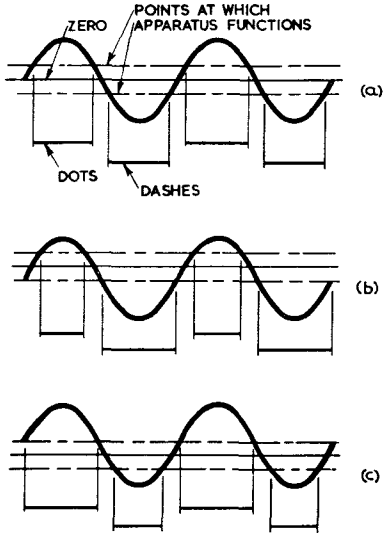


FIG. 17.28. EFFECT OF BIAS ON RECEIVED SIGNALS

(*a*) Normal unbiased signals
(*b*) Dash bias: dots late, dashes early
(*c*) Dot bias: dots early, dashes late

The bias corrector works in conjunction with the fork relay and the synchronizing unit of a regenerator which is described later and is so designed that when dots arrive early and dashes arrive late, i.e. a dot bias exists, a suitable bias correction is automatically applied by the device to the fork relay. Conversely, when dashes arrive early and dots late, due to a dash bias, an opposite correction is made to the fork relay.

The butt contacts on the fork relay are carried on a pivoted stage which is movable in minute steps by means of a finely threaded screw to which a ratchet wheel is fixed. The contacts may thus be moved bodily in either direction and so produce a dot or dash bias, according to which one of two ratchet pawls is caused to act upon the ratchet wheel. The ratchets are operated by the corrector electromagnets which are wound differentially and connected so that an early dot, or a late dash, operate the right hand electromagnet and cause an increase in dash bias, whilst an early dash, or late dot, operate the left hand electromagnet and cause an increase in dot bias on the fork relay.

It will be seen from Fig. 17.29 that current passes through the windings of both corrector electromagnets of the fork relay but their magnetic effects are additive in the windings of one electromagnet and in opposition in the other; thus only one electromagnet is operated at a time. The operation of the corrector circuits may best be followed by considering the case of a dot which has arrived early, that is to say the synchronizer correcting electromagnet has caused the discharge of the 4 μF capacitor at a time when the synchronizer blade is on the advance contact, causing the advance electromagnet of the synchronizer and the early bias corrector electromagnet to be operated. The armature of the latter now completes a circuit from + 100 V via the armature of the dash single-sounder, both of the fork relay corrector electromagnet windings, the armature of the early bias corrector electromagnet and the shunted capacitor, to — 100 V. The direction of the current in the windings of the corrector electromagnets will be seen to be such that only the dash bias electromagnet is operated as the result of the early arrival of the dot.

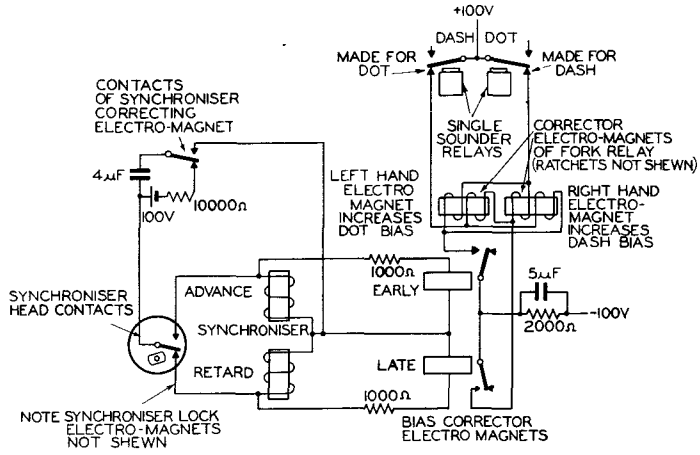


FIG. 17.29. FORK RELAY AUTOMATIC BIAS CORRECTOR

Valve Magnifiers

A valve magnifier comprises the apparatus necessary for shaping, as well as amplifying, the signals received from a cable and includes an output relay.

or equivalent device, for connexion to a receiving instrument or signal regenerator as required.

The cable is connected to the amplifier via a transformer which serves the double purpose of eliminating the effects of direct earth current and providing a voltage step-up to the grids of the amplifier valves. The use of a transformer coupling between the cable and the amplifier results in the alternating current components only of the signals in the primary winding being reproduced in the

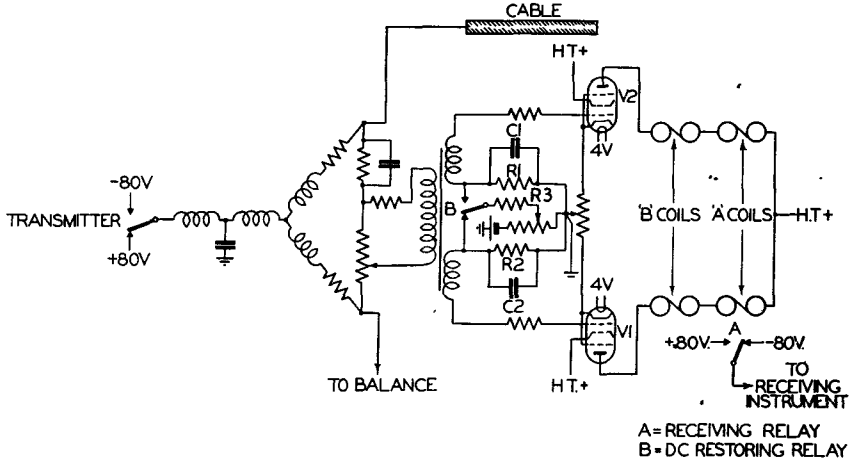


FIG. 17.30. BASIC CIRCUIT OF A D.C. VALVE AMPLIFIER

secondary. The transients in the received signals produce impulses in the secondary corresponding to the successive instants of modulation in the signals.

It is a generally agreed principle in telegraph apparatus design that to avoid characteristic distortion the disturbance introduced into a circuit by a changeover from mark to space or vice versa, shall have been substantially completed before the next changeover takes place. If a changeover from mark to space takes place in a circuit consisting of a transformer inserted between the transmitting tongue and the receiving relay, there follows in the secondary circuit an impulse whose duration is a function of the time-constant of the circuit, i.e. of the L/R ratio.

If this time-constant is considerably shorter than the unit element, the impulse will have died away before the next changeover occurs and theoretically, transmission can be distortionless. If, on the other hand, the time constant is long, there will be interference between the disturbances created by successive changeovers and distortion will result. It would appear therefore that in impulse working the values of the circuit components should be chosen so that the impulse has substantially died away in the period of the unit element. Unfortunately if this is done the receiving relay is then subject to false operation by interference due to noise or imperfect balance conditions in the case of duplex circuits.

The use of a long time-constant has the advantage that if it is sufficiently long a holding current is available over a period of several elements but the adverse distortion effects of the long transient must then be avoided by introducing, after the relay has operated, an equal and opposite disturbance to balance out the tail of the first. This is equivalent to the restoration of the d.c. and low frequency components cut out by the transformer.

The basic circuit of a valve amplifier employing the foregoing principle is shown on Fig. 17.30, whilst Fig. 17.31 illustrates the action of the circuit for an isolated dot signal.

Fig. 17.31 (*a*) shows the original signal voltage:
Fig. 17.31 (*b*) shows the voltage applied to the grids of valves $V1$ and $V2$ by the transformer secondary:
Fig. 17.31 (*c*) shows the compensating voltage in the grid circuits of $V1$ and $V2$:
Fig. 17.31 (*d*) shows the sum of (*b*) and (*c*), which is the resultant voltage applied to the grids of $V1$ and $V2$:
Fig. 17.31 (*e*) shows the sum of the voltages applied between the grids.

It will be noted that in the ideal case, the waveforms of both the original and compensating disturbances are exponential in shape and can be reproduced with great accuracy by the use of suitable reactors and resistors.

In this repeater a long time-constant is used. It requires a transformer having a uniform insertion

loss from the highest relevant signal frequencies down to about 1 c/s.

Signal Shaping Network. If the circuit is to have no characteristic distortion, the attenuation and phase must be approximately equalized at least up to a frequency equal to the fundamental frequency of reversals at the highest signalling speed to be transmitted. The equalization should preferably be carried to about 20–50 per cent above this frequency. Fig. 17.30 indicates the basic network employed in the input to the amplifier for equalization.

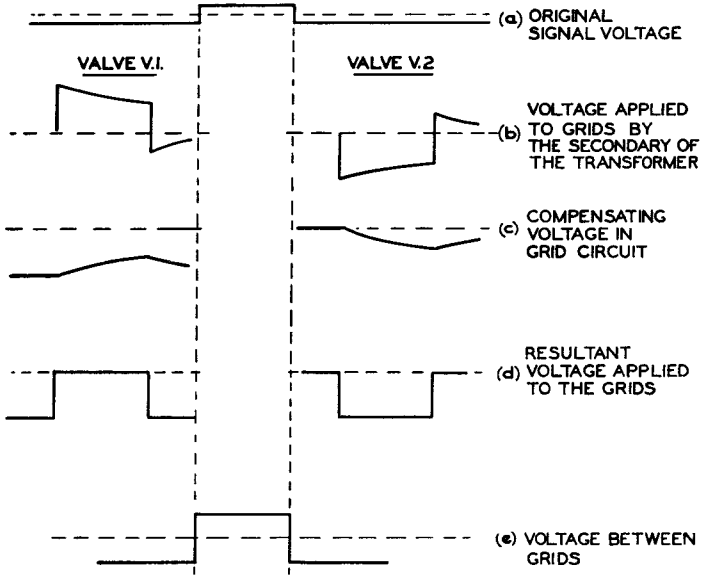


FIG. 17.31. ACTION OF D.C. VALVE AMPLIFIER FOR DOT SIGNAL

Amplifier and d.c. Restoring Circuit. This consists of an input transformer followed by two valves in push-pull, the windings of the receiving relay A which provides double-current output signals being in the anode circuits of the two valves. The time-constant of the input circuit is of the order of $\frac{1}{2}$ sec and therefore a signal changeover in the primary winding of the input transformer produces an impulse in the secondary, i.e. in the amplifier grid circuit, which dies away very gradually. To compensate for this die-away, an equal and opposite voltage is introduced into the grid circuit by the additional relay B in the valve anode circuits. This relay, having operated to the signal, applies a voltage to the appropriate grid circuit through resistor $R3$, and across $C1$, the voltage of which gradually rises to compensate for the gradual fall of potential across the secondary of the transformer. In the other grid circuit, the potential across $C2$ falls at very nearly the same rate as it rises across $C1$. The algebraic sum of the voltage across $C1$ and $C2$ is the required compensating voltage illustrated in Fig. 17.31 (*c*).

The time-constants of the CR networks in the grid circuits can be made equal to that of the LR network consisting of the input transformer and the equalizer terminating resistor. At frequencies of 1 or 2 c/s the impedance of the equalizer, which is in parallel with the terminating resistor, is so high that its effect on the time-constant is negligible. The amplifier including the d.c. restoring circuit is a unit independent of the cable on which it is worked. The equalizer is designed to suit the cable with which it is associated and experience has shown that this can be done accurately and without great difficulty.

One practical application of the foregoing type of repeater is on the Anglo-Norwegian telegraph cables where it is operated in tandem with land-line V.F. channels to provide point-to-point teleprinter communication. One of these submarine cables is approximately 410 n.m. long, has a total resistance of 2,238 Ω and total capacitance of 146 μF. The duplex distortion on the cable using the repeater is less than 10 per cent at 50 bauds.

Reception on Long Cables. On very long cables, e.g. trans-Atlantic, much greater gain is necessary in the amplifier and several stages of amplification of the cable signals need to be used. The number of valve stages required depends upon the characteristics of the cable. The number of stages is usually four or less and interstage couplings—excluding shaping networks—are of the resistance/capacitance type. High stage gain is of less importance than stability and freedom from distortion, e.g. the gain obtainable from a three or four-stage amplifier exceeds that which can be employed on a long non-loaded cable on account of disturbance due to extraneous causes.

The amplifying elements have no special feature and interest mainly centres on the circuits used for reducing signal distortion. These are dependent to a large extent upon the operating conditions for which the amplifier is designed, i.e. the type of cable, the method and speed of signalling etc. The main objects are to counteract the rising frequency-attenuation characteristic and to compensate for the unequal rates at which currents of different frequencies are propagated, i.e. compensation for attenuation and phase distortion.

It is also necessary that the response of the shaping devices should be negligible at frequencies higher than those essential for the production of good signals and that the effect of slowly varying currents should likewise be small; this assists duplex balancing on the one hand and minimizes the effects of earth currents and other extraneous disturbances on the other. The discrimination of the shaping networks against low frequencies which is necessary to prevent zero wander due to earth currents, results in too rapid decay of long signals of one polarity. This effect is compensated by applying a local holding voltage to the output stage through a correction network having a long time-constant, a principle long established in connexion with moving coil cable relays.

As an alternative to excluding earth currents from the amplifier, a zero correcting device may be incorporated in the final amplifier stage by means of an auxiliary output relay which applies a correcting voltage to the grid of the last valve when the signals exceed a given amplitude on one side of zero or the other. The local correction method is generally the more satisfactory.

For the reception of double-current signals only, the range of low frequencies excluded by the signal shaping network may be extended until the last amplifying stage receives little more than those signals corresponding to the fundamental frequency of reversals at the highest signalling speed used. The output relay is then operated by single impulses approximately sinusoidal in form, and is provided with a local locking circuit. The conditions to be fulfilled by the shaping network are less exacting in this case than those for amplifiers dealing with a wider frequency band. In practice, the resistors, capacitors and inductors forming a shaping network are made adjustable over a fairly wide range and optimum final adjustments are determined from the results of practical signalling trials. All units are carefully shielded from parasitic electric and magnetic fields and input networks are made symmetrical to eliminate trouble in duplexing due to unbalanced capacitances to earth in the amplifier.

The input impedance of the amplifier should be equal in magnitude and phase angle to the characteristic impedance of the cable at the fundamental, or slightly higher, signalling frequency. On duplex circuits, the impedances of the bridge ratio arms and artificial line must be taken into account in determining the best value for the amplifier input impedance.

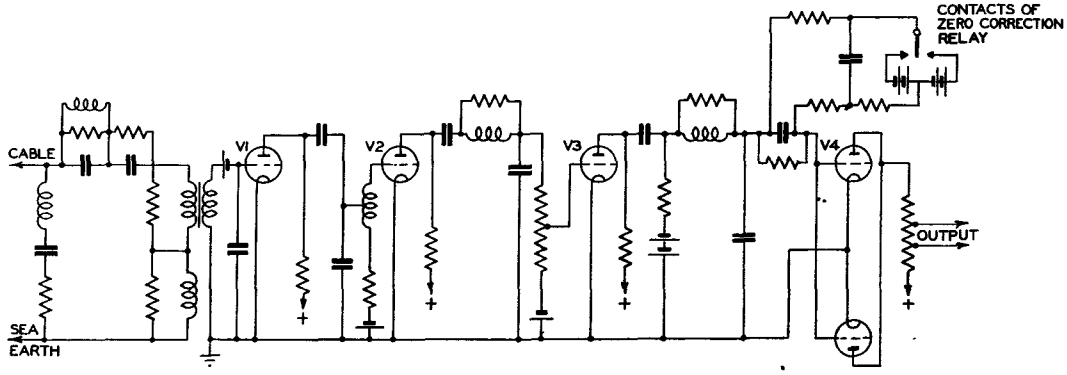


FIG. 17.32. PRINCIPLE OF SIGNAL SHAPING VALVE AMPLIFIER FOR A LONG CONTINUOUSLY LOADED TELEGRAPH CABLE

Fig. 17.32 shows schematically a signal shaping amplifier suitable for a continuously loaded trans-Atlantic cable. The amplifier consists of three single triode valve stages and an output stage of two triodes in parallel; the adjustable signal shaping networks are distributed between the pre-amplifier network and the inter-stage valve couplings.

Multi-channel Working. There are two basic methods of multi-channel telegraph working *viz*—

(*a*) Multi-channel frequency-division systems, in which the band-width of a line is subdivided by means of band-pass filters into a number of separate bands, each of which is permanently allotted for the use of a telegraph channel, and

(*b*) Multi-channel time-division systems in which the whole band-width of a line is allocated successively, in rapid time sequence, to a number of telegraph channels. Thus each telegraph channel has the full use of the line repeatedly for short intervals of time.

The first method, i.e. multi-channel frequency-division, is not normally employed on telegraph cables as these are single core cables of very limited band-width and therefore unsuitable for

frequency-division. Frequency-division is usually only used where telegraph channels are provided over repeated telephone cables, e.g. from the United Kingdom to the Continent of Europe. In such cases an audio or carrier telephone channel is provided for telegraph use and normal M.C.V.F. telegraph terminal equipment, as employed for land line circuits, may be used to provide 6, 12, 18 or 24 telegraph circuits depending upon the traffic requirements. The principles of operation of M.C.V.F. telegraph systems have already been described in Chapters 5 and 10 and require no further elaboration here.

Submerged Repeaters. In recent years a great deal of research and development work has been done in the United Kingdom and elsewhere on the design of submerged repeaters, both for telephone and telegraph cables. The B.P.O. installed such a repeater in a paragutta co-axial telephone cable between Holyhead and the Isle of Man in 1943 and this was the first submerged repeater brought into practical operation in the world. In 1945 a further repeater was installed by the B.P.O. in a cable between Lowestoft, England, and Borkum, Germany and subsequently a system for operating a number of repeaters in tandem was developed and used successfully on cables to the Continent of Europe. The use of submerged repeaters enables the traffic capacity of cables to be increased considerably at relatively small capital cost. Their development and use is therefore of great commercial significance.

Attention has latterly been directed to the development of deep sea repeaters and the successful development of repeaters of this type has now been accomplished. Such repeaters give prospect of revolutionizing trans-oceanic telephony and telegraphy, even for cables of trans-Atlantic and trans-Pacific length, e.g. the trans-Atlantic telephone cable laid in 1955–56 provides 36 telephone circuits and a 12-circuit M.C.V.F. frequency-modulated telegraph system using carrier frequencies spaced 120 c/s apart has been provided initially within half the band-width of one of the telephone circuits. The telegraph circuits are capable of signalling speeds up to 80 bauds.

The problems of deep sea repeaters are great as not only are considerable mechanical problems involved, owing to the high sea pressures to be withstood, but it is also essential to ensure extremely high stability and long life of the electrical components employed in the repeaters. The life of the thermionic valves used gives rise to many problems in design and manufacture as it is desirable to obtain a valve life of at least 20 years. The d.c. power supply for submerged repeaters has to be fed over the cable from the shore stations and when repeaters are operated in tandem this involves the use of high voltage d.c. power supplies.

The insulation of the cable must be able to withstand this voltage without risk of breakdown and this limits the application of submerged repeaters in the case of old telegraph cables as these are only capable of withstanding low d.c. voltage. Submerged repeaters can however be utilized near the shore end of such cables by replacing the shore ends with modern cable having polythene insulation.

Submerged telegraph repeaters have been installed on a few telegraph cables in recent years but so far these have only been used for amplifying the received signals near the shore ends where the sea depth is shallow. This use is nevertheless extremely valuable as it enables the very weak received signals to be amplified a hundred or so miles out at sea before encountering the high interfering noise levels which may occur in the shore ends of the cable. This considerably improves the signal-noise ratio of the signals received at the terminal station and enables the traffic carrying capacity of the cable to be increased appreciably.

For further information on the subject of submerged telephone and telegraph repeaters the reader is recommended to refer to the bibliography given at the end of this Chapter.

Time-division Multiplex Working. As already explained earlier in this chapter, telegraph cables usually employ cable code or five-unit code signalling. Both of these codes are suitable for use in time-division multiplex systems but a fundamental difference in the principle of operation is necessitated in the two cases, arising from the fact that in cable code the number of code elements varies for different characters, whereas in five-unit code every character has a constant number of elements, i.e. five. Thus in time-division multiplex working when using cable code, it is necessary to connect the line successively to the channels for time intervals corresponding to the duration of one signal element only. In five-unit code systems, the line is normally allocated to each channel in succession for a time period corresponding to the duration of five-code elements at the aggregate signalling speed. (*Note.* The aggregate signals are the signals in the line and the aggregate signalling speed in a T.D.M. system is therefore the sum of the speeds of the individual channels.)

In cable code working, the aggregate signals from two channels (A and B) will consist of a succession of unit signal elements from the channels in the order $A\ B\ A\ B \ldots A\ B$. In five unit code working the aggregate signals from two channels will comprise $A1$, $A2$, $A3$, $A4$, $A5$; $B1$, $B2$, $B3$, $B4$, $B5$:

*A*1 etc.; where *A*1 . . . *A*5, and *B*1 . . . *B*5 correspond to the five code elements of successive characters in channels *A* and *B* respectively. Similarly in a four-channel time-division system, the aggregate signals would comprise *A*1 . . . *A*5, *B*1 . . . *B*5, *C*1 . . . *C*5, *D*1 . . . *D*5, *A*1 etc.; where *A*, *B*, *C* and *D* correspond to channels *A*, *B*, *C* and *D*.

There are exceptions to these arrangements in special cases. Thus in cable code systems it is sometimes necessary on a chain of cables, e.g. where a fast cable is interconnected to two slower cables having different signalling speeds, to channel the fast cable on an uneven time division basis and so provide a fast channel *A* and a slower channel *B*. If a ratio of 2:1 is required in the speeds of channels *A* and *B* then the time division system is arranged by means of cam operated contacts to allocate the line in unit signalling periods in the sequence *A A B*, *A A B*, etc. If a ratio of 3:2 is required then the time division system allocates the line in the sequence *A A B A B*, *A A B A B*, etc.

In five-unit systems it is sometimes desired to interleave the signalling elements of different channels. A typical arrangement of the sequence employed in a four-channel system is indicated in the following example *A*1, *B*1, *A*2, *B*2, *A*3, *B*3, *A*4, *B*4, *A*5, *B*5; *C*1, *D*1, *C*2, *D*2, *C*3, *D*3, *C*4, *D*4, *C*5, *D*5; *A*1, *B*1, etc., where *A*1, *A*2, *A*3, *A*4, *A*5 represent the five code elements corresponding to a character in channel *A*; and similarly *B*1 . . . *B*5, *C*1 . . . *C*5, and *D*1 . . . *D*5 represent the code element corresponding to a character in channels *B*, *C* and *D* respectively.

From consideration it will be clear that in such a system it is easily possible, if desired, to halve the number of channels and halve the aggregate speed by connecting one channel to the segments of *A* and *B*, and the second channel to the segments of *C* and *D*.

Synchronous Methods of Working Circuits

For reasons already explained, the majority of submarine cables employ synchronous methods of working, the cable being used to provide either a single channel or a number of channels, depending upon the traffic requirements and the baud speed permitted by the cable characteristics. When a number of channels is required, time-division multiplex systems are employed. In both cases the fundamental requirement is the maintenance of synchronism between the transmitting and receiving apparatus and regenerative repeaters if these are employed; this entails refined methods of speed and phase control.

Although it is comparatively simple in practice to make the speed of a transmitter and a receiver almost identical, it will be appreciated that even an extremely small difference in speed will give rise to an appreciable difference in phase in a short time. Means must be provided to minimize this phase difference otherwise excessive loss of margin will occur and cause errors in reception. For this purpose, the basic principle employed in all synchronous systems is the use of a slight deviation of phase as a means of bringing corrective action into play to prevent an indefinite increase in phase error.

The method employed in the Baudot multiplex system (see Chapter 2) is a good example of a typical old technique. In this system the speed of the receiving equipment at the slave station is governed to run at a slightly higher speed than the transmitting equipment at the master, i.e. controlling station. A cumulative phase difference therefore begins to occur between the transmitting and receiving equipments and when this exceeds a given amount, the special speed correcting signals, which are transmitted at each revolution of the distributor at the master station, cause a brake to be applied to the distributor at the receiving end, so reducing its speed. This action occurs repeatedly and thus maintains synchronism with reasonable accuracy. The method is satisfactory for comparatively short lines having low distortion but it is not adequate for long submarine cable circuits in which high speed distortion is present. Another disadvantage of the method is that it involves transmission of special signals for speed correction and this is wasteful of line time.

Modern methods make use of the normal traffic signals as a means of controlling synchronism. The speed of the equipment at the transmitting, repeating and receiving stations is made as nearly equal as possible, the motor drives being controlled either from clock-controlled vibrating reeds, valve maintained tuning forks or quartz crystal oscillators. This ensures a high degree of precision and the slight drift of phase caused by speed variations between transmitting, receiving and repeater stations, is corrected automatically by the cable signals received. The corrective action may be effected by varying the frequency of the speed control source at the receiving station (or repeater station) or changing the phase position of the receiving equipment, or both.

Cable Code Systems. The principle of the methods employed in the Cable & Wireless and British Commonwealth network will now be described to illustrate typical methods for a synchronous cable code system.

The cable code transmitter is driven by a phonic motor which is driven in turn from direct current

impulses controlled by a clock-controlled reed.* The rate of vibration of the reed is checked and controlled by a synchronome clock (i.e. one having an electro-mechanically maintained pendulum) which for this purpose sends out a controlling pulse at 1 sec intervals. The accuracy of the clock can be adjusted fairly easily to approximately 1 sec per day, so that the speed of the phonic motors is maintained to an accuracy of about 1 part in 10^5.

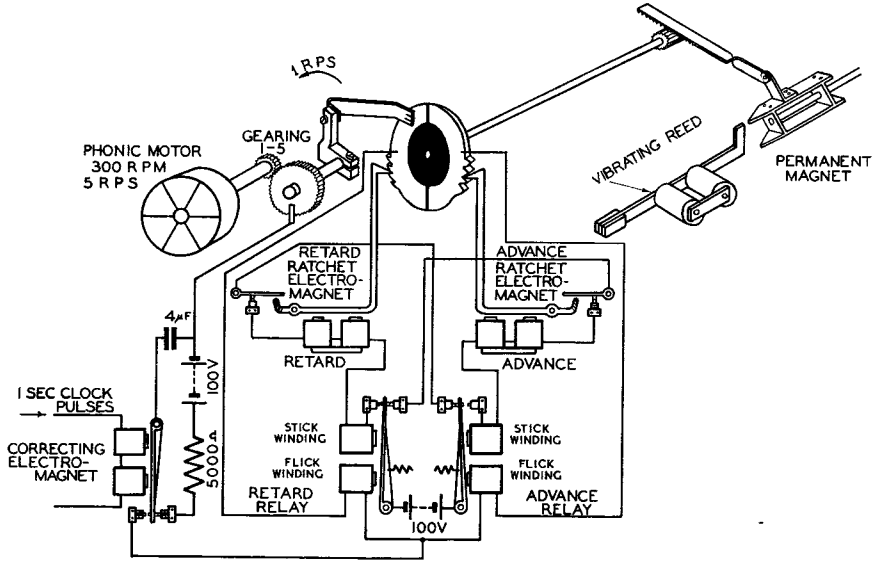


FIG. 17.33. PRINCIPLE OF HIGGITT CLOCK-CONTROLLED REED

Similar speed control arrangements for the apparatus at intermediate and receiving stations in a cable chain are also provided.

To maintain synchronism, the received signals have only to compensate for the slight speed difference between the clocks at the different stations. This is done by a "synchronizer" which is able to make phase corrections in very small steps (equivalent to $\frac{1}{120}$ of a signal element) either forward or backward, under the control of the received signals. It should be noted that the effect of signal distortion will at times cause the synchronizer to make small phase changes which are not called for by speed discrepancy. Although this will cause distortion in the signals regenerated at this station, the amount in practice is extremely small and is unlikely to exceed two to three per cent.

Higgitt Clock-controlled Reed. This system, invented by H. V. Higgitt of C. & W. Ltd., simultaneously applies both a speed and a phase correction to the vibrating reed. This feature produces remarkable stability by preventing the hunting which would inevitably arise if speed correction only were applied. The Higgitt system employs a Murray reed which is adjusted, by varying the positions of loading weights, to a speed of 30 complete vibrations per sec. This frequency is employed to drive phonic motors at a speed of 300 r.p.m., from which the different speeds required by the apparatus are secured by suitable gearing.

A small soft iron armature (see Fig. 17.33) is fixed to the free end of the reed at right angles to its length and vibrates in the field of a permanent horseshoe magnet which can be turned bodily on the axis of its carrier in order to vary the effect of the field on the armature. When the magnet poles are in line with the armature its effect is at a maximum and is equivalent to stiffening the reed, so increasing its rate of vibration. As the magnet is turned, the effect of the field diminishes, thus slowing down the rate of vibration of the reed. The deflection of the magnet is the means adopted to control the speed.

The phase control is effected by ratchet operated

* Of late years, alternative controls using valve maintained tuning forks vibrating at 600–1,000 times per second have been introduced. A high degree of short term stability is obtained and with thermostat controlled ovens and the use of Invar forks, which have a very small temperature coefficient, a long term stability of 2–3 parts in 10^6 can be obtained. The phonic motors may be driven at 30 c/s by means of frequency division or in some cases phonic motors are driven at 1,000 c/s direct. This latter type provides a very steady drive with no perceptible sway and is useful on the higher speed circuits.

mechanism. The reed drives the phonic motor of the clock-controlled unit at 300 r.p.m. which by a one to five reduction gearing revolves a brush over the face of a copper disc, divided by a slot into two equal parts. The brush therefore makes one revolution of the disc per second and if the frequency of the reed is precisely 30 vibrations per second, the brush will be on the same spot on the disc at the instant of arrival of the successive one-second impulses.

Assume the brush is making contact on the left-half of the disc when the one second impulse arrives, then the operation of the correcting magnet will connect the 4 μF capacitor via the armature and front stop of the correcting electromagnet and thus allow it to discharge through the "flick winding" of the retard relay, thus attracting its armature to the front stop. This completes a circuit from the 100 V battery through the retard ratchet electromagnet and the back stop of the advance relay so actuating the retard ratchet. The resulting anti-clock-wise movement of the disc rotates the slot, separating the two halves of the disc, by one tooth towards the position of the brush. This action continues for each successive one-second pulse until the brush bridges the two segments of the disc. During the foregoing action the permanent magnet is moved in its relation to the vibrating reed so as to reduce the rate of vibration of the reed. The speed of the reed and hence that of the rotating brush will now be slow, so that when the next one-second pulse arrives the brush is in contact with the right-hand segment of the disc. The discharge of the 4 μF capacitor will now take place through the flick advance relay so causing the advance ratchet electromagnet to operate and actuate the advance ratchet. This in turn, speeds up the reed slightly and moves the disc in a clock-wise direction.

The foregoing action quickly results in the brush assuming a position in which it is bridging the segments of the disc at the instant when the one-second pulse arrives and at the same time the speed of the reed will have been adjusted to 300 vibrations per second. It will be noted, that when the brush is bridging the disc segments when a one-second pulse arrives, the discharge of the 4 μF capacitor operates the flick windings of the advance and retard relays and so prevents the ratchet electromagnets from operating and changing the speed of the reed.

Gang Driving of Phonic Motors—Fig. 17.34 refers. In practice the reed does not directly drive the phonic motors of the clock control and transmitters and synchronizers, as the inductance of these is considerable and the amplitude of excursion of the reed being very small at the point where the motor driving contacts are made, frequent attention to these contacts, due to sparking, would be necessary. It is therefore arranged that the reed drives relays having higher resistance than the phonic motors, so that the inductive effects on the reed contacts are greatly reduced. Each reed will drive four relays, and the latter can drive three or four phonic motors. One clock-controlled reed can

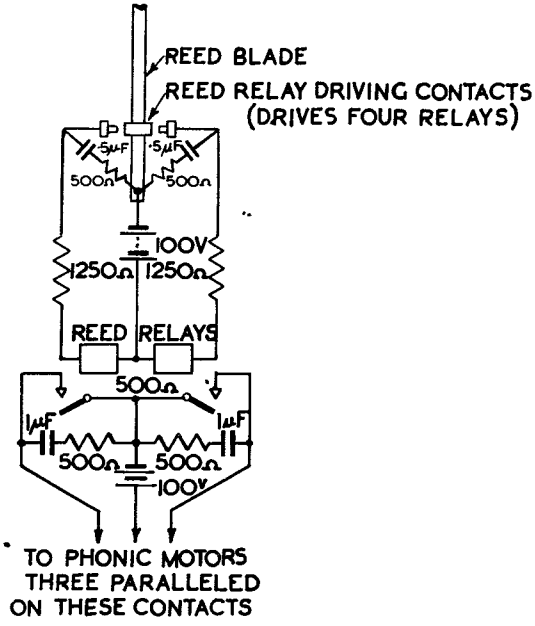


FIG. 17.34. GANG DRIVING OF PHONIC MOTORS

therefore drive twelve phonic motors. By the employment of slave reeds, additional relays and, in turn, motors may be driven.

When 1,000 c/s forks are employed, gang driving of 30 c/s motors is arranged by causing a 1,000 c/s motor to drive a cam shaft which produces up to twelve 30 c/s drive outputs. The objection to using a 30 c/s motor for driving such a unit is that any sway in the motor would cause bigger sway in the driven motors and this would become cumulative on a long cable chain. The absence of sway in the 1,000 c/s motors overcomes this.

Synchronizer. The function of a synchronizer is to keep the receiving apparatus on a cable in synchronism with the transmitting apparatus. A synchronizer is necessary at each intermediate regenerator station, as well as at the terminal receiving station, on a cable. The synchronizing unit consists essentially of a motor which is driven from a clock-controlled reed in the station concerned. The motor is geared to a cam-shaft which

it drives at the same nominal speed as the transmitter at the controlling terminal station. The cam-shaft controls the operation of contacts which drive the motor of the regenerative repeater (i.e. interpolator), receiving perforator or direct printer as the case may be. Synchronism is then maintained by employing the incoming signals to control an advance and retard mechanism. The action is similar in principle to that already described in the case of the clock-controlled reed, except that cams which was originally conceived by Baudot, consists of selecting the central, and therefore probably the least distorted portion of each signal element to determine the signal condition to be recorded or regenerated for that element. The regenerative repeater automatically retransmits perfect signals and thus avoids the need for manual retransmission at intermediate stations.

A good example of the use of regenerative repeaters is the Commonwealth cable chain from

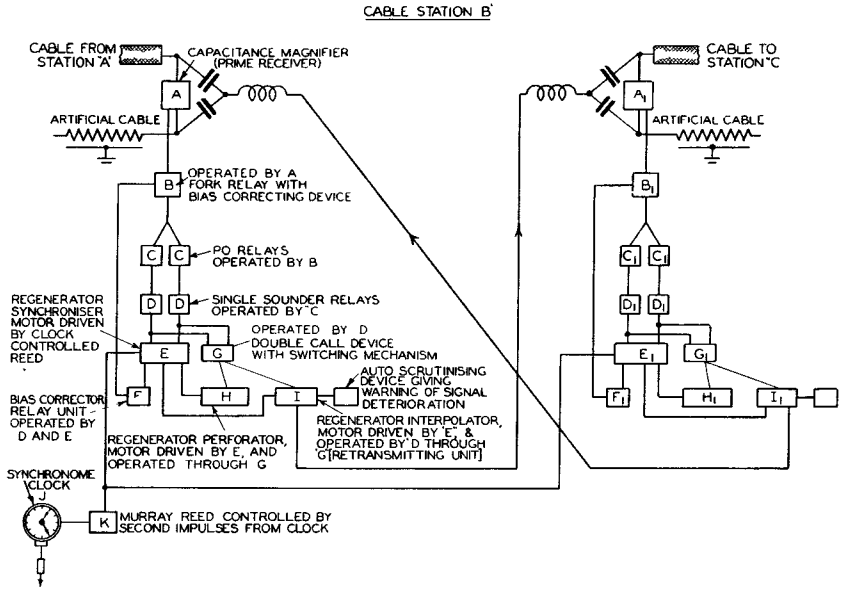


FIG. 17.35. REGENERATOR APPARATUS FOR AUTOMATIC RETRANSMISSION OF SIGNALS AT AN INTERMEDIATE CABLE STATION

and contacts replace the segmented disc and brush, and the synchronizing pulses are derived from the instants of changeover of the received signal elements instead of by means of one-second clock pulses. By this means the operation of the motor driving contacts of the synchronizer is advanced if the synchronizer cam-shaft is slow compared with the incoming signals, and retarded if the cam-shaft is fast. Synchronism is thus maintained, within very closely controlled limits, at all stations on a cable chain.

Regenerative Repeaters. At one time it was necessary to receive and retransmit messages by hand at each station along a chain of cables. In some cases this involved as many as ten retransmissions, with consequent delays and increased possibility of errors, particularly as many of the messages are in coded form. This can be avoided by signal regeneration which has already been referred to in Chapter 5. The fundamental principle used, London to Hong Kong with twelve intermediate stations at Porthcurno, Carcavelos, Gibralta, Malta, Alexandria, Suez, Port Sudan, Aden, Seychelles, Colombo, Penang and Singapore. At these stations the signals are automatically regenerated, synchronism being maintained at all stations by use of the methods already described. When clear of traffic an idle signal, comprising T E T E T E, is automatically transmitted at intervals equivalent to 120 centre holes to maintain synchronism.

The form of regenerative repeater used for cable code operation is termed an "interpolator" and includes means for alternative control from a perforated message tape, so that messages which originate at stations along a chain of cables may be transmitted when there is no other traffic passing.

Fig. 17.35 shows in schematic form the regenerative repeater at an intermediate station on a cable and the figure is annotated to indicate the correlation of the various components.

The Interpolator. Fig. 17.36 shows in schematic form the layout of an interpolator unit which also includes a transmitter for alternative use with a perforated tape. The operation of the interpolator will now be described with reference to Fig. 17.36 and Fig. 17.37 which show the principle used in the mechanism to operate the contacts from which the regenerated signals are retransmitted.

The interpolator consists essentially of—

(*a*) A phonic motor which, through suitable gearing, drives a cam-shaft which accurately controls various timing instants. A mercury-loaded flywheel is fitted to minimize hunting.

(*b*) Dot and dash selector electromagnets which are operated in accordance with the distorted received signals.

(*c*) A mechanical signal selection mechanism which examines the received signals at the centre of each element to determine whether the corresponding signal element shall be a dot, dash or space.

(*d*) A signal timing and earthing cam which, in conjunction with a contact block, controls the transmission of the regenerated signals.

The phonic motor of the interpolator is driven from the cable synchronizer and thus is maintained at the correct speed and phase with respect to the incoming signals. The received signals via the local circuit of the magnifier operate the dot and dash selector electromagnets depending upon the polarity of the signals received. Clamped to the armature spindle of each electromagnet is a selector depressing lever whose function is to operate the associated selector lever when the armature is attracted. Fig. 17.37, for the sake of clarity, shows the dot selector depressing lever only, but precisely similar arrangements are made for the dash selector lever, the dot and dash

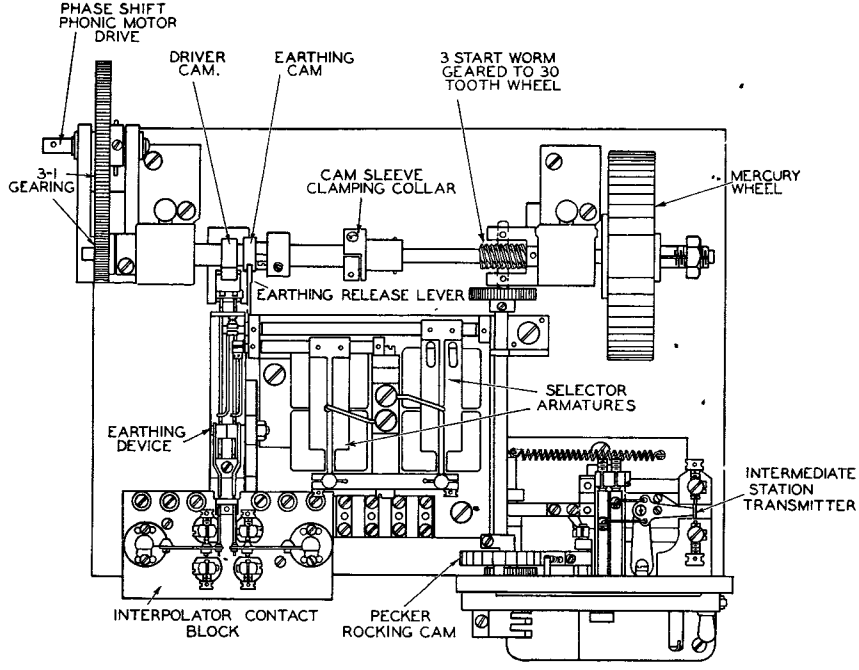


FIG. 17.36. CABLE CODE INTERPOLATOR: LAYOUT OF UNIT, SHOWING TRANSMITTER

electromagnets being placed side by side as may be seen in Fig. 17.36.

The phonic motor driving the interpolator rotates cams *C* and *E* continuously: the former causes the dot and dash selector drivers to be pushed forward and then retracted twice per revolution. If a dot or a dash selector lever has been depressed then it will be pushed forward by its associated selector driver and its extremity will set the interposed lever in a forward position. The interposed lever drives forward a thrust rod which carries the spring loaded contact lever forward to its front contact stop. During the forward movement of the interposed lever the latch lever drops behind it, under the action of its spring, so locking the interposed lever, and hence the contact lever, in the forward operated position. The timing of cam *C* thus determines the instant at which each

regenerated signal element commences. The further rotation of cam *C* allows the selector driver to retract under the action of its spring and this, in turn, also permits the selector lever to retract under the action of its spring. The interposed lever is not released until permitted by the action of the earthing cam *E*. *E* operates the cranked lever *A* which lifts the latch lever so permitting the interposed lever, which is a cantilever spring, to fly back to normal so breaking the signal contact. In the unoperated position of the contacts the cable is earthed. The orientation of the earthing cam on the camshaft is adjustable, thus the time of termination of the signalling current for each element can be set so as to give any desired interval of earthing. The earthing period is usually 15 per cent of the signal element but the precise period is determined from the results of practical tests in conjunction with the receiving station.

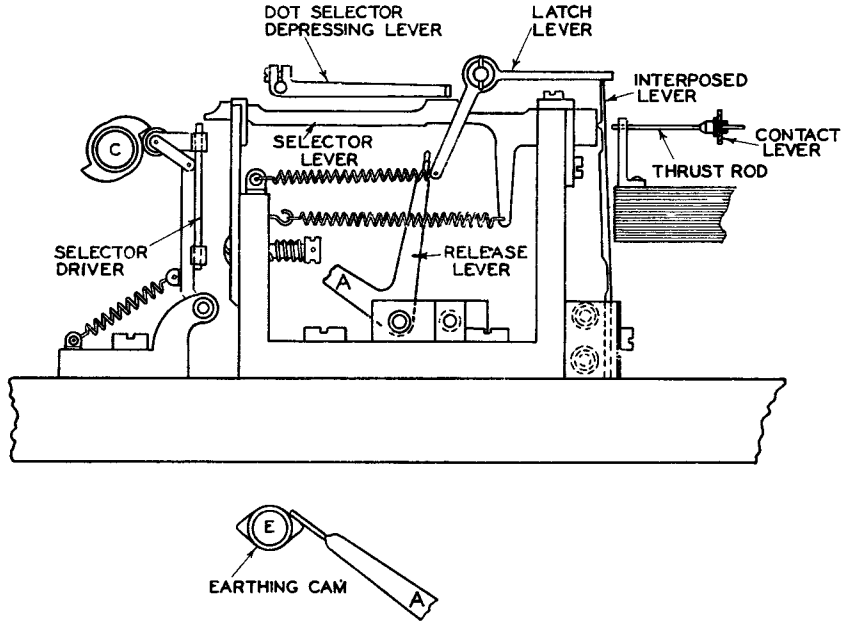


FIG. 17.37. CABLE CODE INTERPOLATOR: MECHANISM FOR ACTUATING SIGNALLING CONTACTS

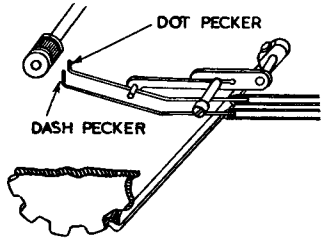


FIG. 17.38. OSCILLATING LEVERS OF TRANSMITTER

Local Transmitter of Interpolator. In order that messages which originate at the stations along a chain of cables may be dealt with, a transmitter forms part of each interpolator unit. The dot and dash peckers Fig. 17.38 are moved up and down together by an oscillating lever which is controlled by a toothed cam driven through suitable gearing from the main shaft of the interpolator. The dot and dash perforations in the tape permit the dot and dash peckers to pass through the tape and so operate the contacts. The contacts send operating current into the interpolator selector electromagnets and thus initiate signals which are transmitted to line in the manner already described.

An idle signal is used on all circuits to maintain synchronism when no traffic signals are being sent. If a long cable chain is broken-up by the sending terminal sending a special switching signal indicating that he wishes to send only to an intermediate station, it is so arranged that the intermediate station sends on the idle signal to maintain synchronism. As the intermediate station's interpolator will still be controlled by signals from the sending terminal the rest of the chain is kept in synchronism with the sending terminal station and no delay ensues when the line is restored for normal through-working.

Cable Code Multiplex Working—Higgitt Capacitor Storage System. A notable example of multichannel time-division multiplex working using cable code signalling is that invented by H. V. Higgitt of Cable & Wireless Ltd. It was introduced to deal with cases in which signals from two cables, working at equal speeds, had to be combined at one station and retransmitted over a common cable. The system may also be used to deal with two channels of unequal signalling speed. The common cable must be capable of operation at the aggregate speed of the two cables to be combined because the signal elements from the two cables have to be retransmitted alternately into the common cable. In the case of equal speed sub-channels, the aggregate signals have a baud speed which is twice that of a sub-channel. Synchronism is essential for multiplex working and for signal regeneration; the arrangements must therefore ensure that the phase relationship between signals from the two slow cables and those of the aggregate signals are precisely controlled.

From what has already been described regarding control of synchronism, it will be clear that there is no difficulty in maintaining accurate speed and phase relationship between the signals from one of the slow cables and those in the fast cables. The problem is to secure equally close relationships for the second channel; this will now be studied.

Consider two stations A and B transmitting over separate cables to station X, at which the signals are to be combined and automatically retransmitted over a common cable to station C. Fig. 17.39 illustrates the arrangement schematically.

Any divergence between the speeds of the signals arriving at X from A and B will depend upon their respective clock-controlled reeds, or equivalent speed control sources. Consequently, over a period, a cumulative phase difference will arise between the signals arriving at X which would cause errors in the aggregate signals. The Higgitt capacitor storage system overcomes this difficulty by providing a group of small capacitors on which, by means of a distributor, the successive signal elements from one cable are stored until they are required to be retransmitted in the aggregate signals.

The number of capacitors provided for storage has to be related to the speed differences between the clock-controlled reeds of the two slow cables. In practice 30 pairs of 0·5 μF capacitors are found to be adequate and this permits continuous operation for about four to five hours without attention for manual readjustment of the store. The pairs of storage capacitors are charged in turn in accordance with the operation of dot and dash relays. The capacitors are subsequently discharged through relays, under the control of a second distributor, which controls the polarity of the signals retransmitted from the stored channel into the fast cable. The signal elements from the stored channel alternate, i.e. are interleaved, with those of the other slow cable, the signals from the latter being retransmitted without storage.

Fig. 17.40 illustrates the schematic circuit arrangements. The signals received from station B

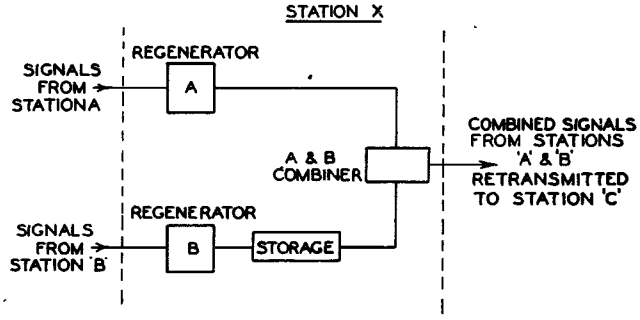


FIG. 17.39. HIGGITT CAPACITOR STORAGE SYSTEM

operate an interpolator, which in turn controls the operation of a dot relay and a dash relay. The tongues of these relays are connected to the distributor rings $BR1$ and $BR2$ via 5,000 Ω protective resistors. A pair of distributor brushes $BB1$ and $BB2$ are rotated by a phonic motor which is controlled from the synchronizer of the B cable. The distributor brushes rotate at a speed equivalent to one segment of the distributor per signal element of the B cable. Thus each signal element from the B cable causes the tongues of the dot and dash relays to control the charge of one pair of dot and dash storage capacitors connected to the distributor segments. If a dot signal is being received from station B then the dot relay will be operated and the dash relay unoperated, so resulting in the distributor brushes $BB1$, $BB2$ charging a dot capacitor negative and a dash capacitor positive. For a dash signal, a dot capacitor will be charged positive and a dash capacitor negative. For a space signal, both a dot and a dash capacitor will be charged positive.

The dot and dash capacitors are also connected to the segments of a second distributor and are discharged through polarized dot and dash repeating relays via brushes $AB1$ and $AB2$ respectively and rings $AR1$ and $AR2$. These relays are adjusted to neutrality so that the tongues when deflected remain in that position until a reverse discharge current occurs. The distributor brushes $AB1$, $AB2$ are rotated by a phonic motor which is driven from

the synchronizer of the A cable and the phase position of the brushes is adjusted so that the signal elements derived from the dot and dash repeating relays are half an element out of phase with the signals from the dot and dash relays operated by the signals from station A. This is illustrated in

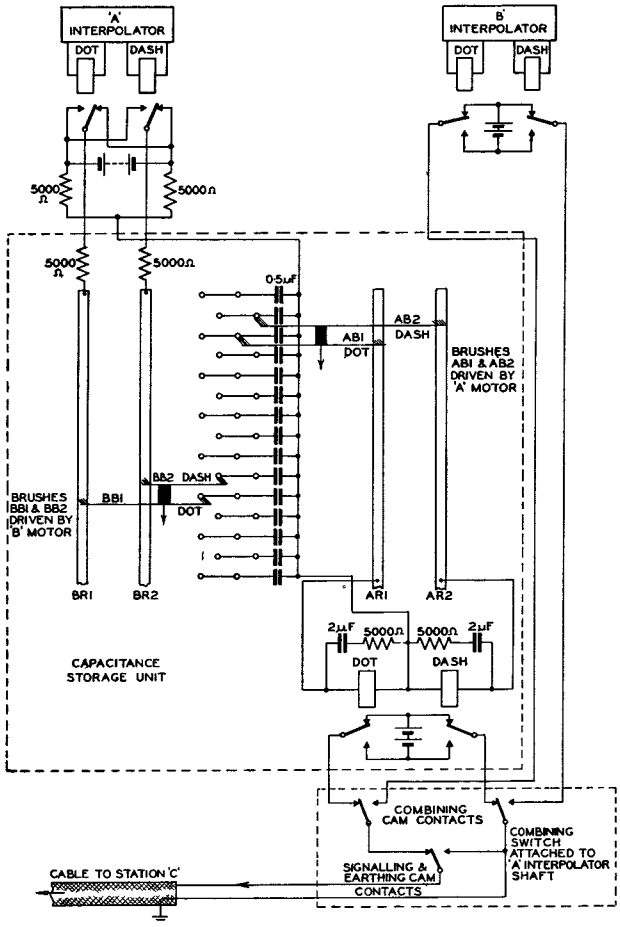


FIG. 17.40. SCHEMATIC CIRCUIT ARRANGEMENT OF HIGGITT CAPACITOR STORAGE SYSTEM

Fig. 17.41 which also shows the relative timing of the multiplex combining cam contacts and the signalling and earthing cam contacts whose function will now be described.

In order to combine the signals from stations A and B for transmission to station C, it is necessary to connect the cable alternately for the transmission of a signal element from A and then for the transmission of a signal element from B. This is done by means of the multiplex combining switch which is incorporated in the retransmitting interpolator of the unstored cable A. Fig. 17.40 indicates the schematic circuit connexions. The switch comprises three contact blades, with associated pairs of contacts, operated by three cams. Two of these cams control the reversing contact blades whose function is to switch the fast cable to station C, alternately to the dot and dash relays of the unstored cable A and the output relays of the stored cable B. The third cam operates a contact blade which controls the duration and earthing period of the aggregate signal elements retransmitted to station C.

The blades associated with the combining cam contacts are operated alternately to their side contacts in the manner indicated in Fig. 17.41. From this it will be seen that the two blades make contact with the output relays of the stored cable B for the centre 50 per cent of a signal element and then are switched to make contact with the output of the dot and dash relays of cable A for the centre 50 per cent of a signal element from station A.

The cam-shaft of the multiplex combining switch is coupled to the shaft of the interpolator of the unstored channel A; thus the signalling speed of the unstored channel controls the aggregate signalling speed which is therefore twice that of the unstored channel.

The blade controlled by the signalling and earthing cam determines the duration of the individual signal elements in the aggregate signals and applies the requisite earthing period. Fig. 17.41 shows typical aggregate signals resulting from a series of dots in channel A and channel B.

The aggregate signals received at C from A and B may be automatically regenerated and retransmitted to another station, or they may be split up into their respective sub-channels. The latter operation is performed by a simple arrangement employing a phonic motor driven cam-shaft which operates contact blades in correct timed sequence to split up the incoming combined signals to their respective channels. When split up, the signals operate locking relays which in turn pass the signals to their respective receiving perforators or direct printers.

The converse of this process is necessary at station C when it is desired to transmit combined signals over the cable to X where they are separated to operate cables A and B. The alternation of the signals from the A and B transmitters at station C presents no problem, since both the transmitters and the cam-operated changeover switch are driven from the clock-controlled reed at C. The signals arriving at X are similarly distributed into the cables to A and B by a cam-operated switch driven by the synchronizer.

The foregoing description relates to the plan

most generally adopted in which the two slow cables are worked at equal speeds. It is, however, immaterial whether the speeds of the two cables to be combined are, within limits, different from each other, but the sum of the two must very closely equal the speed of the cable into which the combined signals are retransmitted. The arrangements are a little more complex since it is necessary to store the signals from both channels. If the ratio of the speeds of two cables A and B are as 3:2, then the signals are transmitted in the following sequence $ABAABABAABAB$ etc. It will also be clear that the speeds must bear a fairly simple integral ratio to each other in order to avoid undue complication.

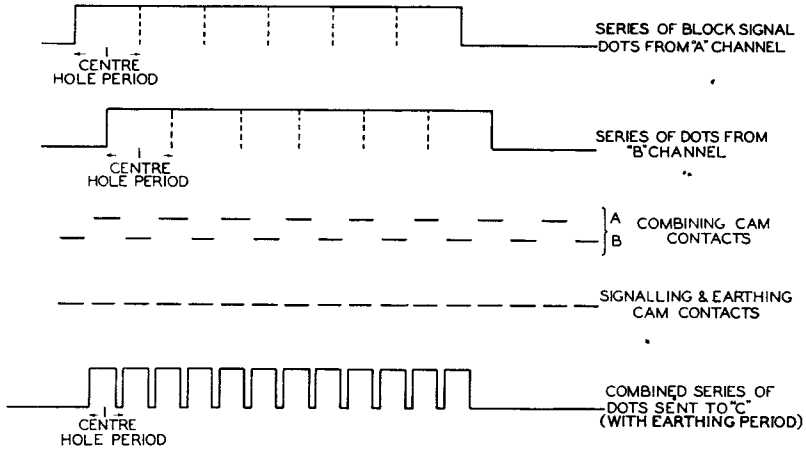


FIG. 17.41. TIMING ARRANGEMENTS EMPLOYED FOR CHANNEL COMBINING IN HIGGITT CAPACITOR STORAGE SYSTEM

Synchronous Five-unit Code Systems

The relative advantages of cable-code and five-unit code have been discussed earlier in this Chapter and it has been explained why the increasing use of five-unit start-stop systems for land-line circuits has given rise to a desire to standardize also the use of five-unit code for submarine circuits. However, whereas land-line circuits employ five-unit start-stop signalling, submarine telegraph cables usually employ synchronous signalling, in order to make more efficient use of the restricted band-width of the cable. When submarine cables are relatively short, e.g. U.K.–Europe, it has been the practice for many years to employ a common cable for both telephony and telegraphy and the telegraph circuits are provided by means of 18- or 24-circuit M.C.V.F. telegraph systems operating over carrier telephone channels. In such cases, the need for economy in the utilization of band-width is less acute than in the case of purely telegraph cables and this permits five-unit start-stop signalling to be employed.

Until recent years the provision of long distance submarine telephone cables has not been practicable owing to excessive attenuation of the higher frequency currents which would occur. However, the advent of the deep-sea type of submerged telephone repeater now permits wide-band submarine telephone cables to be laid which will carry several 12-channel groups of telephone circuits. The operation of M.C.V.F. telegraph systems over long distance submarine telephone cables has thus become a practicable possibility and it seems likely that the laying and operation of such cables for joint telephone and telegraph use will increase in the future and slowly supplant the use of the present purely telegraph cables. The use of start-stop signalling may then be extended even to long submarine telegraph circuits, so avoiding the need for the specialized techniques which are at present involved in interconnecting synchronous and start-stop circuits. The economic advantage of synchronous working is, however, so important in the case of long circuits that synchronous systems may be expected to play an important part in submarine cable telegraphy for many years. At the present time, when the majority of long submarine circuits are operated over purely telegraph cables of restricted band-width, the use of five-unit synchronous systems is essential and they have been in extensive use for many years.

One of the largest users of five-unit synchronous systems is the Western Union Telegraph Co., which operates a number of cables across the

Atlantic. One of their later cables, which was laid in 1926, is continuously loaded with permalloy tape; it has an inductance of 85 mH/n.m., a conductor resistance of 2·11 Ω/n.m. and a capacitance of 0·36 μF/n.m. The dielectric is gutta percha. This cable is capable of operation at a signalling speed of approximately 200 bauds and is used to provide eight unidirectional multiplex channels, each channel being operated at a speed of 300 characters per minute, i.e. 25 bauds. The earlier cables

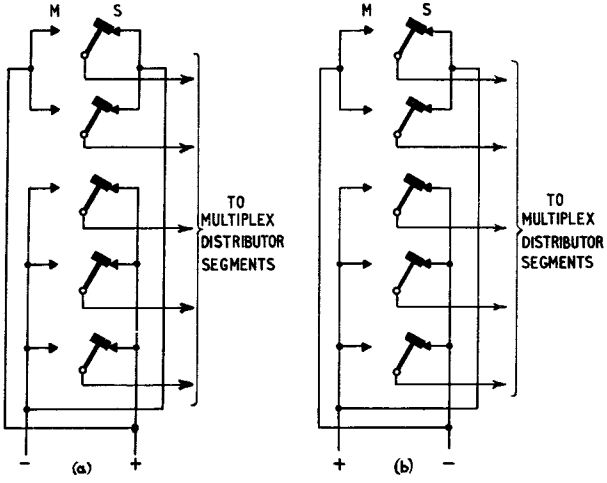


FIG. 17.42. 5-UNIT MULTIPLEX WORKING SIGNALLING ARRANGEMENTS ON CHANNEL TRANSMITTERS

are unloaded and therefore of lower signalling speed, although recent developments in the use of submerged telegraph repeaters at the receiving end of such cables has enabled considerably higher signalling speed to be obtained, e.g. the first repeater fitted by Western Union in an unloaded trans-Atlantic cable enabled the signalling speed to be increased from 300 to 1,000 characters per minute, i.e. from 25 to 83 bauds.

The Western Union Telegraph Co., has sufficient cables to enable some to be worked East to West and others West to East; this avoids the need for duplex working and the consequent complications and difficulties which result from duplex balances. Furthermore, simplex operation is essential for the use of submerged telegraph repeaters. In general, the manner in which a cable is operated, i.e. simplex or duplex, and the number of channels, depends upon the traffic requirements in relation to the number of cables available on a route and their signalling speed. Simplex working imposes less onerous technical conditions but, as already explained, the use of duplex working is often essential, e.g. when only one cable exists on a route and there is a need to transmit traffic in both directions simultaneously. The Western Union Telegraph Co., for example, have standardized the use of four, six and eight-channel five-unit multiplex systems operating at a channel speed of 300 letters per minute or thereabouts. In general, the aim is to derive the maximum traffic carrying capacity and the number of channels operated depends upon the cable characteristics. It is usually arranged that the channel speed is about 250–300 letters per minute as this corresponds closely to the working speed of one operator.

Speed and Phase Control. The basic principles involved in the operation of modern five-unit synchronous systems have already been described and have much in common with the original Baudot system. As already explained, however, more refined methods of speed and phase control are employed to maintain synchronism between the transmitting and receiving distributors. The speed of the distributors at each station is controlled in the first place by a very accurate source of frequency, e.g. a valve maintained tuning fork, and any small discrepancy in synchronism is automatically corrected at the receiving station by means of the received signals. If the speed of the receiving distributor is fast compared with the received signal then either its brush arms are retarded or the rate of vibration of its tuning fork is reduced by magnetic control; conversely if the receiver is slow its brush arms are advanced or the speed of the tuning fork is increased. These methods avoid the need for special speed correction signals and give a continuous and refined control of synchronism.

Signalling Methods. The signals transmitted into a cable from a multiplex distributor are double-current signals with an earthing period of 25–40 per cent for the purpose of curbing. The advantages of earthing have already been discussed earlier in this chapter under "Signal Curbing."

In order to reduce "zero wander" during signalling and idle periods it is arranged that the polarities employed for marking and spacing are reversed on alternate channels and also between the first two and the last three elements of the five-unit code. Fig. 17.42 illustrates the principle employed. Each channel is equipped with a five-unit step-by-step Western Electric or Murray type automatic transmitter (see Chapter 2) and the transmitter contacts are wired as shown in Fig. 17.42 (*a*) and Fig. 17.42 (*b*) for alternate channels. Thus a continuous marking signal in channel one results in the transmission of two elements of positive polarity and three elements of negative polarity, whilst a continuous marking

signal in channel two results in the transmission of two elements of negative polarity and three elements of positive polarity. The distributor automatically inserts the required earthing periods, as will be described later. It will be observed that not only does the foregoing arrangement reduce the risk of sending to line long sequences of polarities of the same sign, with the attendant disadvantages from the point of view of received signal shape, but it also ensures a sequence of reversals of signalling polarity to maintain synchronism during continuous marking or spacing on all channels.

The Transmitting Distributor. Fig. 17.43 indicates schematically the manner in which a four-channel transmitting distributor is connected to the submarine cable and to the individual five-unit automatic transmitters. The cable is connected to the continuous ring (2) via a signal shaping network whilst the channel transmitters are connected to the segments of ring (1), segments $A1$, $A2$, . . . $A5$ corresponding to the five-code elements of channel 1. The transmitters of the other channels are similarly connected to other segments on ring (1). It will be observed that the code segments of ring (1) are separated by smaller segments corresponding to the earth curbing segments on ring (3). The distributor segments are stationary, whilst a set of interconnected brushes, mounted on brush arms, are rotated synchronously over rings (1), (2) and (3), so connecting the cable successively to the code segments and earthing segments of the channels. The size of the distributor segments is cut to give the appropriate percentage earthing period for the cable concerned. The distributor brushes are driven through gearing either by a powerful phonic motor, or by a d.c. motor coupled to a phonic motor so that the latter exercises control over the synchronous running speed. In both cases the phonic motor is driven from the output of a tuning fork or equivalent supply. A heavy flywheel is fitted to the distributor shaft to minimize hunting.

Distributor rings (4) and (5), with their associated brushes, control the transmission of a local pulse to each channel transmitter in turn, which causes the transmitter to step the perforated tape one centre hole in readiness for transmission of the next character. Thus when the brushes sweep over segments $A1$ . . . $A5$, double-current five-unit code signals are transmitted into the cable and immediately afterwards rings (4) and (5) cause a local pulse to be transmitted, via segment $A6$, to the stepping magnet of the transmitter of channel 1. The operation of the stepping magnet performs the following functions: firstly, the code peckers are withdrawn from the tape; secondly, the tape is stepped one centre hole, and finally, the code peckers are released so that they are free to rise and examine the perforations in the tape and the resulting movement of each pecker controls the setting of a transmitter tongue to marking or spacing (see Chapter 2.)

The Receiving Distributor. The manner in which

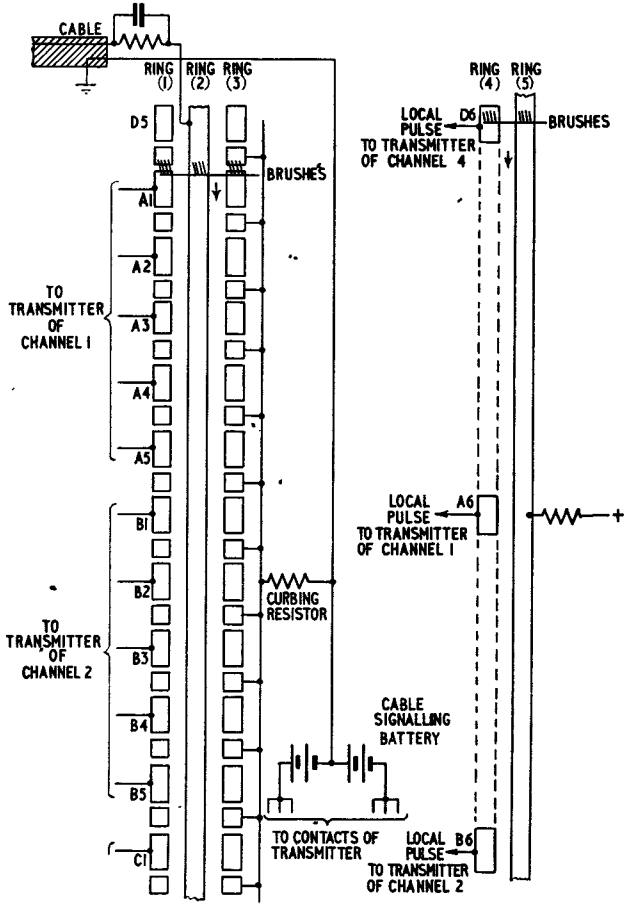


FIG. 17.43. SCHEMATIC CONNEXIONS OF 5-UNIT MULTIPLEX TRANSMITTER DISTRIBUTOR

the received signals from the cable are amplified by a signal shaping valve amplifier has already been described earlier in this chapter. The signals, after amplification, operate a line relay which repeats double-current signals to solid ring (1) of the receiving multiplex distributor as illustrated in Fig. 17.44.

The selection of a character in the receiving instrument, i.e. printer or reperforator, is controlled by the operation of five non-polarized electromagnets—each electromagnet corresponding

to one unit of the five-unit code. These electromagnets are connected to successive segments on ring (2) of the receiving distributor; the length of each segment being restricted to correspond to the middle portion only of the signal elements. This arrangement improves the margin of the receiver, as the selector electromagnets are then actuated by the undistorted portion of each signal element.

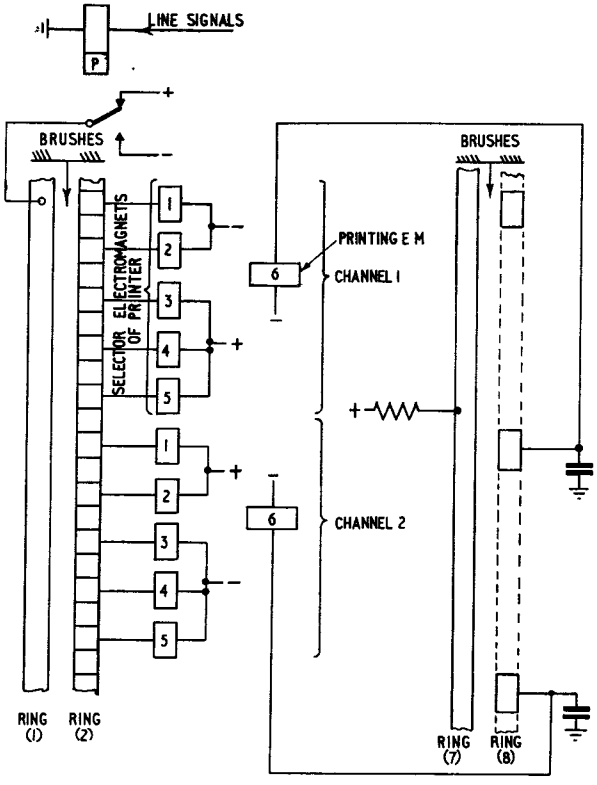


FIG. 17.44. SCHEMATIC CONNEXIONS OF 5-UNIT MULTIPLEX RECEIVING DISTRIBUTOR

Still greater margin can be secured by the use of signal regeneration and the principle of this method will be explained later.

The selector electromagnets are each connected to a battery supply, the polarity for the first and second elements being the reverse of that employed for the third, fourth, and fifth elements. Furthermore, the polarities are reversed on adjacent channels. This arrangement corresponds to that employed on the contacts of the channel automatic transmitter and necessitates the reception of a marking signal to cause a selector electromagnet to operate. When the distributor brushes sweep over the distributor rings in synchronism with the incoming signals the brushes complete a circuit from the tongue of the line relay, via ring (1) and the segments of ring (2), to each of the selector electromagnets of the printer in turn. The five electromagnets are therefore actuated momentarily in accordance with the five-unit code received, and cause selecting bars to be set in readiness for selection and printing of the appropriate character. The printing cycle of the printer is controlled for each character by a sixth electromagnet in the printer which is actuated from a pulse derived from distributor rings (7) and (8). After the character is printed, a cam in the printer resets the selecting mechanism in readiness for reception of the next five-unit code. The electromagnet which controls the printing cycle is connected to a segment on ring (8) and the distributor brush connects this segment to positive battery via ring (7) immediately after the five printer code electromagnets have been operated. Fuller details of the principles of operation of typical multiplex printers are given in Chapter 2.

Synchronization. The principle of the method employed for maintaining the multiplex receiving distributor in synchronism with the transmitting distributor is shown schematically in Fig. 17.45. Two rings $R1$ and $R2$ on the multiplex receiving distributor faceplate, in conjunction with a corrector relay, which is operated by the received line signals, are used to control the current in an electromagnet associated with the tuning fork which drives the receiving distributor. The magnetic field of the electromagnet acting upon the tines of the tuning fork affects the damping action and thus enables the frequency of the fork, and hence the speed of the receiving multiplex distributor, to be varied sufficiently to correct the small discrepancies in speed, and hence of synchronism, between the transmitting and receiving distributors.

The action is as follows. The alternate segments of $R2$ are connected to positive and negative battery and thus apply an alternating voltage of rectangular waveform to the solid ring $R1$ as the distributor brushes rotate. This results in the production of an alternating potential of triangular waveform at the spacing contact S of the corrector relay which is impressed upon capacitor C when the tongue of the corrector relay is on its spacing contact S, thus charging C. When the corrector relay is operated to its marking contact M by the received line signals, the potential on capacitor C is applied to the input of the fork control amplifier F. This potential is zero when the receiving distributor is in phase with the received signals but is positive or negative according to the direction of phase error, when there is an out-of-phase condition—see Fig. 17.45. The output of F controls

the current in the fork damping coil D. Positive feedback is applied, as shown, tending to maintain the coil current at the level set by the last pulse from capacitor C. Thus the speed of the distributor is increased, or decreased, to correct the phase error.

Correction of phase difference in the foregoing method, i.e. by means of speed change, necessarily involves repeated over-correction. The magnitude of this effect in the system described is, however, extremely small and the deviation from true synchronism is less than that attainable by electro-mechanical ("step-the-hands") methods whereby automatic adjustment is made in the position of the face-plate brushes.

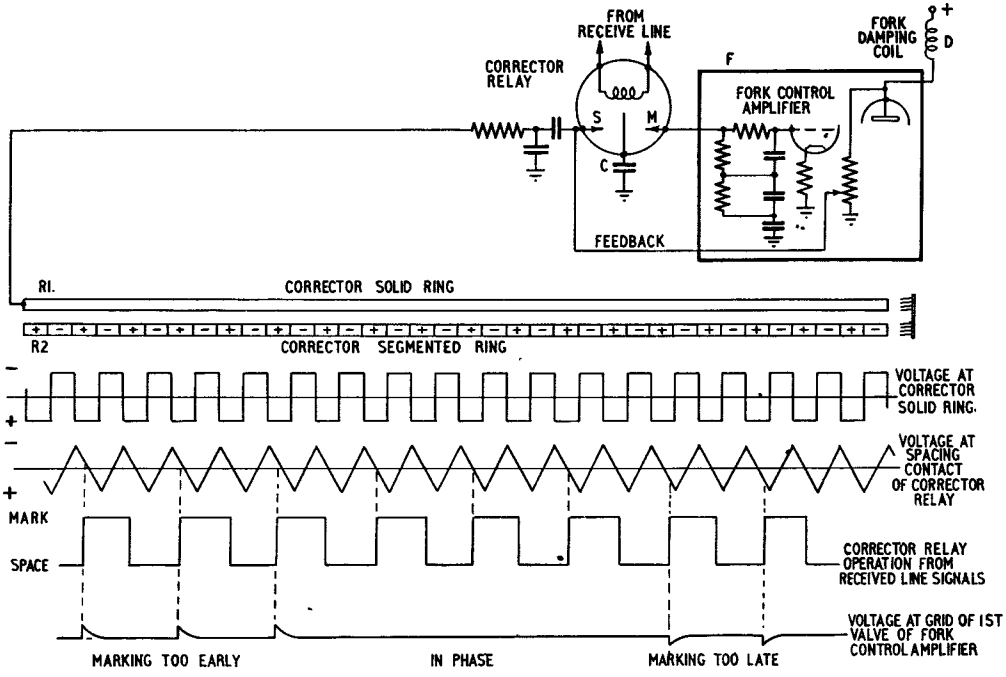


FIG. 17.45. PRINCIPLE OF SYNCHRONIZATION EMPLOYED IN 5-UNIT MULTIPLEX SYSTEM

Synchronous Gulstad Reception

It has already been explained how distortion occurs in the transmission of telegraph signals and the measures taken to improve the wave-form of the received signals. In long submarine cables using five-unit double-current signalling a considerable increase of speed can be obtained by employing the method known as "Synchronous Gulstad Working."

The principle of Gulstad operation of a relay has been described in Chapter 4, and the special adaptation of this principle for synchronous Gulstad submarine cable working will now be described. Briefly the method consists of using the rotating receiving distributor, which is kept in synchronism with the received signals, to control the operation of local windings of a receiving relay. Thus, when the relay is not controlled by signals from the cable it vibrates synchronously at a rate corresponding to the maximum signalling speed, i.e. signal reversals. Fig. 17.46 illustrates the circuit principles employed.

The distributor D is divided into a number of segments each of which corresponds to half a unit signal element. Alternate segments are interconnected and are used to control the operation of the line relay LR and a vibrating relay VR. The line winding of relay LR is under control of the line signals and relay LR controls the operation of the repeating relay RR. The distributor is maintained in synchronism with the received line signals and the brushes B therefore traverse one pair of segments, numbered 1 and 2, during one signal element. Considering the action when no line signals are being received, then it will be seen that with the brushes B on an odd numbered segment and relay LR at marking, a circuit is completed from positive battery via the marking contact and tongue of LR, one coil of relay VR, $R5$, segment 1 of D, brushes B, and the solid ring of the distributor, to negative battery. Relay VR is consequently operated to spacing. When the brushes B bridge an even

numbered segment, a circuit is completed from positive battery via the spacing contact and tongue of relay VR, local winding of LR, $R4$, $R6$, segment 2 of D, brushes B and distributor solid ring, to negative battery. Consequently relay LR is operated to spacing. This in turn causes relay VR to operate to marking when brushes B bridge the next segment 1.

A reciprocal action between relays LR and VR thus takes place, since when brush B is on an odd numbered segment, relay VR is set by relay LR, and when B is on an even numbered segment relay LR is set by VR.

The tongue of LR controls the operation of the repeating relay RR; consequently under the conditions described it will be seen that in the absence of line signals, relay RR will be vibrated by LR and caused to retransmit signal reversals in conformity with the speed of signal reversals from the distant transmitter.

Fig. 17.47 illustrates the action graphically and shows the current-time diagram for relays LR, VR

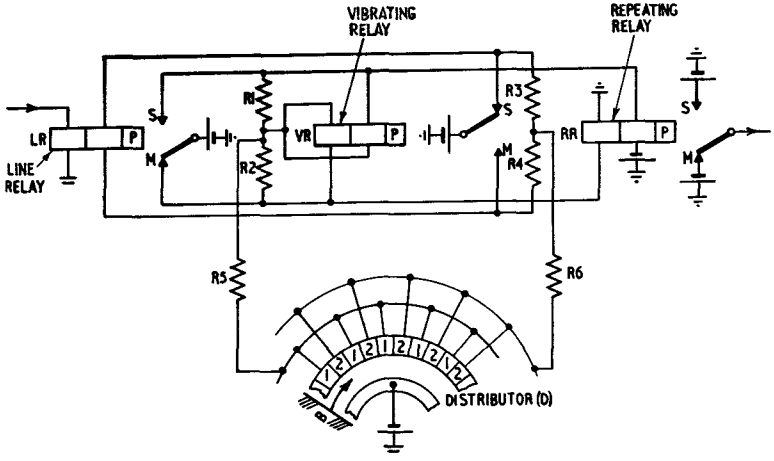


Fig. 17.46. Principle of Synchronous Gulstad Reception in 5-Unit Multiplex System

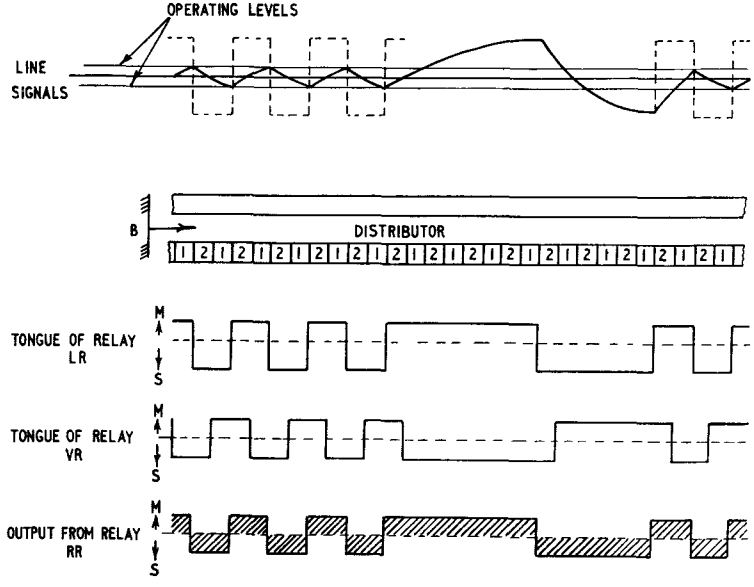


Fig. 17.47. Graphical Representation of Action of Synchronous Gulstad Receiver in 5-Unit Multiplex System

and RR when line signals are being received. The dotted reversals shown in the line signals indicate that these signals as received are very attenuated and almost fully suppressed by the cable, their amplitude, as shown by the full lines, is below the operating level of the receiving relay. Such signals are however automatically inserted in the output from relay RR by the Gulstad action. Signals having a duration greater than one unit element cause the received current in the line coil of relay LR to build-up to a magnitude which is sufficient to exercise an over-riding control of the operation of the relay and so maintain LR, and hence RR, operated for the appropriate signal period. When the next signal transition occurs, and the current falls, the Gulstad action resumes control until overridden by a signal having a duration longer than a unit signal element.

The use of synchronous Gulstad working enables much higher speeds of signalling to be operated than would otherwise be possible. The signal distortion present in the output of the repeating relay is however not negligible, due to the effects of transit time, relay bounce and bias. Still further improvements can be obtained by the use of signal regeneration.

Signal Regeneration

The working margin of multiplex channels can be improved by regenerating the signals at the receiving end before they are employed to operate the printer electromagnets. The principle employed for this purpose is illustrated in Fig. 17.48.

Relay A is operated by the received line signals and its tongue TA repeats the distorted signals to the operate winding of the selector relay B via segments $a1$ or $a2$, etc., and the brushes and solid ring of the distributor. The distributor brushes are rotated in synchronism with the incoming signals and the length of segments $a1$, $a2$, etc., correspond to the central and therefore undistorted portion of each signal element. When relay B is operated by a signal element it is immediately locked by the current which flows from its tongue TB through its local winding and 400 Ω resistor. The required signal pulse corresponding to the received signal is therefore transmitted from TB through the 10 Ω resistor and printer electromagnet when the distributor brushes move to the next segment, i.e. $b1$ or $b2$, etc. Thus the relay B is set successively in accordance with the signal elements via segments $a1$, $a2$, etc., and the printer electromagnets are correspondingly energized via segments $b1$, $b2$, etc.; the printer electromagnets are only operated when marking signals are received.

When a long submarine circuit passes through intermediate stations it is necessary to employ signal regeneration at one or more of these, depending upon the amount of signal distortion in each section. For this purpose a regenerative repeater is employed and the equipment used for multiplex working has many of the features of both a receiving and transmitting multiplex terminal equipment.

As already explained a regenerative repeater is a

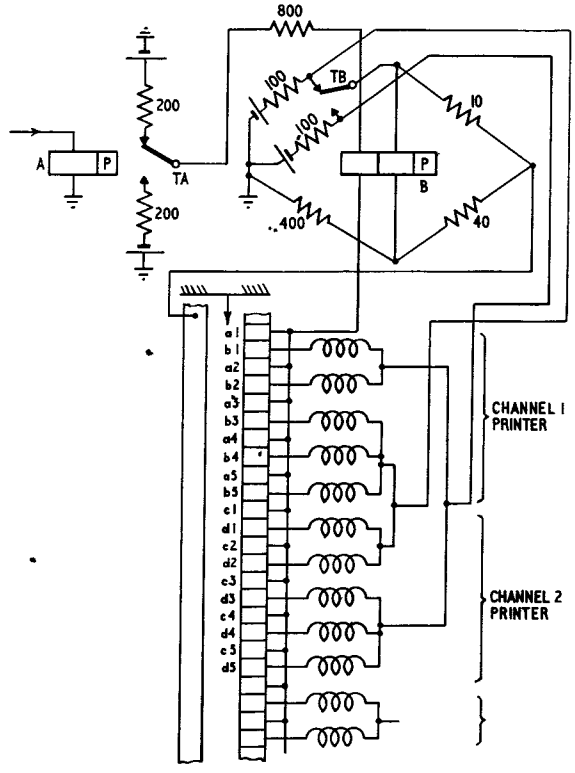


FIG. 17.48. PRINCIPLE OF REGENERATION OF RECEIVED SIGNALS IN A 5-UNIT MULTIPLEX SYSTEM

device which receives distorted signals and retransmits them free from distortion. To attain this end it is essential that the repeating relay must be set to the desired contact (marking or spacing) in advance of the instant of commencement of the retransmitted signal, so that any effects of relay bounce, etc., can be eliminated.

The principle of operation of a typical regenerative repeater is illustrated in Fig. 17.49. The line signals operate the receiving relay LR whose tongue repeats the signals as double-current signals via the solid ring of receiving distributor RD, brushes $B1$ and shortened distributor segments a, b, a, b, . . . to relays A and B alternately. The brushes $B1$ are rotated in synchronism with the received signals

and segments a and b correspond to the centre only of each unit signal element. Thus the receiving distributor in effect samples the polarity of the received signals for these periods only and results in a brief current pulse being transmitted alternately through relays A and B, causing them to be operated in accordance with the line signalling polarity at the instant of sampling.

The tongue of each relay is connected to a high resistance locking circuit via a bias winding on the

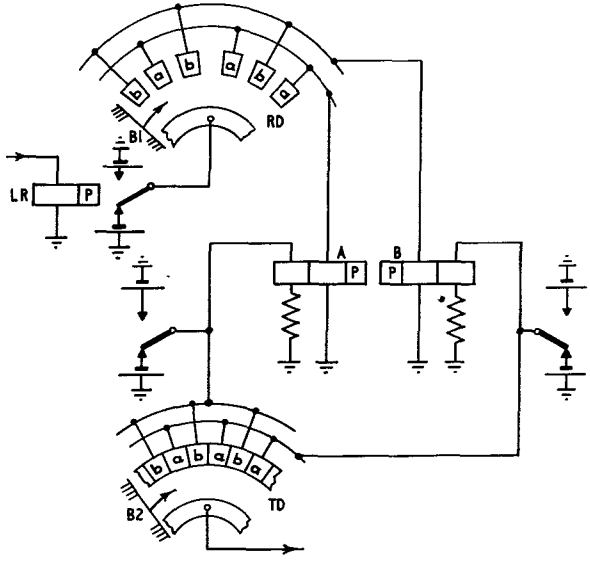


FIG. 17.49. PRINCIPLE OF REGENERATIVE REPEATER FOR 5-UNIT MULTIPLEX SYSTEM

relay. The relay therefore remains set after cessation of the operating pulse until its setting is reversed by a signal pulse of opposite polarity. Brushes $B1$ and $B2$ sweep over their respective a and b segments simultaneously; hence relay A is set on an a segment and the regenerated signal corresponding to this element is retransmitted from the transmitting distributor via the succeeding b segment on TD. The retransmitted signal commences immediately brush $B2$ starts to sweep over the b segment of TD, i.e. half a unit signal element later. The segments on TD are of full-length, hence the regenerated signal elements are of correct duration, i.e. undistorted.

Fig. 17.50 illustrates the action graphically for typical line signals; the line signals from LR are shown distorted, the correct theoretical intervals being indicated by the dotted wave-form. The theoretical timing intervals will be seen to be restored in the regenerated aggregate signals shown at the bottom of Fig. 17.50 and it will be observed that the process of signal regeneration has caused the instants of modulation to occur one unit interval after the corresponding theoretical instants in the received signal. Signal regeneration is employed in five-unit synchronous systems at intermediate repeater stations on long cable chains and also in the receiving multiplex equipment at terminal stations.

Interconnexion of Multiplex Channels. It is sometimes necessary to interconnect channels in one multiplex system to those in another in order to make up through-circuits and fork-off circuits at intermediate multiplex terminals to other stations. For this purpose multiplex channel repeaters are employed.

The channel repeater, which is shown schematically in Fig. 17.51, connects a receiving channel of one multiplex circuit to a sending channel of another. Synchronism between the two multiplex circuits is not necessary but the speed of the sending, i.e. outgoing, channel must be higher than that of the receiving, i.e. incoming, channel.

Five-unit codes corresponding to the character combinations from the receiving distributor are set up alternately in two banks, No. 1 and No. 2, each of five polarized relays. The five-unit codes for the characters are retransmitted alternately from these banks to the sending distributor, means being provided to ensure that retransmission from a bank takes place after the relays have been properly operated by the character code impulses from the receiving distributor. When this condition is in danger of being upset, i.e. by reason of the higher speed of the sending distributor, alternation of the banks on the sending side only is interrupted once, whilst the repeater inserts a blank character, i.e. five spacing elements, on the sending channel. This re-establishes maximum storage in the repeater and alternate retransmission is resumed.

Alternate reception on the two banks is achieved by means of two receiving transfer relays, A and B, which are operated and released by local pulses on successive revolutions of the receiving distributor. Similarly, the relay contacts of the two banks are connected to the sending segments by sending transfer relays, $A1$ and $B1$, which are operated from the sending distributor. The condition of minimum permissible storage, which requires the momentary interruption of alternate retransmission and the insertion of a blank, is detected by a circuit shown schematically in Fig. 17.52, comprising contacts 1 of relays A and $A1$, auto-stop segment 6 on the local ring of the sending distributor, auto-stop relay AS, and line battery relay LB. Additional contacts (not shown) on

relay *LB* connect all relay contacts in both bank 1 and bank 2 to spacing battery when *LB* is operated.

Interconnexion of Multiplex and Start-stop Channels. It is sometimes necessary to connect a start-stop channel and a multiplex channel and this involves the use of special repeaters namely—

(*a*) A start-stop/multiplex repeater to convert received start-stop 7 or 7·5 unit signals into corresponding five-unit synchronous signals, and

(*b*) A multiplex/start-stop repeater to convert five-unit synchronous signals into corresponding 7 or 7·5 unit start-stop signals for reception by a teleprinter or reperforator.

The principles employed for these purposes will now be described.

Start-stop/Multiplex Repeater. Transmission from a start-stop channel into a multiplex channel necessitates elimination of the teleprinter start and stop signals at the multiplex terminal, together with some form of character storage at that point. Both requirements are satisfied by the use of a start-stop reperforator from which the tape passes into a five-unit transmitter connected to the multiplex sending channel. The reperforator and transmitter may be separate units, placed closely together to minimize the length of the tape loop between them. In this case the reperforator is arranged to feed-out blank tape automatically when reception from the start-stop circuit ceases, so that the last characters on the tape may pass through the multiplex transmitter. In recent years the Teletype Corporation of America has introduced an instrument which combines the functions of a reperforator and auto-transmitter in one compact machine which is

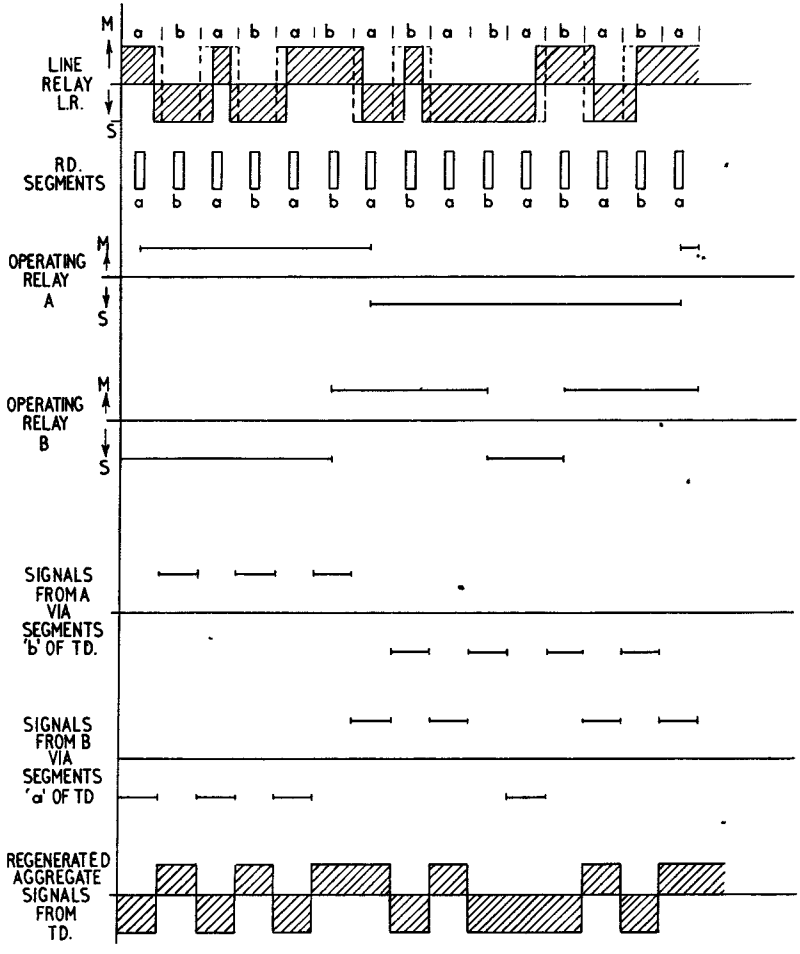


FIG. 17.50. GRAPHICAL REPRESENTATION OF ACTION OF REGENERATIVE REPEATER FOR 5-UNIT MULTIPLEX SYSTEM

capable of transmitting the last character received without the need for feeding-out blank tape. It incorporates a pivoted transmitter assembly which moves up the perforated tape at the end of a message to transmit to the multiplex channel the last character punched by the reperforator. This multiplex distributor and the tongues of these relays are connected, in sequence, to the five code segments of the start-stop distributor. The start-and-stop segments on the start-stop distributor are permanently connected, as required, to add the start-and-stop signals necessary for transmission

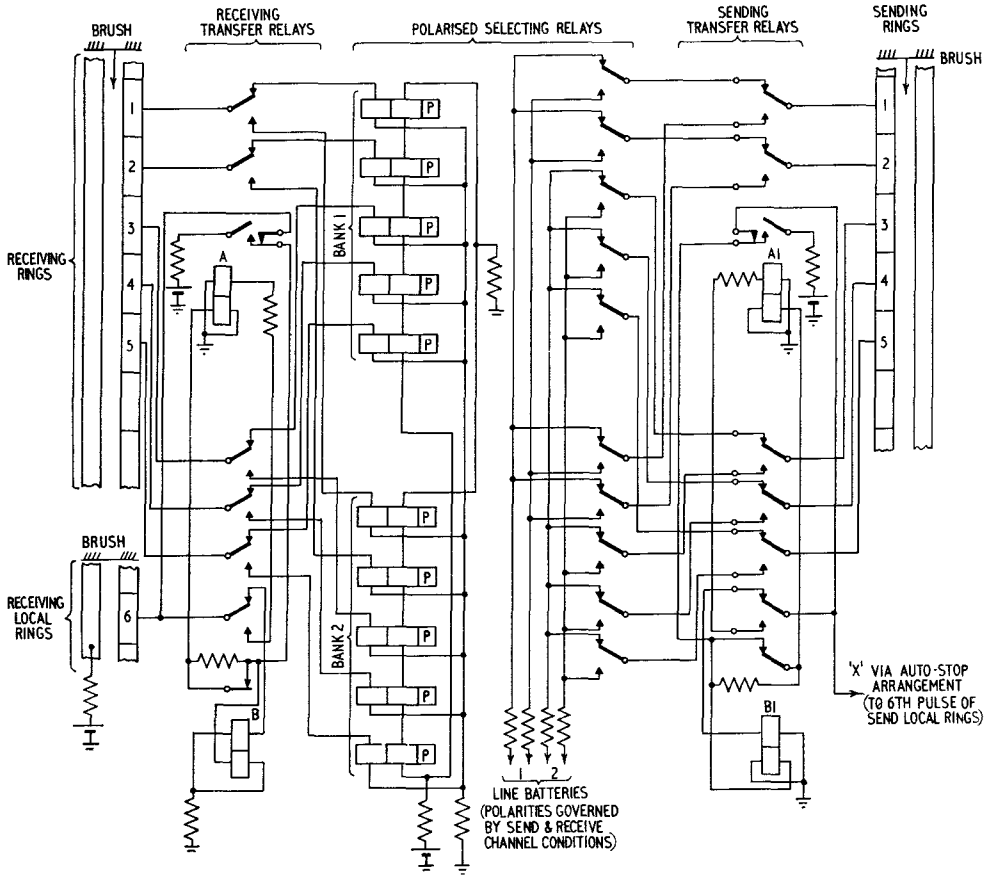


FIG. 17.51. PRINCIPLE OF CHANNEL REPEATER USED FOR INTERCONNEXION OF 5-UNIT MULTIPLEX CHANNELS

instrument, known as a FRXD Reperforator-Transmitter Distributor, is being increasingly used in up-to-date practice.

Multiplex/Start-stop Repeater. One method which may be employed for connecting a multiplex receiving channel to a receiving teleprinter circuit is by means of a bank of five polarized relays and a start-stop distributor. The principle of operation is as follows and is illustrated schematically in Fig. 17.53.

The five repeating relays $RR1$, . . . $RR5$ are operated in accordance with the five code elements of a character from the receiving segments of the over the teleprinter circuit. When the five code elements have been received on the relay bank, a sixth pulse is supplied from the local rings of the multiplex distributor to the start electromagnet ST which controls the release of the brush arm of the start-stop distributor. The start-stop brush arm is thereby released and makes one revolution and thus transmits in succession, the start signal, the five code elements and the stop signal of the teleprinter character to the teleprinter send relay TR. The rotation of the brush arm is arrested when it again reaches the stop segment and remains at rest on this segment until released by the next sixth

pulse. The contacts of relay TR are wired for double-current working and thus its tongue repeats double-current start-stop signals to the receiving teleprinter circuit.

The sixth pulse circuit to the start electromagnet ST is disconnected by a cut-off relay (not shown on Fig. 17.53) unless one or more of the repeating relays have been operated to their marking contacts; this prevents transmission of unwanted blank characters to the teleprinter when the multiplex channel is idle.

An alternative method of extending a receiving channel of a multiplex system to a start-stop circuit is illustrated schematically in Fig. 17.54. This method is to be preferred for simplicity and reliability of operation but necessitates the use of a fixed relationship between the speed of the synchronous system and that of the start-stop apparatus. Each of the five receiving segments of the multiplex faceplate (considering only one of the receiving channels) is connected to a selector relay, so that the five relays, i.e. $\frac{A}{2}$, $\frac{B}{2}$, $\frac{C}{2}$, $\frac{D}{2}$ and $\frac{E}{2}$ are operated in accordance with the incoming five-unit code. The tongues of the selector relays, i.e. $A2$, $B2$, $C2$, $D2$ and $E2$ are connected to the segments of another ring on the multiplex face-plate, called the teleprinter ring, and thence in sequence, through the revolving face-plate brushes to a teleprinter send relay $\frac{T}{1}$, the contacts of which are wired for double-current signalling, and its tongue is connected to the receiving teleprinter circuit. The teleprinter send segments are so positioned in relation to the multiplex receiving segments that all five elements of the character code are stored in the selector relays before transmission of the character to the start-stop circuit begins.

The teleprinter send ring includes a start signal segment, located immediately ahead of the first of the five-unit code segments, and a rest, i.e. stop segment, placed immediately behind the fifth code segment. The seven segments are so spaced around the ring that at the pre-arranged speed of revolution of the faceplate brushes, i.e. at the predetermined channel speed, the on-going teleprinter signals are of standard duration.

Each selector relay has two contacts namely a start contact, e.g. $A1$ and a code contact, e.g. $A2$. The five start contacts are connected in parallel and if any one of them is closed when the face-plate brush reaches the start signal segment the teleprinter send relay $\frac{T}{1}$ is operated to spacing and therefore a start signal is sent into the teleprinter line. When any of the start contacts of the selector relays are closed positive battery is connected to the five code contacts from the tongues of which the five code pulses, in accordance with the character received from the multiplex channel, are communicated in sequence to the teleprinter send relay as the brush passes in turn over the teleprinter send segments. The teleprinter send relay, which is non-polarized and has a marking bias, therefore repeats the start-stop signals for the

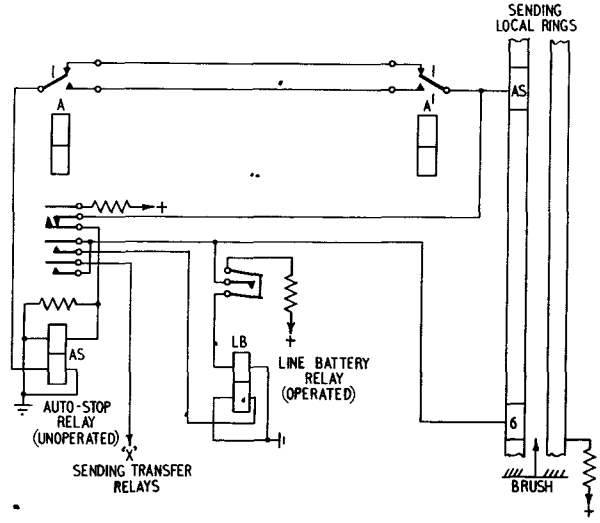


FIG. 17.52. AUTOMATIC "BLANK" SIGNAL INSERTION

character to the receiving teleprinter. The teleprinter send relay transmits a marking signal corresponding to the stop segment and remains in the rest position until reception of the next character from the synchronous channel causes transmission of a start signal. In practice electronic devices are often used instead of electromagnetic relays, with some advantage.

The Varioplex System

This ingenious system, which was developed by the Western Union Telegraph Co., enables a number of five-unit time-division multiplex channels to be employed to provide a much larger number of comparatively lightly loaded sub-channels, e.g. as many as 40 two-way point-to-point sub-channels can be operated over a two, three or four-channel send and receive multiplex system.

The sub-channels terminate at each end in sending and receiving teleprinters and although each sub-channel is continuously available for use whenever required, it is only actually connected to

the multiplex channels when traffic is being transmitted. When sub-channels are in use they are connected consecutively to the multiplex circuit, character by character, so that the line-time is shared equally between the sub-channels in use; no line-time is allotted to sub-channels which are idle. Two-way working is available on the sub-channels and the operation of a sub-channel in one direction is independent of that in the sub-channel in the reverse direction.

The varioplex system thus enables a multiplex circuit to be utilized very efficiently by a number of sending stations as the line time in each direction of transmission is shared equally between only those sub-channels requiring transmission at the same time. The success of the system relies upon the fact that the amount and incidence of traffic is different on the various sub-channels so that the number of sub-channels requiring to pass traffic in one direction at any one time is, on average, only a fraction of the number of sub-channels connected. Due regard has to be paid to the amount and incidence of traffic to be expected in individual sub-channels when determining the number of sub-channels permitted to be connected to a given multiplex system.

The varioplex system is employed by The Western Union Telegraph Co., on certain long distance land-line telegraph circuits and also over trans-Atlantic telegraph cables. The sub-channels may be leased to private subscribers for a charge which is based on the number of characters transmitted:

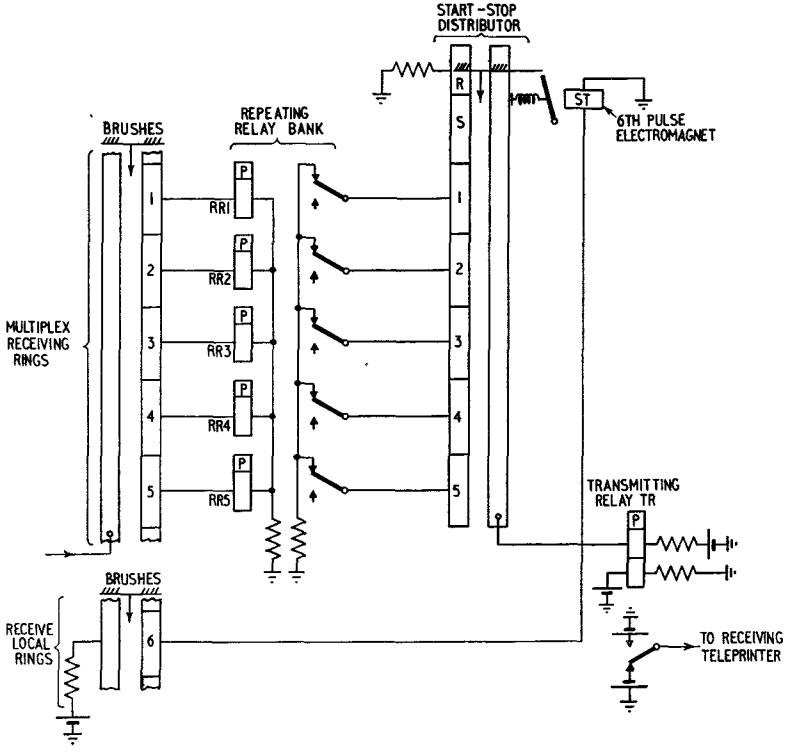


FIG. 17.53. PRINCIPLE OF 5-UNIT MULTIPLEX TO START-STOP SIGNAL REPEATER (METHOD 1)

The varioplex system is employed by The Western Union Telegraph Co., on certain long distance land-line telegraph circuits and also over trans-Atlantic telegraph cables. The sub-channels may be leased to private subscribers for a charge which is based on the number of characters transmitted: for this purpose meters are incorporated in the terminal equipment which record the number of characters sent in each sub-channel.

A detailed description of the varioplex system is beyond the scope of this book but it is of interest to indicate the general principles employed.

Principles of Operation. Varioplex terminal equipment consists essentially of three principal groups of apparatus *viz*—

1. (*a*) Circuits and equipment for receiving signals from the sending teleprinter of a sub-channel and recording them on a reperforator in the form of a perforated tape which is fed to a multiplex transmitter.

(*b*) Circuits for transmitting incoming signals to the receiving teleprinter.

(*c*) Facilities for monitoring sub-channels.

2. Circuits and equipment for connecting sub-channel transmitters to any of the multiplex channels of the system and for connecting multiplex channels at the receiving end through equipment which converts the five-unit signals into five-unit start-stop signals. If a four-channel multiplex system is used, the principal equipment consists of four sending and four receiving line-seizing relays per sub-channel at each terminal, and associated with each such group of relays is a control relay, the operation of which determines whether or not the sub-channel shall be connected to a multiplex channel.

3. Circuits and equipment for operating the control relays associated with each sub-channel group of line-seizing relays. This equipment consists essentially of rotary switches and relays which operate the control relay at the sending terminal and transmits signals over two of the multiplex channels to cause operation of the control relay at the receiving terminal, through a rotary switch and relay circuits.

When a message is transmitted from the teleprinter of a sub-channel, its signals operate a reperforator at the varioplex terminal station and so produces a perforated five-unit message tape. The tape is permanently looped to a multiplex transmitter which is controlled by an auto-stop switch. Automatic tape feed-out mechanism is provided at the reperforator so that those characters which have not been fed to the transmitter by following characters sent by the sub-channel operator may be stepped through the transmitter. This automatic feed-out action is timed to take place several seconds after the last character received, thus permitting short pauses in the transmission without its occurrence. The tape transmitter is provided with circuits which read the code perforations in the tape and determine whether a "blank" or a normal character (i.e. one having one or more marking elements) is over the code reading pins of the transmitter.

The transmitter is arranged so that it is caused to feed automatically blank characters which precede the sub-channel transmission without transmitting them to the multiplex circuit. When the first character of a message appears over the transmitter code pins the transmitter is stopped and automatically connected through line-seizing relays to a sending relay bank of a channel of the multiplex circuit. The operation of a control relay associated with each sub-channel group of line-seizing relays causes the appropriate one to operate. The control relay, in turn, is operated by the "cut-in" mechanism. The term "cut-in" denotes the connexion of a sub-channel to the multiplex circuit. The time required to connect a sub-channel to the multiplex circuit may vary from four to eight seconds after the first character is sent by the sub-channel teleprinter.

The operation of the cut-in mechanism transmits

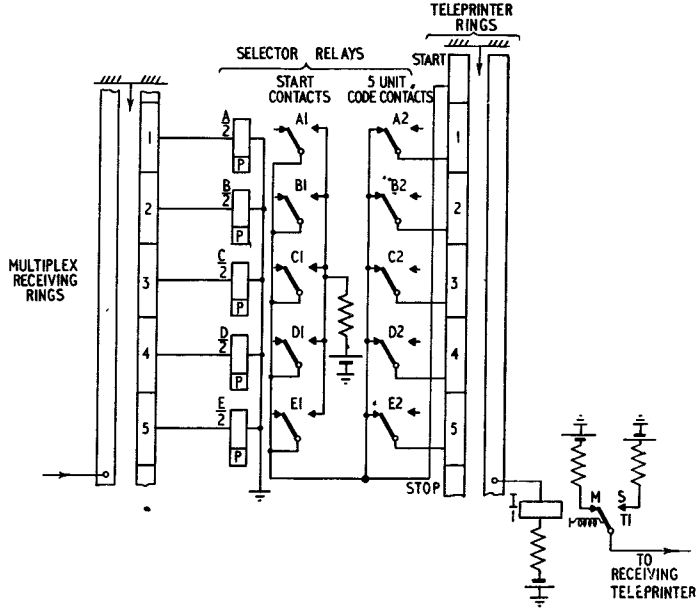


FIG. 17.54. PRINCIPLE OF 5-UNIT MULTIPLEX TO START-STOP SIGNAL REPEATER (METHOD 2)

signals over two of the multiplex channels which are read by the cut-in mechanism at the receiving end thus operating the appropriate control relay associated with the receiving line-seizing relays. When the sub-channel has been cut-in, the transmitter again operates and sends the characters perforated in the tape. The circuits of the line-seizing relays and control relay are such that they operate automatically to connect the proper sub-channel at each end of the system to the same channel of the multiplex circuit.

If only one sub-channel of a system is in operation it is connected to one of the multiplex channels. Similarly, if only two, three or four sub-channels are in operation each will be connected to a separate channel of the multiplex system—assuming it to be a four-channel system. However, when more than four sub-channels are cut-in they are connected to the multiplex channels character by character, in

consecutive order, so that each sub-channel in turn has an opportunity to transmit one character. This results in a varying speed of operation of the sub-channels depending upon the number of such sub-channels in use at any particular time. Thus, if the channel speed of a four-channel multiplex system is 66 w.p.m., then if four sub-channels are in use the speed of transmission of each will also be 66 w.p.m. If more than four sub-channels are in operation, then the speed of each sub-channel will be the total capacity of the multiplex channels, i.e. 4×66 w.p.m., divided by the number of sub-channels in operation, e.g. if 8 sub-channels were in use, the sub-channel speed would be 33 w.p.m. It should be noted that despite the foregoing limitation to the sub-channel transmission speed, the sending operator is not limited in the same way, as her signals are received and stored at the varioplex terminal on a reperforator.

As already mentioned, each multiplex transmitter is under the control not only of the character perforations over its code reading pins but also of an auto-stop. When the tape loop shortens, the auto-stop operates to feed out blank tape automatically and so passes the last character perforated in the tape through the transmitter. When blank characters pass through the transmitter, following the last perforated character in the tape, the cut-in mechanism is operated to disconnect the line-seizing relays from the multiplex circuit and to send signals over two of the multiplex channels to the receiving end, where they operate the control relays and disconnect the receiving line-seizing relays.

At the receiving end, incoming signals operate five polarized relays for each multiplex channel and the signals are stored temporarily on associated valve circuits which, operating in conjunction with a distributor, convert the signals into five unit start-stop signals for transmission to the receiving teleprinter on the sub-channel through contacts of the receiving line-seizing relays. Full monitoring facilities are provided on each sub-channel.

Numerous protective features are provided throughout the system to indicate failures of either equipment or line signals. The principal ones are associated with the cut-in signals as without such protective features it would be possible for line failures to cause improper connexion or disconnexion of a sub-channel, or sub-channels, at the receiving end. The method employed for this purpose consists of repeating the transmission of each cut-in signal with its polarity reversed and reading and comparing the two transmissions at the receiving end. If a disparity is revealed it results in the disconnexion of all sub-channels and operation of an alarm. The method is very effective in practice.

Comprehensive controls are also provided at each terminal to facilitate handling and maintenance of the equipment.

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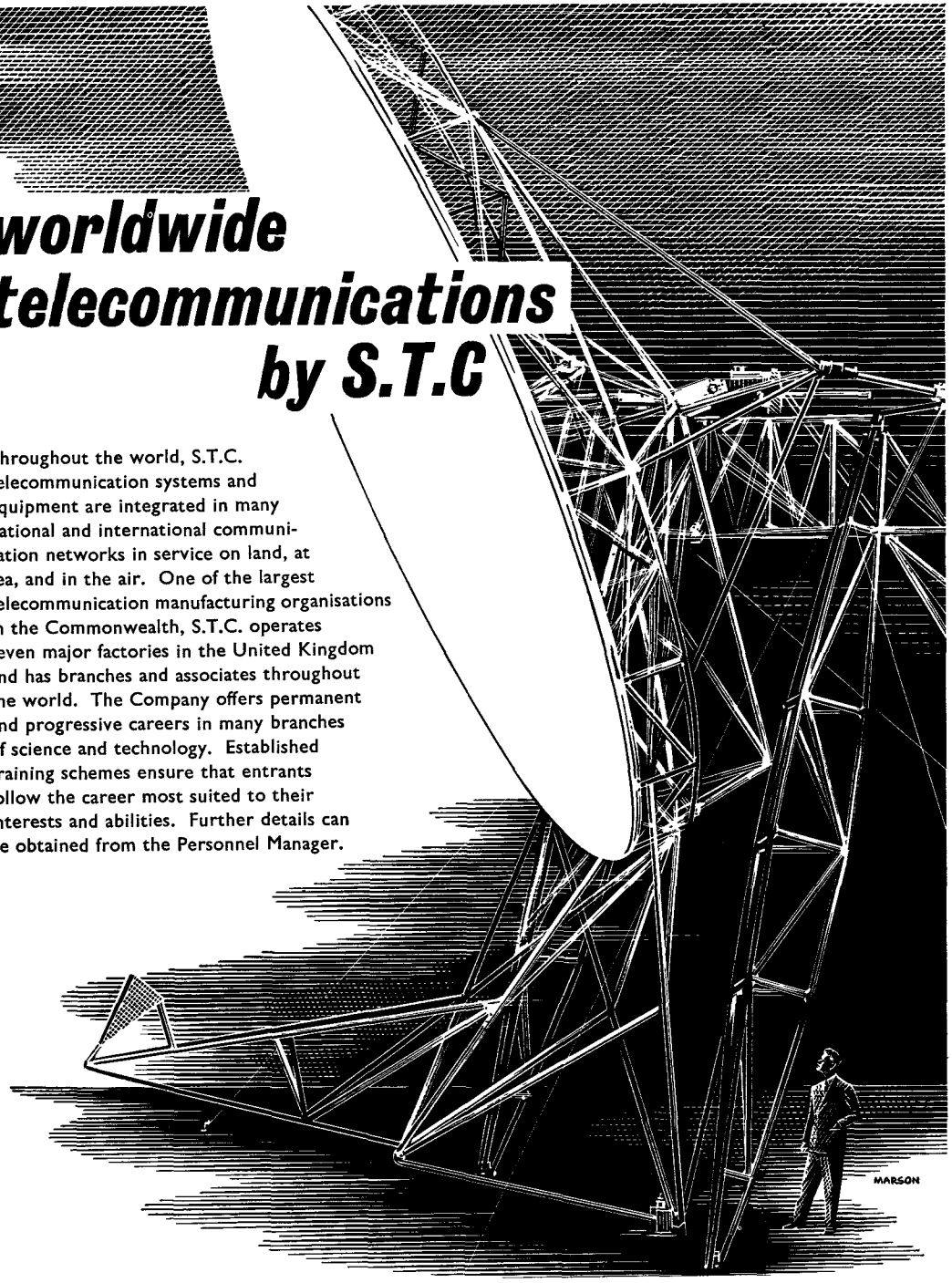
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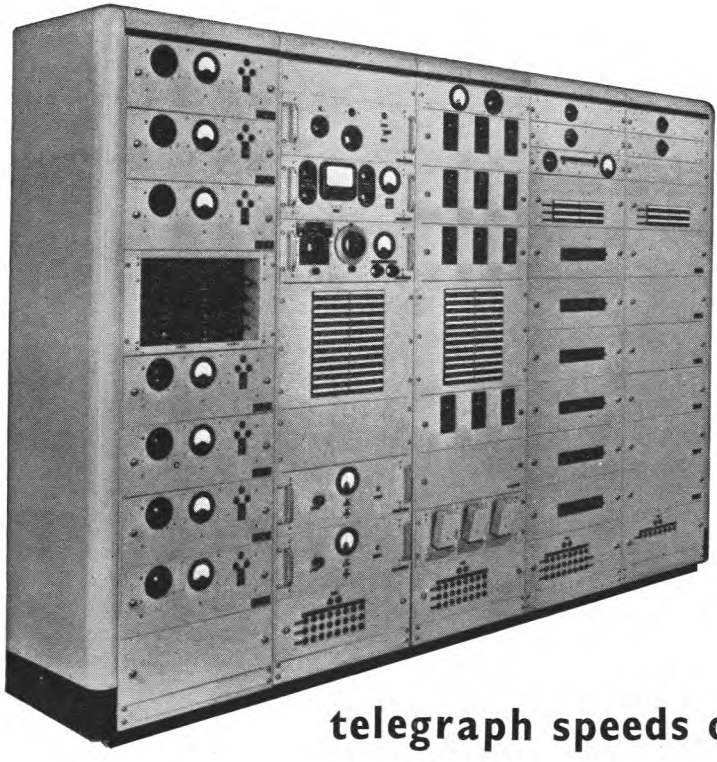
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telegraph speeds of 280 bauds

The overall performance of long distance radio link telegraph systems can, in many cases, be greatly improved by the introduction of Siemens Ediswan Frequency Modulated Voice Frequency Telegraph Equipment on the land line circuits feeding remotely located radio transmitters or receivers. This equipment provides six channels, five of which will each handle telegraph traffic at speeds up to 280 bauds and one for medium speed traffic up to 140 bauds.

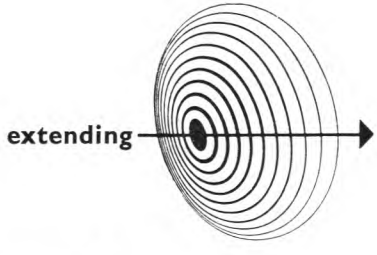
Developed by Cable & Wireless, this telegraph system is now in extensive use by the British Post Office and various overseas administrations.

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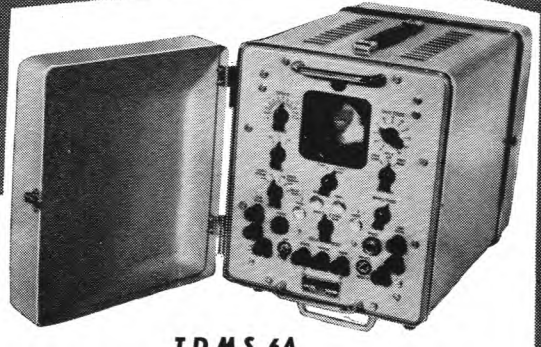
Distortion Detected – Transmission Perfected

The introduction of electronic techniques to the measurement and correction of telegraph distortion brings laboratory precision to the maintenance of modern line and radio telegraph circuits and all equipment, including teleprinters. The equipment described and illustrated on this page is representative of the contribution made by ATE to this field.



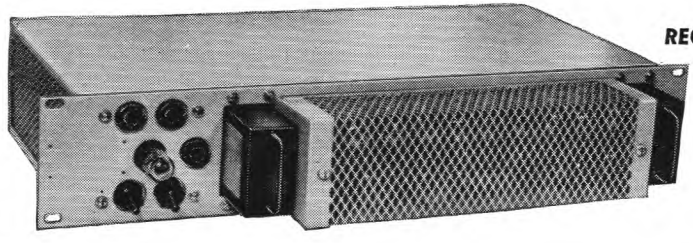
T.D.M.S. 5A

Sends an automatic test message, or characters, or reversals at any speed between 20-80 bauds with or without distortion. The CRO has a circular time base for distortion measurements on synchronous signals only, or relay adjustment. Weight 37 lb.



T.D.M.S. 6A

For distortion measurements on working circuits without interrupting service. Each element of a start-stop signal appears separately on the spiral time base display. Adjustable speeds from 20-80 bauds. Weight 33 lb. Higher speed versions can be supplied to order.



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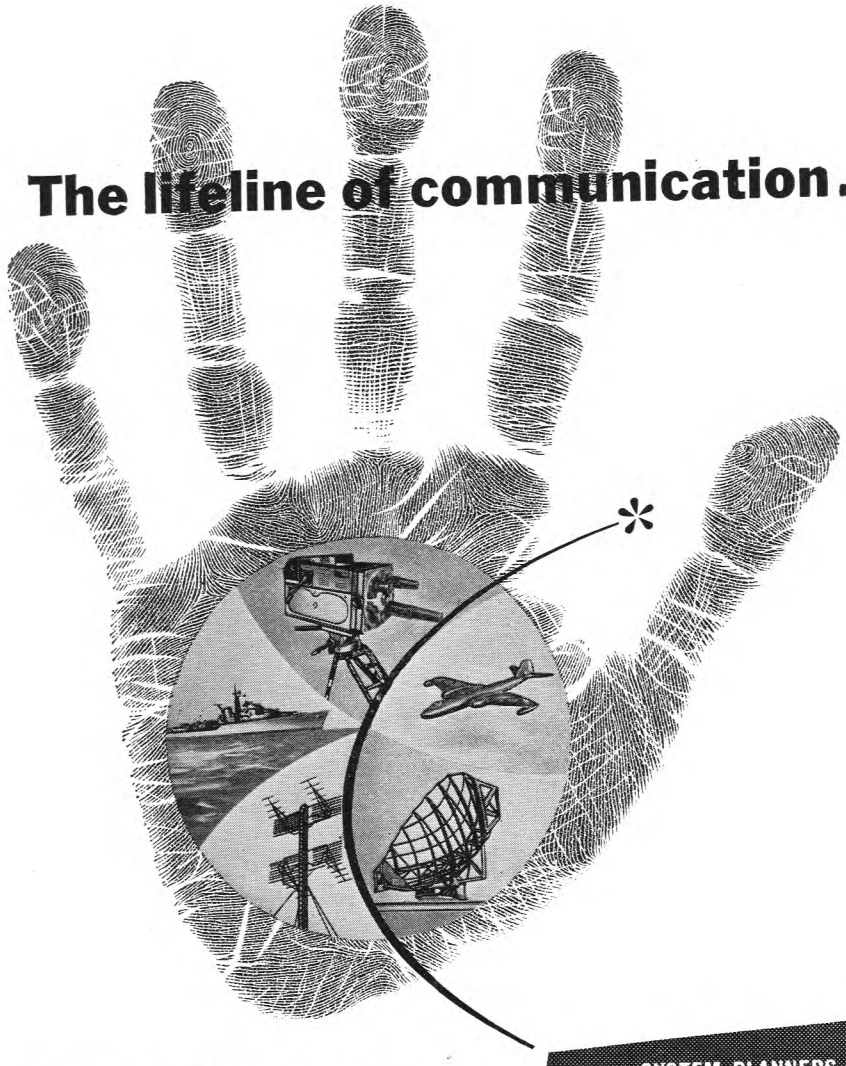
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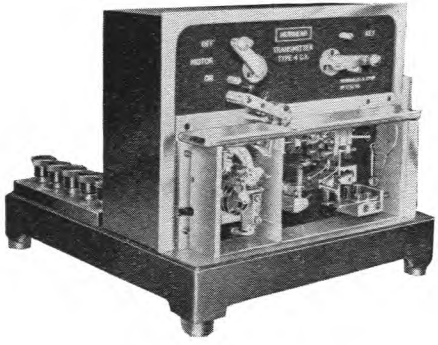
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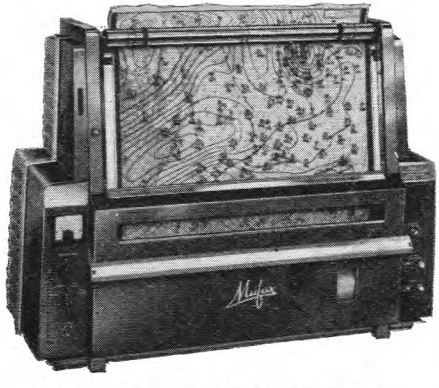
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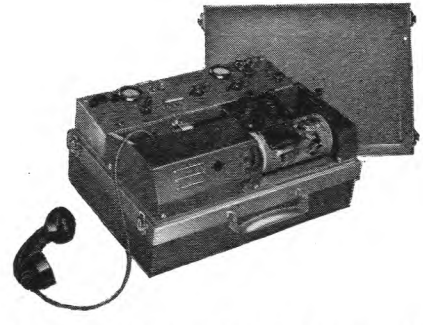
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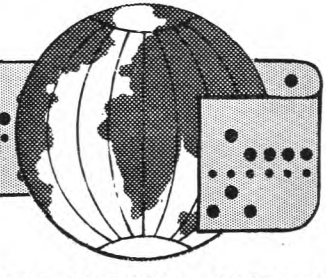
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