As you are now the owner of this document which should have come to you for free, please consider making a donation of £1 or more for the upkeep of the (Radar) website which holds this document. I give my time for free, but it costs me in excess of £300 a year to bring these documents to you. You can donate here https://blunham.com/Radar

Please do not upload this copyright pdf document to any other website. Breach of copyright may result in a criminal conviction.

This document was generated by me Colin Hinson from a document held at Henlow Signals Museum. It is presented here (for free) and this version of the document is my copyright (along with the Signals Museum) in much the same way as a photograph would be. Be aware that breach of copyright can result in a criminal record.

The document should have been downloaded from my website https://blunham.com/Radar, if you downloaded it from elsewhere, please let me know (particularly if you were charged for it). You can contact me via my Genuki email page: https://www.genuki.org.uk/big/eng/YKS/various?recipient=colin

You may not copy the file for onward transmission of the data nor attempt to make monetary gain by the use of these files. If you want someone else to have a copy of the file, please point them at the website (https://blunham.com/Radar).

Please do not point them at the file itself as the file may move or be updated.

I put a lot of time into producing these files which is why you are met with this page when you open the file.

In order to generate this file, I need to scan the pages, split the double pages and remove any edge marks such as punch holes, clean up the pages, set the relevant pages to be all the same size and alignment. I then run Omnipage (OCR) to generate the searchable text and then generate the pdf file.

Hopefully after all that, I end up with a presentable file. If you find missing pages, pages in the wrong order, anything else wrong with the file or simply want to make a comment, please drop me a line (see above).

It is my hope that you find the file of use to you personally – I know that I would have liked to have found some of these files years ago – they would have saved me a lot of time !

Colin Hinson
In the village of Blunham, Bedfordshire.

MODEL ANSWERS

TO

CITY & GUILDS OF LONDON
INSTITUTE EXAMINATIONS

RADIO AND LINE TRANSMISSION A

$37\frac{1}{2}$p

POST OFFICE ELECTRICAL ENGINEERS' JOURNAL
2–12 Gresham Street, London, EC2V 7AG
Reprinted 1972

MODEL ANSWERS

TO

CITY & GUILDS OF LONDON
INSTITUTE EXAMINATIONS

RADIO AND LINE TRANSMISSION A

$37\frac{1}{2}$p

POST OFFICE ELECTRICAL ENGINEERS' JOURNAL
2–12 Gresham Street, London, EC2V 7AG
Reprinted 1972

Reprinted by Lewis Reprints Limited,
London and Tonbridge

PREFACE

The syllabus of the City and Guilds of London examination in Radio and Line Transmission A was revised in 1965, and this book has been prepared on the basis of the revised syllabus. A selection has been made of questions from previous Radio and Line Transmission A examinations, and of questions which are now considered appropriate to this syllabus, but which were previously set in other telecommunication examinations.

The answers, some of which contain more detail than would be expected under examination conditions, have been grouped under the headings given in the Table of Contents, which corresponds to the published syllabus, the divisions of which are reproduced at the beginning of each section.

The Board of Editors wishes to acknowledge the help of members of the Post Office Staff in the preparation of the answers, and to thank the Department of Technology, City and Guilds of London Institute, for permission to reproduce the questions.

RADIO AND LINE TRANSMISSION A

CONTENTS

SYLLABUS

1. The use and advantage of logarithmic units for the expression of ratios of powers, currents and voltages. Definition of the decibel.
2. Sinusoidal variation with time. Frequency. The audio-frequency range. Harmonics. Bandwidth as an essential requirement for the transmission of information.
3. The use of a carrier; amplitude modulation; modulation depth. Waveforms of a carrier amplitude-modulated by a sinusoid. Statement of frequencies comprising the modulated waves of a carrier, amplitude-modulated by (*a*) a sinusoid, (*b*) a musical note and (*c*) speech.
4. Carrier frequency ranges in common use; frequencies normally transmitted over lines and radio links. Relationship between frequency, wavelength and velocity of propagation.
5. Block schematic diagrams of a simple line-communication system and of a simple radio-communication system. Introduction to 2-wire and 4-wire terminations. Multi-station broadcasting.
6. Characteristics and performance of common types of resistors, inductors, transformers and capacitors used in line and radio systems for communication and broadcasting.
7. Characteristics and performance of carbon, crystal and moving-coil microphones. Moving-iron and moving-coil loudspeakers and telephone receivers.
8. Series and parallel tuned circuits; approximate frequency of resonance (without derivation). Use in selection of narrow bands centred on carriers of different frequencies. Bandwidth, half-power (−3db) points.
9. Characteristics and essential features of semiconductor diodes and transistors, thermionic diodes, triodes, tetrodes, beam tetrodes and pentodes.
10. Descriptive treatment of Class-A, Class-B and Class-C operation of simple tuned transistor and valve amplifiers. The principle of operation of simple resistance-loaded small-signal transistor and valve amplifiers. Use of load lines. Simple equivalent circuits. Factors affecting stage amplification. Qualitative consideration of the effect upon frequency response of the interstage couplings, and of the input impedance of the subsequent stage.
11. Descriptive treatment of simple triode-valve oscillators with tuned circuit in anode or in grid. Simple mutual inductance-coupled transistor oscillators.
12. Descriptive treatment of the detection of amplitude-modulated waves by semiconductor and thermionic devices.

1—THE DECIBEL

The use and advantage of logarithmic units for the expression of ratios of powers, currents and voltages. Definition of the decibel.

Question 1

Define the decibel and explain why it is a convenient unit for use in transmission problems.

The input level to an amplifier is $+ 24$ *db relative to* $1\mu V$ *and the amplifier has a gain of* 30 *db. If the input and output impedances of the amplifier are equal and the output is matched to the load, calculate the input and output voltages.*

ANSWER. The decibel is a logarithmic unit used in communication work to express ratios. If P_1 and P_2 are two values of power, and N the number of decibels denoting their ratio, then

$$N = 10 \log_{10} \frac{P_1}{P_2} \text{ decibels.}$$

The sign associated with the number of decibels indicates which power is the greater; thus a negative sign means that P_1 is less than P_2.

The practical value of the decibel arises from its logarithmic nature. This permits the enormous ranges of power involved in communication work to be expressed in terms of decibels without running into inconveniently large numbers. The logarithmic character of a decibel also makes it possible to express the ratio of input to output powers in a complicated circuit as the sum of the ratios, expressed in decibels, of the input and output powers of the different parts of the circuit. Further, the decibel is very convenient for expressing sound intensities since the effect that sound waves have on the ear is roughly proportional to the logarithm of the intensity. Finally, the power which a radio wave is able to supply to a receiving aerial is proportional to the square of the electric field strength. Hence the field strengths of two radio waves may be compared in decibels or, by suitable calibration of an aerial, the field strength of a radio wave may be expressed in decibels relative to 1μV or 1mV or 1 volt per metre.

Since the impedances are equal, the power is proportional to the square of the voltage. Then

$$N = 10 \log_{10} \frac{P_1}{P_2} = 10 \log_{10} \left(\frac{V_1}{V_2}\right)^2 = 20 \log_{10} \frac{V_1}{V_2}.$$

Now, in the question, $N = 24$ db, $V_2 = 1\mu V$ and $V_1 = V_{in}$.

$$\therefore\ 24 = 20 \log \frac{V_{in}}{1}, \text{ or } 1{\cdot}2 = \log V_{in}.$$

$$\therefore\ V_{in} = \text{antilog } 1{\cdot}2 = \underline{15{\cdot}8\ \mu\text{V}.}$$

For the conditions stated, the output $= (24 + 30)$ db relative to 1μV
$= 54$ db relative 1 μV

$$\therefore\ N = 54 = 20 \log \frac{V_{out}}{1};\ \text{or } 2{\cdot}7 = \log V_{out}$$

$$\therefore\ V_{out} = \text{antilog } 2{\cdot}7 = 501\ \mu\text{V}.$$

Question 2.

Define the decibel and give three reasons why its use is convenient in transmission problems.

The input signal to an amplifier varies between 23·5 mW and 1·25 W. Express each power in db relative to 1 mW and state the fluctuation in the level of the signal in db.

ANSWER. For the answer to first part of question see Answer 1.

In the first case, $P_1 = 23{\cdot}5$ mW and $P_2 = 1$ mW.

$$\therefore\ N_1 = 10 \log\frac{23{\cdot}5}{1} = 10 \times 1{\cdot}3711$$

$$= \underline{13{\cdot}711 \text{ db rel. } 1 \text{ mW.}}$$

In the second case, $P_1 = 1{\cdot}25$ W $= 1{,}250$ mW and $P_2 = 1$ mW.

$$\therefore\ N_2 = 10 \log\frac{1{,}250}{1} = 10 \times 3{\cdot}0969$$

$$= \underline{30{\cdot}97 \text{ db rel. } 1 \text{ mW.}}$$

$$\text{The fluctuation in signal level} = 10 \log\frac{1250}{23{\cdot}5} = N_2 - N_1,$$

$$= 30{\cdot}97 - 13{\cdot}71$$

$$= \underline{17{\cdot}26 \text{ db.}}$$

2—FREQUENCY AND BANDWIDTH

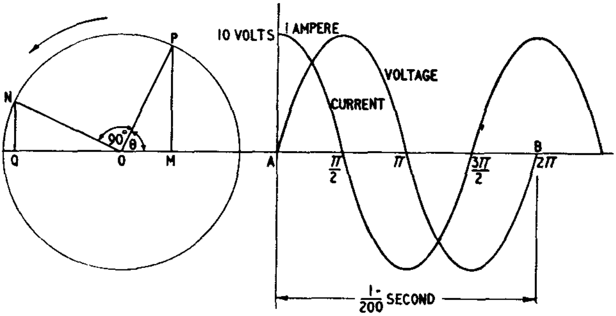
Sinusoidal variation with time. Frequency. The audio-frequency range. Harmonics. Bandwidth as an essential requirement for the transmission of information.

Question 3.

Explain how a sinusoidal waveform can be derived from a rotating radius vector. Using this method, or otherwise, construct a curve representing one cycle of a sinusoidal alternating voltage having a periodic time of 1/200 *second and amplitude of* 10 *volts.*

On the same axes construct a sinusoidal current waveform of the same frequency leading the voltage by a phase difference of 90° *and having an amplitude of* 1 *ampere. Without calculating any component value, sketch a simple circuit that will produce this phase difference between current and voltage.*

ANSWER. Sketch (*a*) shows a radius vector rotating at a uniform speed about an axis perpendicular to the paper at O. The instantaneous amplitude of the vector is represented by PM while θ represents the instantaneous angular displacement of the vector. OM is produced to form the horizontal axis of an amplitude/time graph. Uniform time intervals on the horizontal axis correspond to uniform angular displacements of the vector. As the vector rotates the values of PM corresponding to particular values of θ are plotted on the graph. The curve so produced is sinusoidal since PM is proportional to sin θ. The periodic time is the time taken for the vector to complete one revolution.

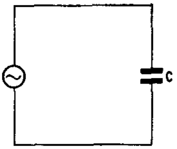


(*a*)

In sketch (*a*) OP = 10 volts and the periodic time, represented by AB, is 1/200 second.

ON represents a current vector, of amplitude 1 ampere, leading the voltage vector by a phase difference of 90°. The value of NQ is projected on to the amplitude/time scale as before producing a sinusoidal waveform displaced from the voltage waveform by 90°.

Sketch (*b*) shows a simple circuit that will produce the desired phase difference.



(*b*)

Question 4.

Explain the meaning of the following terms used in connexion with alternating current:

(*a*) *frequency, periodic time, amplitude.*

What is meant by the phase difference between the voltage across a circuit and the current flowing in it?

(*b*) *Draw diagrams to illustrate the following:*

(*i*) *a sinusoidal voltage having an amplitude of* 1 *volt and a frequency of* 50 *c/s.*

(*ii*) *a sinusoidal current that leads the voltage in* (*i*) *by* 90°,

(*iii*) *a sinusoidal current in antiphase with the voltage,*

(*iv*) *a voltage of double the frequency and amplitude of that in* (*i*).

ANSWER. (*a*) The *frequency* of an alternating current is the number of repetitions of the wave pattern per second, *f*.

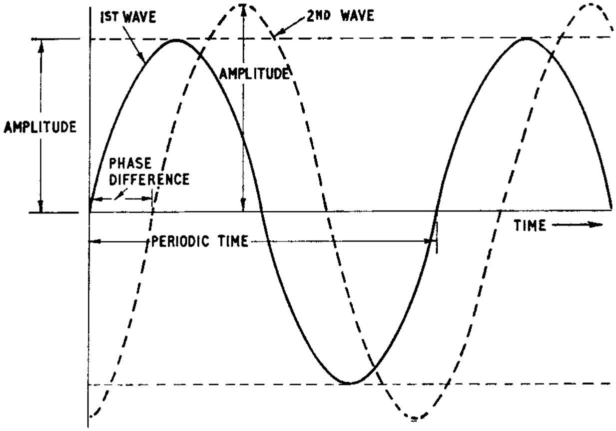
The *periodic time* of an alternating current is the time in seconds occupied by one complete wave pattern. The periodic time is related to the frequency by:

periodic time = 1/frequency, i.e. $t = 1/f$.

The *amplitude* of the waveform of an alternating current is the maximum excursion above, and below, the mean of a complete wave pattern. It can also be defined as half the peak-to-peak excursion of the waveform.

The *phase difference* between the voltage across a circuit and the current flowing in it is the angular difference between corresponding points in the two waveforms, taking 2π radians as representing one complete cycle of either wave pattern.

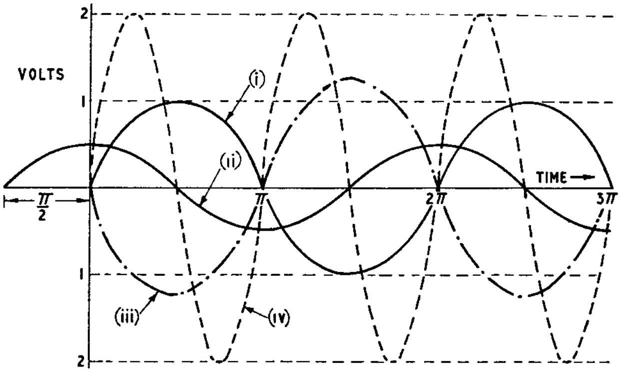
These four quantities are illustrated in sketch (*a*) for two waves of the same frequency but different amplitudes.



(*a*)

(*b*) In sketch (*b*) are shown:

(*i*) A sinusoidal voltage having an amplitude of 1 volt and a frequency of 50 c/s. One wave pattern of this voltage occupies 1/50 seconds, and has a peak-to-peak amplitude of 2 volts.



(*b*)

(*ii*) A sinusoidal current that leads the voltage in (*i*) by 90°. In determining the relative phase of two sine waves it should be noted that a point on the right-hand side of the time axis occurs after a point on the left-hand side. In moving from left to right on the time axis, therefore, a current zero occurs first; and 90° later in time, i.e. $\pi/2$ radians further to the right, a voltage zero occurs.

(*iii*) A sinusoidal current in antiphase with the voltage. "Antiphase" means 180° out-of-phase, and the same result is arrived at whether the phase difference is considered to be either leading or lagging by π radians (i.e. 180°).

(*iv*) A voltage wave of double the frequency and amplitude of that in (*i*). There are two complete wave patterns of this wave in the time interval occupied by one wave pattern of the 50 c/s wave. It has a frequency of 100 c/s and a peak amplitude of 2 volts. The peak-to-peak value is therefore 4 volts.

Question 5.

State the approximate values of carrier frequencies and bandwidths used for the following applications:

(*a*) *A sound-broadcast service to serve a relatively small area.*

(*b*) *A long-distance overseas point-to-point radio-telephony service.*

(*c*) *The provision of* 600 *telephone channels over a coaxial cable.*

(*d*) *The provision of* 24 *voice-frequency telegraph channels over a pair-type cable.*

Briefly explain what determines the bandwidths required in each case. The velocity of propagation in a cable is 2×10^8 *m/s. Calculate the wavelength of a* 200 *Mc/s television signal through such a cable.*

ANSWER. (*a*) To provide a high-quality sound-broadcast service to serve a relatively small area, transmission in the v.h.f. band will be very suitable, i.e. the carrier frequency would be in the range 80–100 Mc/s. In order to reproduce the overtones and harmonics, which give character to the various instruments of an orchestra, it is necessary to reproduce frequencies within the range from about 30 c/s to 15,000 c/s. Thus, with double-sideband amplitude modulation a radio-frequency bandwidth of 30 kc/s is required. With frequency modulation, the bandwidth will be 150 kc/s.

(*b*) A long-distance overseas point-to-point radio-telephony service would use carrier frequencies in the high-frequency range 3–30 Mc/s (more especially 4–25 Mc/s), and employ single-sideband or independent-sideband transmissions. In either type of transmission, the radio frequency occupied by each telephone channel would be 3 kc/s, such a bandwidth being adequate for commercial speech.

(*c*) Twelve telephone channels are commonly assembled at 4 kc/s intervals to form a "group" within the frequency band 60–108 kc/s. Five such groups may then be assembled to form a "super-group" within the frequency band 312–552 kc/s. Finally, to provide for 600 telephone channels over a coaxial cable, ten such super-groups may be assembled to occupy a bandwidth of 2,400 kc/s (i.e. 600 × 4 kc/s) within the frequency band 60–2,540 kc/s, using carrier frequencies spaced at suitable intervals between 612 and 2,852 kc/s.

(*d*) To provide 24 voice-frequency telegraph channels over a pair-type cable, 24 telegraph channels, each occupying a bandwidth of 100 c/s, are commonly assembled at 120 c/s intervals to occupy 2,880 c/s of bandwidth, within the frequency band 420–3,300 c/s. The 24 carrier frequencies range from the lowest at 420 c/s up to the highest at 3,180 c/s, spaced at 120 c/s.

The velocity of propagation, v, is related to its frequency, f, and wavelength, λ, by

$$v = f \times \lambda,$$

where v is in metres/second, λ is in metres, and f is in cycles/second.

Hence, $\lambda = \dfrac{v}{f}$.

Substituting the values given,

$$\lambda = \frac{2 \times 10^8}{200 \times 10^6} = \underline{1 \text{ metre.}}$$

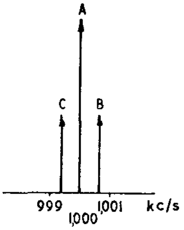
Question 6.

With reference to an amplitude-modulated wave, what is meant by the term sidebands?

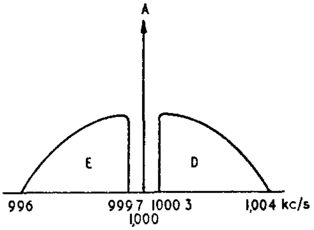
Why do medium-wave broadcast receivers, used for the reception of amplitude-modulated signals, require a total bandwidth of about 9 kc/s?

Briefly describe the effects on the reception of a medium-wave broadcast signal if the total bandwidth of the receiver were made (*a*) *much less than, and* (*b*) *much greater than, 9 kc/s.*

ANSWER. The sidebands of an amplitude-modulated wave are the component waves that appear in addition to the carrier wave when the carrier wave is modulated by a band of frequencies. Sketch (*a*) shows the spectrum of a 1,000 kc/s carrier wave amplitude-modulated by a 1 kc/s sine-wave tone. The spectrum now consists of three component waves, the carrier A of frequency 1,000 kc/s and two additional waves B and C, of lower amplitude than A and having frequencies 1,001 kc/s and 999 kc/s, i.e. 1,000 ± 1 kc/s. These waves are known as the upper side-frequency (B) and the lower side-frequency (C). Sketch (*b*) shows the spectrum of a 1,000 kc/s carrier wave amplitude-modulated by commercial quality speech having components in the band 0·3 to 4 kc/s. Each single-frequency component in the complex speech wave generates an upper and lower side-frequency and the band of side-frequencies corresponding to the whole speech wave are called the upper sideband (D) and the lower sideband (E). The upper sideband extends from (1,000 + 0·3) kc/s to (1,000 + 4) kc/s and the lower sideband from (1,000 − 0·3) kc/s to (1,000 − 4) kc/s.



(*a*)



(*b*)

In order to accommodate a reasonable number of radio broadcast transmissions on the long and medium wavebands, it has been agreed internationally that the carrier-frequency spacing shall be 9 kc/s. Hence, the highest audio frequency transmitted by any station is 4·5 kc/s; this gives reasonable quality when music is broadcast.

If the total bandwidth of the receiver, used to receive the above transmissions, is much less than 9 kc/s, then the highest audio frequency produced at the output of the receiver would be much less than 4·5 kc/s. This, particularly with music, would mean very poor quality reception.

If the total bandwidth of the receiver, used to receive broadcast transmissions having a 9 kc/s spacing of carrier frequencies, is greater than 9 kc/s, the side-bands from adjacent-channel transmissions would be received simultaneously with the wanted transmission, and result in interference.

Question 7.

State, with explanations, the bandwidths required for each of the following line systems:

(*a*) 18 *channels of voice-frequency telegraphy, each signalling at* 50 *reversals per second* (*bauds*)

(*b*) 12 *telephone channels*

(*c*) *a high-quality music channel*

(*d*) *a* 405-*line television channel.*

ANSWER. (*a*) The baud, which is the unit of signal speed in telegraphy, expresses the number of signal elements occurring per second. As only the fundamental component of the waveform need be transmitted the minimum bandwidth of the telegraph signal, per channel, in the example is 25 c/s. For multi-channel transmission, this signal will be used to amplitude modulate a carrier wave, and consequently the minimum bandwidth necessary to accommodate both sidebands will be 50 c/s per channel. To allow for the fact that the necessary bandpass filters cannot have perfectly rectangular insertion-loss characteristics, 120 c/s is allocated to each channel. Thus, the full bandwidth required for an 18-channel signal would be $18 \times 120 = 2{,}160$ c/s.

(*b*) For commercial telephony a frequency band from about 300 to 3,400 c/s is transmitted for each conversation. For multi-channel operation, this band of frequencies is modulated on to one of a number of carrier frequencies in the frequency range 64–108 kc/s. For economic reasons, single-sideband transmission is usually employed so that each channel only occupies 4 kc/s of high-frequency bandwidth. The difference between the 3·1 kc/s bandwidth of the telephony signal and the 4 kc/s of h.f. spectrum allocated to it gives small frequency gaps between adjacent channels to allow for the filter characteristics. Thus, $12 \times 4 = 48$ kc/s bandwidth is required.

(*c*) High-quality music requires a greater bandwidth than speech. For the very highest quality a band from about 20 c/s to 15 kc/s is required, but such bandwidths are not normally used for line transmission or radio broadcasting. Very good quality is obtained if the upper frequency limit is made 10 kc/s, and a band of 30 c/s to 8 kc/s is acceptable for many purposes.

(*d*) In a television picture it is desirable to make the vertical and horizontal definitions approximately equal. In the British 405-line system, 25 pictures are transmitted per second. The aspect ratio i.e. the ratio of picture width to picture height is $\frac{4}{3}$; there are therefore $405 \times \frac{4}{3}$ horizontal picture elements corresponding to 405 vertical picture elements. The total number of elements per picture is, therefore, $405 \times 405 \times \frac{4}{3}$.

Thus, number of elements per second $= 405 \times 405 \times \frac{4}{3} \times 25$. In the worst case, picture elements will be alternately black and white.

$\therefore$ No. of cycles per second $= 405^2 \times \frac{4}{3} \times 25 \times \frac{1}{2} = 3{\cdot}45$ Mc/s.

In practice, not all 405 lines are transmitted (time must be allowed for synchronizing pulses and flyback time), and the bandwidth used is 3 Mc/s.

3—AMPLITUDE MODULATION

The use of a carrier; amplitude modulation; modulation depth. Waveforms of a carrier amplitude-modulated by a sinusoid. Statement of frequencies comprising the modulated waves of a carrier, amplitude-modulated by (a) a sinusoid, (b) a musical note and (c) speech.

Question 8.

With reference to an amplitude-modulated wave, what are meant by the terms side-frequencies, sidebands and depth of modulation?

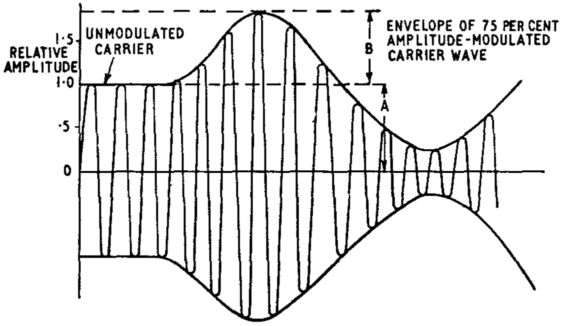
Sketch the waveform of a radio-frequency wave, amplitude-modulated by a sine-wave tone to a depth of 75 *per cent.*

If a radio-frequency carrier wave is amplitude-modulated by a band of frequencies, 300 *c/s to* 3,400 *c/s, what will be the bandwidth of the transmission and what frequencies will be present in the transmitted wave, if the carrier frequency is* 104 *kc/s?*

ANSWER. *Side-frequencies.* When a carrier wave is amplitude-modulated by a low frequency, the resultant waveform has three components. There is one at the original carrier frequency, and two more, one above and one below this frequency. The latter two components, which are called the upper and lower side-frequencies, respectively, are displaced from the carrier frequency by an amount equal to the modulating frequency. Thus, for example, if the carrier frequency was f_c and the modulating frequency f_m, the three components of the modulated wave would have the frequencies $f_c - f_m$, f_c and $f_c + f_m$.

Sidebands. If the carrier wave is modulated by a band of frequencies, every frequency present in this band will produce its own pair of side-frequencies, and these are collectively called sidebands. There are two sidebands: the upper sideband, which comprises the band of upper side-frequencies, and the lower sideband, which consists of the lower side-frequencies.

Depth of modulation. If the amplitude of an unmodulated carrier wave is A, and it is amplitude-modulated by a low-frequency wave of amplitude B, then the amplitude of the envelope of the modulated wave will vary, at the frequency of the modulating wave, between the limits $A - B$ and $A + B$. The depth of modulation, m is equal to B/A.



The sketch shows the waveform of a carrier wave when amplitude-modulated by a sine-wave to a depth of 75 per cent.

If f'_m is the highest modulating frequency, the highest sideband frequency will be $f_c + f'_m$ and the lowest sideband frequency will be $f_c - f'_m$. Therefore, the bandwidth of the transmission is

$$(f_c + f'_m) - (f_c - f'_m) = 2f'_m.$$

Using the figures quoted in the question, the bandwidth occupied by the transmission will be 2 × 3,400 c/s = 6,800 c/s.

The upper sideband will extend from 104·3 kc/s (= 104 kc/s + 300 c/s) to 107·4 kc/s (= 104 kc/s + 3,400 c/s.)

The lower sideband will extend from 103·7 kc/s (= 104 kc/s − 300 c/s) to 100·6 kc/s (= 104 kc/s − 3,400 c/s).

Therefore, the frequencies present in the transmitted wave will be as follows:

(*a*) the lower-sideband components from 100·6 to 103·7 kc/s,
(*b*) the carrier-frequency, 104 kc/s, and
(*c*) the upper-sideband components from 104·3 to 107·4 k/cs.

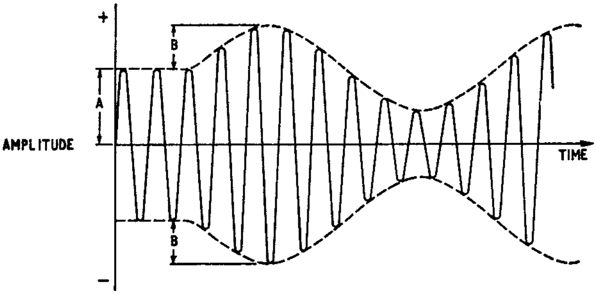
Question 9.

With reference to amplitude-modulation explain the terms "modulation envelope" and "depth of modulation" and distinguish between "side-frequencies" and "sidebands".

The amplitude of a 310 *kc/s wave is modulated sinusoidally at a frequency of* 5 *kc/s between* 0·9 *volts and* 1·5 *volts.*

Determine the amplitude of the unmodulated carrier, the depth of modulation and the frequency components present in the modulated wave.

ANSWER. When a carrier wave of frequency f_c is amplitude-modulated by a single low-frequency tone of frequency f_a, the resultant waveform has three components, the original carrier frequency f_c, and two other frequencies $f_c + f_a$ and $f_c - f_a$. The latter two components are called the upper and lower side-frequencies. If the carrier wave is amplitude modulated by a band of frequencies, every frequency present in this band will produce its own pair of side-frequencies and these are collectively called sidebands.



If the amplitude of an unmodulated carrier wave is *A* and it is amplitude-modulated by a low frequency of amplitude *B*, then the amplitude of the modulated wave will vary, at the frequency of the modulating wave, between the limits $(A - B)$ and $(A + B)$ as shown in the sketch. It is usual to refer to the dotted line, which outlines the changing amplitude, as the modulation envelope. The depth of modulation, m, is equal to $\frac{B}{A}$.

With reference to the question:

$$A + B = 1{\cdot}5 \text{ volts} \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

$$A - B = 0{\cdot}9 \text{ volts} \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

Adding equations (1) and (2), $2A = 2{\cdot}4$.

$\therefore$ A, the amplitude of the unmodulated carrier $= \underline{1{\cdot}2 \text{ volts.}}$

Substituting in equation (1) or (2) gives $B = 0{\cdot}3$ volts.

$$\therefore \text{ Depth of modulation, } m = \frac{B}{A} = \frac{0{\cdot}3}{1{\cdot}2} = \underline{0{\cdot}25 \text{ or } 25 \text{ per cent.}}$$

Carrier frequency, $f_c = \underline{310 \text{ kc/s.}}$

Side-frequency, $f_c + f_a = 310 + 5 = \underline{315 \text{ kc/s.}}$

Side-frequency, $f_c - f_a = 310 - 5 = \underline{305 \text{ kc/s.}}$

Question 10.

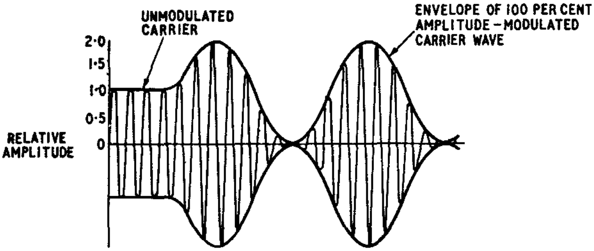
Sketch the waveforms of a radio-frequency carrier wave, amplitude-modulated by a sinewave tone, when the depth of modulation is:

(*a*) 100 *per cent*

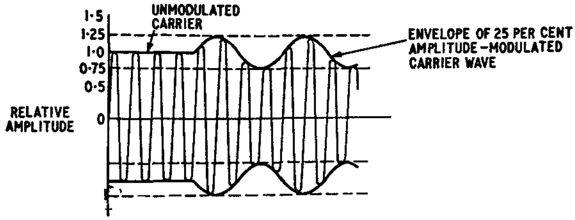
and (*b*) 25 *per cent.*

If a radio-frequency carrier wave is amplitude-modulated by a band of speech frequencies, 50 *c/s to* 4,500 *c/s, what will be the bandwidth of the transmission and what frequencies will be present in the transmitted wave, if the carrier frequency is* 506 *kc/s?*

ANSWER. Sketches showing the waveforms of an r.f. carrier wave when modulated 100 per cent and 25 per cent are shown in (*a*) and (*b*), respectively.



(*a*)



(*b*)

When a carrier wave is amplitude-modulated by a low frequency the resultant wave has three components. There is one at the original carrier frequency, and two more, one above and one below this frequency. The latter two components, which are called the upper and low side-frequencies, respectively, are displaced from the carrier frequency by an amount equal to the modulating frequency. Thus, for example, if the carrier frequency was f_c and the modulating frequency f_m the three components of the modulated wave would have the frequencies, $f_c - f_m$, f_c and $f_c + f_m$. If the carrier is modulated by a band of frequencies, every frequency present in this band will produce its own pair of side-frequencies, and these are collectively called sidebands.

If $f^1{}_m$ is the highest modulating frequency, the bandwidth of the transmission will be $(f_c + f^1{}_m) - (f_c - f^1{}_m) = 2f_m$.

Therefore, using the figures quoted in the question, the bandwidth occupied by the transmission will be 2 × 4,500 c/s = 9,000 c/s.

The upper sideband $(f_c + f^1{}_m)$ will extend from

506 kc/s + 50 c/s = 506·05 kc/s

to 506 kc/s + 4,500 c/s = 510·50 kc/s

and the lower sideband $(f_c - f^1{}_m)$ will extend from

506 kc/s − 50 c/s = 505·95 kc/s

to 506 kc/s − 4,500 c/s = 501·50 kc/s.

In addition, there will be the carrier itself at 506 kc/s.

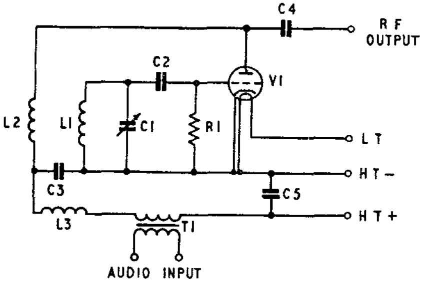
Question 11.

Explain, with the aid of a diagram, how an oscillator may be anode-modulated by an external audio-frequency signal.

The amplitude of a 205 *kc/s wave is modulated sinusoidally at a frequency of* 3 *kc/s between* 0·5 *volt and* 1·5 *volts.*

Determine the depth of modulation and state the frequencies present in the modulated wave.

ANSWER. The circuit diagram of an anode-modulated medium frequency LC oscillator is given in the sketch. The tuned circuit L1C1 is connected to the grid of the triode valve V1, and oscillations are maintained by inductive feedback from coil L2, coupled to coil L1. The grid capacitor C2 and leak resistor R1 provide self-bias. The output is taken through an h.t. blocking capacitor, C4. The output is amplitude-modulated by applying an audio-frequency signal to the primary of the audio-frequency transformer T1, the secondary being connected in series with the h.t. supply to the anode of V1. The radio-frequency choke L3 and coupling capacitor C3 prevent radio-frequency currents entering the audio circuits; C5 is an audio-frequency decoupling capacitor which keeps audio-frequency currents out of the h.t. supply unit.



If the amplitude of an unmodulated carrier wave is A and it is amplitude modulated by a lower frequency, of amplitude B, then the amplitude of the envelope of the modulated wave will vary, at the frequency of the modulating wave, between the limits of $A - B$ and $A + B$. The depth of modulation, m, is equal to $\frac{B}{A}$.

With reference to the question,

$$A + B = 1{\cdot}5 \text{ volts} \ldots\ldots\ldots (1)$$

$$A - B = 0{\cdot}5 \text{ volt} \ldots\ldots\ldots (2)$$

Adding (1) and (2), $2A = 2{\cdot}0$ or $A = 1{\cdot}0$ volt.

Substituting for A in (1) or (2) gives $B = 0{\cdot}5$ volt.

$$\therefore \text{ Depth of modulation, } m = \frac{B}{A} = \frac{0{\cdot}5}{1{\cdot}0} = \underline{0{\cdot}5 \text{ or } 50 \text{ per cent.}}$$

When a carrier wave of frequency f_c is amplitude modulated by a tone of frequency f_m, the resultant waveform has three components. They are f_c, $f_c + f_m$ and $f_c - f_m$.

Referring to the question, the frequencies present in the modulated wave will be as follows:

Carrier frequency, $f_c = \underline{205 \text{ kc/s.}}$

Side frequency, $f_c + f_m = 205 + 3 = \underline{208 \text{ kc/s.}}$

Side frequency, $f_c - f_m = 205 - 3 = \underline{202 \text{ kc/s.}}$

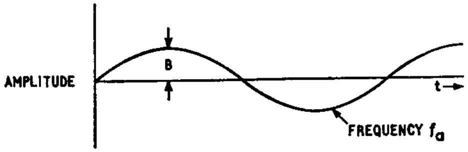
Question 12.

What is an amplitude-modulated wave?

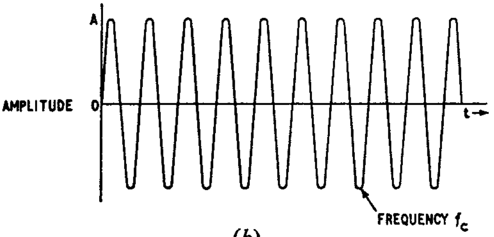
Why do broadcast receivers used for the reception of amplitude-modulated signals have a total bandwidth of about 9 kc/s?

ANSWER. To obtain efficient transmission and reception of radio signals, fairly high frequencies must be employed; for example, a broadcast transmitter may employ a carrier frequency of 1 Mc/s.

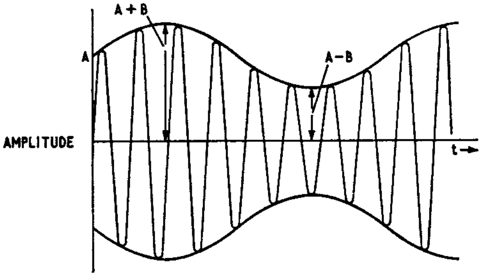
To transmit information this carrier frequency must be modulated. Amplitude-modulation consists in varying the amplitude of the carrier wave in sympathy with that of the modulating signal.



(*a*)



(*b*)



(*c*)

Sketch (*a*) shows an unmodulated carrier wave of amplitude A and frequency f_c, and sketch (*b*) shows an audio-frequency sinusoidal modulating signal of amplitude B and frequency f_a. Sketch (*c*) shows the carrier wave amplitude-modulated, the amplitude of the wave varying by an amount $\pm B$ between the limits $A - B$ and $A + B$; the frequency of the variation is that of the modulating signal, namely, f_a. The depth of modulation $m = B/A$.

It can be shown that the wave indicated in sketch (*c*) consists of three components, the original carrier wave of frequency f_c together with two other waves, known as sidebands, of frequencies $f_c - f_a$ and $f_c + f_a$. Thus, the signal occupies a frequency band of $2f_a$.

In order to accommodate a reasonable number of radio broadcast transmissions on the long and medium wavebands it has been agreed internationally that the carrier frequency spacing shall be 9 kc/s. Hence, the highest audio frequency, f_a, transmitted by any station is 4·5 kc/s; this gives reasonable quality when music is broadcast. To avoid loss of quality it is therefore necessary for the receiver to have a bandwidth of 9 kc/s. If the receiver bandwidth is greater than 9 kc/s the sidebands from adjacent-channel transmissions will be received simultaneously and interference will result.

Question 13.

Draw careful sketches to show the appearance of each of the following signals when displayed in a cathode-ray oscilloscope:

(*i*) *A carrier wave amplitude-modulated to a depth of* 50 *per cent by a low-frequency sinewave.*

(*ii*) *A carrier wave amplitude-modulated by a low-frequency rectangular-wave having a mark/space ratio of* 2 : 1.

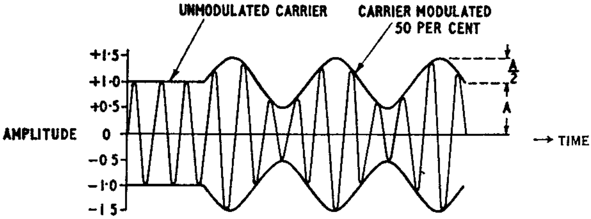
Assume the carrier leak during the "space" period to be − 20 *db relative to the unmodulated carrier amplitude.*

(*iii*) *A sine-wave to which has been added* 50 *per cent second harmonic.*

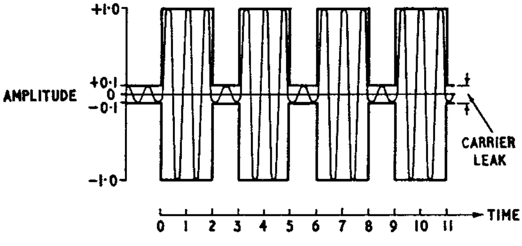
(*iv*) *A sine-wave to which has been added* 50 *per cent third harmonic.*

Each sketch must clearly show the scales in the axes.

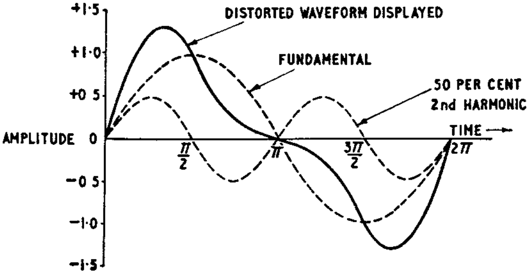
Answer. The required diagrams are given in sketches (*a*), (*b*), (*c*) and (*d*). The carrier leak during the "space" period, shown in sketch (*b*), is $\frac{1}{10}$ of the amplitude of the unmodulated carrier, i.e. − 20 db.



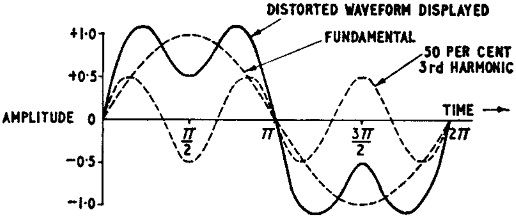
(*a*)



(*b*)


DISTORTED WAVEFORM DISPLAYED
FUNDAMENTAL
50 PER CENT
2nd HARMONIC
+1·5
+1·0
+0 5
AMPLITUDE 0
−0 5
−1·0
−1·5
TIME →
$\frac{\pi}{2}$
π
$\frac{3\pi}{2}$
2π

(*c*)


DISTORTED WAVEFORM DISPLAYED
FUNDAMENTAL
50 PER CENT
3rd HARMONIC
+1·0
+0·5
AMPLITUDE 0
−0·5
−1·0
TIME →
$\frac{\pi}{2}$
π
$\frac{3\pi}{2}$
2π

(*d*)

4—PROPAGATION

Carrier frequency ranges in common use; frequencies normally transmitted over lines and radio links. Relationship between frequency, wavelength and velocity of propagation.

Question 14.

If the maximum frequency tolerance for fixed service-stations operating in the frequency band 4·0 *to* 27·5 *Mc/s is* ± 30 *parts in* 10^6 (± 0·003 *per cent) and for television operating in the frequency band* 40·0 *to* 70·0 *Mc/s is* ± 10 *parts in* 10^6 (± 0·001 *per cent), to what frequency variations in cycles per second do these tolerances correspond in the case of:*
(*a*) *a fixed-service station on* 12·3 *metres,*
and (*b*) *a television station on* 5·5 *metres?*

At what wavelength does a fixed service-station, having a variation of ± 300 *c/s, become outside the permitted tolerance?*

ANSWER. $\text{Frequency} = \dfrac{\text{Velocity}}{\text{Wavelength}}$

and, for electromagnetic waves in free space,

$$\text{frequency} = \frac{300 \times 10^6}{\text{wavelength in metres}} \text{ cycles/second.}$$

(*a*) When the wavelength of the fixed-service station = 12·3 metres,

$$\text{frequency} = \frac{300 \times 10^6}{12{\cdot}3} \text{ cycles/second}$$
$$= 24{\cdot}39 \times 10^6 \text{ c/s.}$$

∴ Maximum frequency variation permitted

$$= \pm \frac{30}{10^6} \times 24{\cdot}39 \times 10^6 \text{ c/s}$$
$$= \pm \underline{731{\cdot}7 \text{ c/s}}.$$

(*b*) When the wavelength of the television station = 5·5 metres,

$$\text{frequency} = \frac{300 \times 10^6}{5{\cdot}5} \text{ c/s}$$
$$= 54{\cdot}54 \times 10^6 \text{ c/s.}$$

∴ Maximum frequency variation permitted

$$= \pm \frac{10}{10^6} \times 54{\cdot}54 \times 10^6 \text{ c/s}$$
$$= \pm \underline{545{\cdot}4 \text{ c/s}}.$$

Maximum frequency variation permitted

= maximum permitted tolerance × frequency of station.

$$\therefore \text{ Frequency of station} = \frac{\text{Permitted variation}}{\text{Permitted tolerance}}$$

$$= \frac{\pm 300}{\pm 30/10^6} \text{ c/s}$$

$$= 10 \times 10^6 \text{ c/s} = 10 \text{ Mc/s.}$$

$$\text{Wavelength} = \frac{300 \times 10^6}{\text{Frequency (c/s)}} \text{ metres}$$

$$= \frac{10 \times 10^6}{300 \times 10^6} = 30 \text{ metres.}$$

Hence station becomes outside tolerance at 30 metres.

Question 15.

State the approximate values of carrier frequencies you would expect to find used for the following applications:

(a) a high-quality sound broadcast service to serve a relatively small area

(b) a group of 12 *telephone channels to be transmitted over a pair-type cable*

(c) a point-to-point television radio-relay system.

A radio wave is propagated through a block of polythene, in which its velocity of propagation is 2×10^8 *metres/s. If its wavelength is found to be* 4 *cm, what is the frequency of the wave?*

ANSWER. (*a*) To provide a high-quality sound-broadcast service the medium-wave band is no longer satisfactory in this country, owing to the very large number of stations broadcasting simultaneously in Europe. As the question specifies that the service area is relatively small, the v.h.f. band will be very suitable, the carrier frequencies lying between 80 and 100 Mc/s.

(*b*) Groups of telephony channels are commonly assembled at 4 kc/s intervals within the frequency band 60–108 kc/s. This band is either transmitted directly, or translated down to the band 12–60 kc/s.

(*c*) The microwave bands are used for point-to-point television radio-relay systems, suitable frequencies lying between 1,000 and 10,000 Mc/s. Within these frequencies limits certain bands are specifically allocated for this type of service by international agreement.

The velocity of propagation of a wave V is related to its frequency f and wavelength λ by the relation:

$$V = f\lambda,$$

where V is in metres/second, λ is in metres, and f is in cycles/second.

$$\text{Hence, } f = V/\lambda.$$

Substituting the values given,

$$f = \frac{2 \times 10^8}{4 \times 10^{-2}} = 5{,}000 \text{ Mc/s.}$$

Question 16.

State for what types of radio-transmission service the following frequencies are used:

1·6 *kc/s;* 1 *Mc/s;* 45 *Mc/s.*

Indicate, very approximately, the distance over which useful signals are obtained in each case.

A half-wave dipole aerial is to be used for the reception of signals at a frequency of 45 *Mc/s. What will be the length of the aerial?*

ANSWER. Frequencies of 16 kc/s are used for slow-speed telegraph transmission. Speech frequencies cannot be used because the bandwidth of the signals would necessitate the use of a large part of the very-low-frequency spectrum; the design of transmitters and receivers would also be difficult. These signals will travel many thousands of miles with comparatively little attenuation, and world-wide communication is possible. Propagation conditions are almost constant and reliable transmission occurs at all times of the day and year.

Frequencies of 1 Mc/s are used for sound broadcasting. Reliable transmission over distances of 50–100 miles is obtained at all times. Considerably greater range, several hundred miles, occurs at night due to propagation by signals which are absorbed during the daytime.

Frequencies of 45 Mc/s are used for the transmission of television signals. These signals require a large bandwidth and the necessary frequency spectrum is available at these frequencies. The range is the distance over which "line of sight" transmission is possible and is about 30 miles; reliable reception is, however, obtained over rather longer distances.

$$v = f\lambda,$$

where v = velocity of propagation in metres/sec

f = frequency in c/s

λ = wavelength in metres.

$$\text{Now, } v = 3 \times 10^8 \text{ m/s},$$

$$\text{and } f = 45 \times 10^6 \text{ c/s}.$$

$$\therefore 3 \times 10^8 = 45 \times 10^6 \times \lambda$$

$$\therefore \lambda = \frac{3 \times 10^8}{45 \times 10^6} = 6{\cdot}67 \text{ metres}$$

$$\text{Length of aerial} = \lambda/2 = \frac{6{\cdot}67}{2}$$

$$= \underline{3{\cdot}34 \text{ metres.}}$$

Question 17.

Indicate the frequency bands in common use for present-day radio communication.

Outline the general uses of the medium-frequency and high-frequency bands.

ANSWER. The radio-communication frequency bands are listed below, together with brief notes on their properties and uses.

Below 30 *kc/s (very low frequencies).* These waves have very low ground-wave attenuation and are used for world-wide communication from a fixed station to ship or land stations. The General Post Office Rugby radio station uses a frequency of 16 kc/s.

30 *kc/s*–300 *kc/s* (*low frequencies*). These waves have greater ground-wave attenuation. The ground wave, however, provides reliable communication at all times for distances up to 1,000 km (660 miles). Frequencies within the band are used for broadcasting, navigation, coast and ship stations.

300 *kc/s*–3 *Mc/s* (*medium frequencies*). This frequency band is used for:

Distress signals	—	500 kc/s
Navigational aids	—	320 kc/s and 410 kc/s
Marine telegraphy	—	510 kc/s
Broadcasting	—	535 kc/s to 1,605 kc/s
Meteorological aids	—	2 Mc/s
Standard frequency transmissions	—	2·5 Mc/s

During the daytime the coverage is by means of the ground wave, the sky wave being almost completely attenuated, and the range is small. At night appreciable energy reaches distant points, far beyond the range of the daytime signals, by means of the sky wave.

3 *Mc/s*–30 *Mc/s* (*high frequencies*). One of the main uses of this band is for long-range point-to-point communication circuits, the signals travelling many thousands of miles by means of the sky wave. Certain frequencies within the band are used for long-range broadcasting. Various frequencies within the band are allocated for amateur use. Standard frequency transmissions are made at 10, 15, 20 and 25 Mc/s. Frequency bands at 28 Mc/s and 30 Mc/s are allocated for meteorological aids and navigation.

30 *Mc/s*–300 *Mc/s* (*very high frequencies*) *and* 300 *Mc/s*–3,000 *Mc/s* (*ultra-high frequencies*). These signals travel approximately along optical paths and the transmitter and receiver must be almost in sight of each other; the range is therefore limited to about 30 miles. The frequency bands are used for various communication and broadcast services. The 2,000 Mc/s band is used for radio-relay purposes.

The high carrier frequencies make these bands ideal for transmitting wideband signals such as television signals.

Question 18.

State the carrier frequencies and bandwidths suitable for the following applications:

- (*a*) *a long-distance telex service to ships,*
- (*b*) *a long-distance overseas point-to-point radio telephony service,*
- (*c*) *a short-distance broadcast service,*
- (*d*) *a private mobile radio telephone service.*

A fixed service (*point-to-point*) *transmitter is assigned a wavelength of exactly* 37·5*m. It is found to be working on a frequency of* 8,000·21 *kc/s.*

Calculate the deviation in cycles per second and determine whether the transmitter is working outside the permitted tolerance of ± 30 *parts in* 10^6.

ANSWER. (*a*) A telex service is a telegraph service using start-stop apparatus (teleprinter). A long-distance telex service to ships would use carrier frequencies in the high frequency range between 3–30 Mc/s, more especially in the internationally allocated maritime mobile bands between 4 and 23 Mc/s. For such a service a baud speed of 50–100 is commonly used. Allowing for such factors as frequency stability, fading and adjacent channel interference a bandwidth of about 1·0 kc/s may be used.

(*b*) A long-distance overseas point-to-point radio telephony service would use carrier frequencies in the high frequency range between 3–30 Mc/s, more especially between 4–25 Mc/s and employ single sideband or independent sideband transmissions. In either case the radio frequency bandwidth occupied by each telephone channel would be 3 kc/s, such a bandwidth being adequate for commercial speech.

(*c*) To provide a short-distance broadcast service a carrier frequency in the V.H.F. band, normally between 80–100 Mc/s, would be used. For a high quality broadcast service the bandwidth would be about 30 kc/s for amplitude modulated signals and about 150 kc/s for frequency modulated signals.

(*d*) A private mobile radio telephone service would use carrier frequencies in the V.H.F. range, more especially between 80 and 160 Mc/s. Double sideband amplitude modulation or frequency modulation may be employed utilizing a channel bandwidth of 25 kc/s.

The velocity of propagation V is related to its frequency f and wavelength λ by:

$$V = f \times \lambda$$

When V is in metres/second; λ is in metres and f is in cycles/second.

Hence, $f = \frac{V}{\lambda}$ and substituting the values given, the assigned frequency of the transmitter $= \frac{3 \times 10^8}{37{\cdot}5}$ c/s $=$ 8,000,000 c/s

The working frequency is found to be 8000·21 kc/s = 8,000,210 c/s

Hence the deviation is 8,000, 210 − 8,000,000 c/s

$$= \underline{210 \text{ c/s}}$$

This deviation, expressed as a fraction of the assigned frequency

$$= \frac{210}{8{,}000{,}000} = 26{\cdot}25 \times 10^{-6}$$

This is within the permitted tolerance of ±30 parts in 10^6.

Alternatively, the permitted deviation is

$$\frac{30}{10^6} \times 8 \times 10^6 \text{ c/s} = 240 \text{ c/s}$$

Thus, the deviation of 210 c/s is within the permitted deviation.

5—COMMUNICATION SYSTEMS

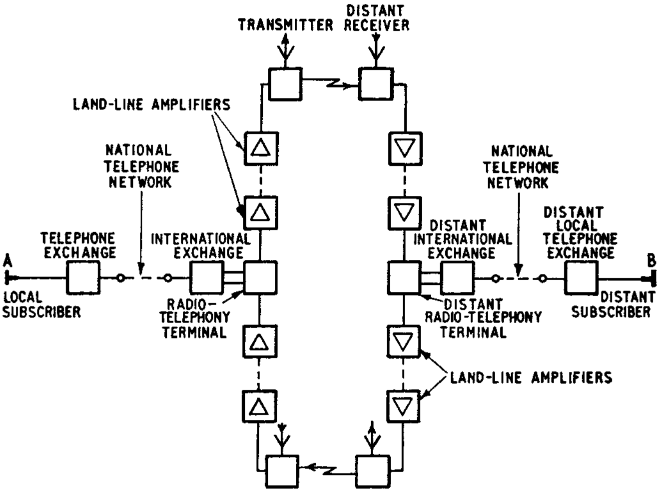
Block schematic diagrams of a simple line-communication system and of a simple radio-communication system. Introduction to 2-wire and 4-wire terminations. Multi-station broadcasting.

Question 19.

With the aid of a block diagram, explain the connexions required for an overseas radio-telephone call between a subscriber on a remote island in one continent and a subscriber in another continent.

Suggest suitable carrier frequencies which might be used on the national telephone network and the international radio circuits involved.

ANSWER. A block schematic diagram of the connexions required for an overseas radio-telephone call between a subscriber on a remote island in one continent and a subscriber in another continent is shown in the sketch.



The calling subscriber A, on the remote island, is connected on an ordinary local-line circuit to his local telephone exchange. The connexion is then routed, via the national telephone network, to the international exchange and on to the radio-telephony terminal, where amplified land-lines extend it to the radio transmitter. At the radio transmitter, the speech signals are made to amplitude-modulate a high-frequency carrier, and this amplitude-modulated high-frequency radio signal passes to the distant radio receiving station. Here the call is extended—via the distant radio-telephony terminal, international exchange, national telephone network, and local telephone exchange—to the distant subscriber B.

The national telephone network may consist of overhead land-lines, underground multi-pair cables, coaxial cables, v.h.f. or u.h.f. radio links and micro-wave radio links. Subscriber A, on the remote island, will probably be connected to the national telephone system by submarine cable or v.h.f. radio link. The carrier frequencies which might be used on the national telephone network are 30–100 Mc/s for v.h.f. radio links, 1,000–8,000 Mc/s for micro-wave radio links, and 400 kc/s–8 Mc/s for coaxial-cable carrier systems. The frequencies used on long-distance radio-telephone circuits are in the range 4–27 Mc/s.

Question 20.

Draw suitably annotated block schematic diagrams of the following simple line and radio communication systems:

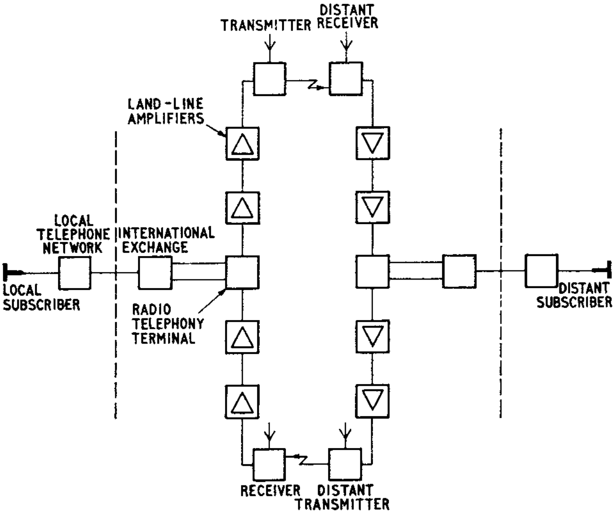
(a) Connexions required for an overseas radio-telephone call between two subscribers on different continents.

(b) Connexions required for a multi-station sound broadcast from an outside-broadcast event.

(c) Connexions required for an overseas radio-telegraphy call between a shipping company and one of its ships.

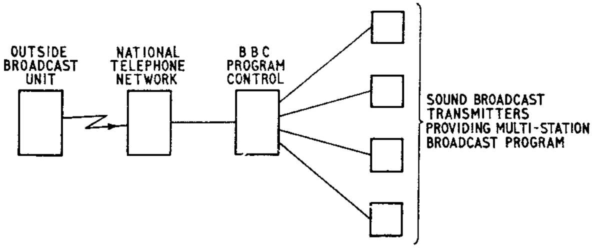
State in each case the approximate carrier frequency and bandwidth appropriate to any radio link involved.

ANSWER. (*a*) Sketch (*a*) shows the connexions required for an overseas radio-telephone call between two telephone subscribers on different continents. The frequencies used for the long-distance radio path would be in the band 3–30 Mc/s. The bandwidth required, using single-sideband transmissions would be 3 kc/s.

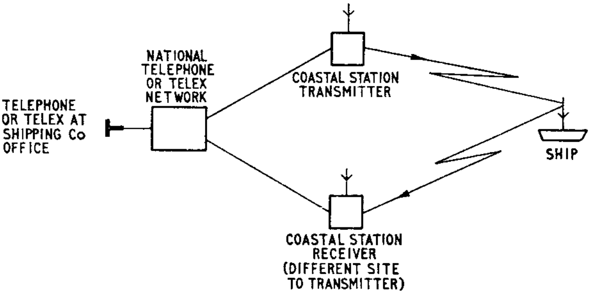


(*a*)

(*b*) Sketch (*b*) shows the connexions required for a multi-station sound broadcast from an outside-broadcast event. In the event of a radio link being used to connect the outside-broadcast unit to the national telephone network, its frequency would be in the v.h.f. (30–300 Mc/s) or u.h.f. (300–3,000 Mc/s) bands and the bandwidth would be of the order of 25–150 kc/s.



(*b*)



(*c*)

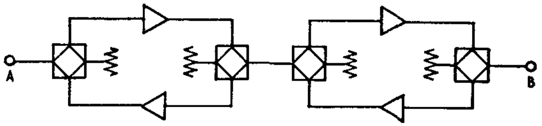
(*c*) Sketch (*c*) shows the connexions required for an overseas radio-telegraphy call between a shipping company and one of its ships. The frequencies used for the overseas radio path would be in either the medium wave (300–3,000 kc/s) or the high frequency (3–30 Mc/s) band. The bandwidth required would be of the order of 100 c/s up to about 1·0 kc/s, depending upon the signalling speed of the system of telegraphy used.

Question 21.

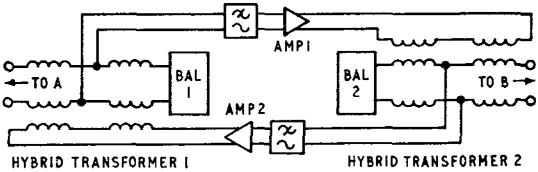
Show by means of a block schematic diagram the equipment required to provide a repeatered audio-circuit on (*a*) *a 2-wire and* (*b*) *a 4-wire basis. Which would you prefer to set up and maintain on a long open-wire route? Give reasons for your reply.*

ANSWER. (*a*) To provide amplification in a 2-wire audio circuit the repeaters must each amplify signals passing along the line in each direction and, to prevent oscillation due to circulating currents, the repeaters are arranged with balanced bridges at input and output.

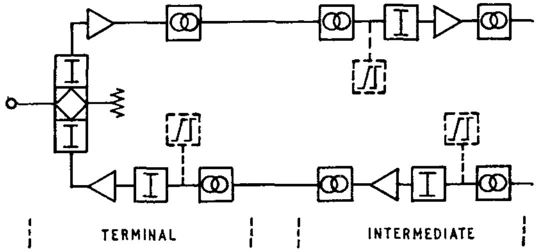
Sketch (*a*) shows the basic layout of a repeatered 2-wire line and sketch (*b*) shows the repeater in greater detail.



(*a*)



(*b*)



(*c*)

The repeater consists of two amplifiers connected to the line via hybrid transformers. If the balancing network has the same impedance as the line connected to the same transformer, the hybrid transformer is balanced and the output of one amplifier (say amplifier 1) will not develop a voltage at the input to the other (amplifier 2). Thus, the repeater will not oscillate. It is not possible to maintain the balance between line impedance and balance impedance at all frequencies and the networks are designed to match the line over the audio range; to prevent oscillation at high frequencies low-pass filters are connected in tandem between the hybrid transformers and the amplifiers' input circuits. The hybrid transformers each give a 3 db loss plus transformer losses for signals passing from an amplifier output to line and from line to an amplifier input.

(*b*) The layout of a 4-wire repeatered system is shown in sketch (*c*); one terminal and one intermediate station are shown with "Transformer and Line Corrector" equipment in use. Hybrid transformers are required only at the terminal stations where the repeatered 4-wire circuit is transformed to 2-wire circuits. Intermediate repeaters have two amplifiers, one for each direction of transmission, which are completely separate electrically. The terminating units are generally an arrangement of two transformers to give transmit and receive impedances of

600 ohms, and the balancing network may be either a 600-ohm resistor or, if a long 2-wire end is used, a network simulating the impedance of the 2-wire line.

With repeaters equally spaced along a 2-wire line the gain of each repeater in each direction must be equal. If the required gain, 2-wire to 2-wire, is to be G db, the amplifier gain will have to be G db + 6 db + losses of two transformers, half of the excess over G being required to compensate for the 2-wire to 4-wire loss in each hybrid transformer. A measure of the balance between the line impedance and the balance impedance is the balance return-loss and this is equal to 20 log $[(Z_0+B)/(Z_0-B)]$ db, where Z_0 is the line impedance and B is the balance impedance. The loss across the hybrid transformer from amplifier output to amplifier input is equal to the balance return-loss + 6 db + twice the transformer losses. If R_1 is the balance return-loss of balance 1 and R_2 is that of balance 2, the repeater will be stable if there is a loss in the loop from the transmit 4-wire winding of transformer 2 to the output of amplifier 1. The repeater will be stable if the circuit losses exceed the amplifier gains, i.e. if $R_1 + 6 + R_2 + 6 > G + 6 + G + 6$ (ignoring transformer losses). Thus, if $R_1 = R_2 = R$ the stability condition is $R > G$, and to prevent too large variations in 2-wire to 2-wire gain, or loss, R should exceed G by at least 10 db.

For a repeatered 4-wire circuit the overall gain will not be in excess of 0 db and R will then have to exceed 10 db. This requirement is easily met by the use of a simple balance network. If the gain of a 2-wire repeater is to be 20 db it would be advisable to have the balance return-loss in excess of 30 db over the audio-frequency band. Such a balance needs many components, all of which may have to be accurately adjusted. Open-wire lines are affected by weather conditions and the line impedance will likewise be affected. Therefore, to maintain a 2-wire repeatered circuit on open-wire lines would probably require frequent readjustment of the balance components to keep the circuit in satisfactory operation; attenuation will also change with weather, and, therefore, frequent gain adjustment would be necessary.

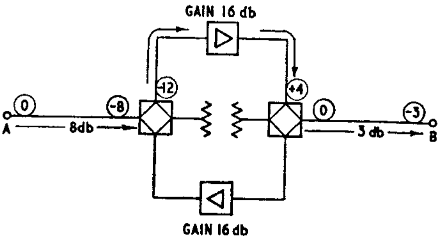
Question 22.

Show, by means of block schematic diagrams, the equipment needed to provide a repeatered audio-junction circuit on (a) 2-wire basis and (b) a 4-wire basis.

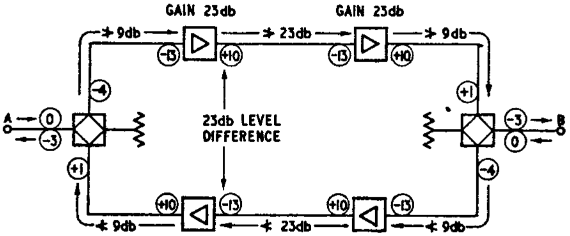
Quote typical losses for each part of the circuit, and explain the advantage of 4-wire operation compared with 2-wire operation.

ANSWER. Sketches (*a*) and (*b*) show the required layout for 2-wire and 4-wire repeatered circuits, respectively. Typical figures for the losses and gains through the circuits are given on the sketches. The ringed figures show typical signal levels at the various points, expressed in decibels relative to one milliwatt.

With 2-wire repeatered circuits the length of cable which may be used depends on the accuracy with which the impedance/frequency characteristics of the cables are matched by the line-balancing networks in the repeater. Sketch (*a*) shows a typical maximum-length circuit using one repeater. In British Post Office practice only one 2-wire repeater is used on a circuit and normally a total line loss of about 11 db is not



(*a*)



(*b*)

exceeded, with not more than 8 db on one side of the repeater. This restriction arises because the repeater is designed for use on circuits of about 30 miles in length and the precision balances used have only a limited range of adjustment.

With 4-wire working, if required, many repeaters may be connected in tandem without producing an instability problem, and the use of precision line balances is unnecessary. The permissible spacing between repeaters is determined largely by crosstalk considerations. In the example illustrated, it will be seen that throughout the circuit the level difference between go and return circuits does not exceed 23 db.

Considering the closed loop formed via the two hybrid transformers in the 2-wire and 4-wire circuits and summing the gains and losses, assuming the loss across one hybrid between go and return circuits to be L db, gives the following.

(*a*) 2-*wire Circuit*

$$-L + 16 - L + 16 = 32 - 2L.$$

Hence, for stability $32 - 2L \nless 0$.

Therefore, $L \nless 16$ db.

(*b*) 4-*wire Circuit*

$$-L - 9 + 23 - 23 + 23 - 9 - L - 9 + 23 - 23 + 23 - 9$$
$$= -2L + 10.$$

Hence, for stability $-2L + 10 \nless 0$.

Therefore $L \nless 5$ db.

The simplified problem of maintaining stability with 4-wire working is therefore apparent.

Question 23.

What transmission advantages would arise from making the circuit from subscriber to subscriber 4-wire throughout? What would be the disadvantages of such an arrangement?

ANSWER. The subscriber's instrument could be simplified, the transmitter being connected to the subscriber's transmit pair and the receiver to his receive pair. To obtain the maximum transference of power, transmitter and receiver could be designed so that their impedances matched the lines' characteristic impedances, or transformers could be provided to give this matching condition. In the present 2-wire instrument a form of hybrid transformer connects the 2-wire line to the transmitter and receiver; this inevitably gives rise to a loss between the 2-wire line and the transmitter and receiver. This loss would be eliminated by the use of a 4-wire instrument, so increasing the sending and receiving efficiencies, and this could be taken advantage of by increasing the local-line limits or by decreasing the conductor gauge. There would be no side-tone from the 4-wire set and this would have the effect of causing the speaker to raise his voice, so increasing the sending efficiency. The total effect would thus be to increase the efficiency of transmission between the two subscribers. As the circuit between subscribers is to be 4-wire throughout no hybrid transformers would be fitted and there would be no "singing loop" to guard against. This could allow a widening of the limits within which the gain of a circuit must be maintained since there would be no possibility of an electrical "singing loop."

There would be one obvious disadvantage in that all the transmission paths of the local equipment, from subscribers to the existing trunk exchanges, would have to be duplicated and the cost of this would be considerable. Because of the increase in sending and receiving efficiencies the crosstalk in lines and exchange equipment would be more disturbing by the sum of the improvements in the sending and receiving efficiencies, and to reduce this disturbing effect the crosstalk attenuation of lines and equipment would have to be increased. The complete absence of side-tone might prove to be disturbing to the subscribers, the circuits appearing "dead," and it is likely that a small amount of side-tone would therefore have to be introduced.

6—COMPONENTS

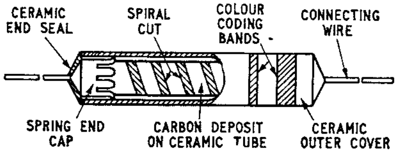
Characteristics and performance of common types of resistors, inductors, transformers and capacitors used in line and radio systems for communication and broadcasting.

Question 24.

Describe, with the aid of sketches, the construction of (a) a carbon-film (surface-type) resistor, and (b) a moulded carbon-composition resistor.

Compare the general characteristics and performances of these two types of resistor.

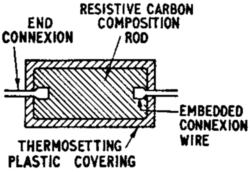
ANSWER. (*a*) Sketch (*a*) shows the construction of a cracked-carbon (or crystalline-carbon film) resistor, which is one form of surface-type carbon resistor. The resistance element consists solely of carbon in a hard grey crystalline form without any binding material mixed with it.



(*a*)

A film of this crystalline carbon is formed, by a heat process, directly on an insulating rod or tube. The carbon film is then sometimes cut spirally to the required resistance value. In other forms of construction the surface film is not spiral cut. Connecting caps of springy metal are pressed on the ends of the rod and a rigid electrical and mechanical contact is thus obtained, to which the terminal connecting wires are attached in some convenient way. The whole is then enclosed in a protecting and insulating ceramic case with ceramic end-seals and is vacuum impregnated for protection against humidity. When a higher wattage rating is required, a non-insulated type (i.e. without the outer insulating cover) is used. Certain manufacturers indicate the resistance values by coloured bands conforming to an internationally-agreed colour code. Others print the resistance and tolerance values on the resistor.

(*b*) Sketch (*b*) shows the construction of a typical moulded carbon composition resistor of the insulated type. Different manufacturers adopt different constructions. The raw material of the resistance element (carbon black, resin binder, and refractory filling) are first graded, then mixed in the required proportions, and sifted. The resultant black powder is compressed into shape and "cured" in a kiln which solidifies the unit. Tests are then carried out with automatic sorting of resistance values before marking with the standard colour code, or resistance value, on the outer insulating cover. The end connexions are made to the resistor by moulding the enlarged ends of tinned copper connecting wires directly into the carbon rod. There are various other methods of attaching the end connexions. A thermosetting plastic insulation is moulded



(*b*)

around the resistance element, hence the term insulated type, to prevent short circuit to adjacent components and metal chassis, and to form protection against humidity.

Characteristics

(*i*) Power handling capacity. Much the same. Commonly up to about 2 watts. Rarely much higher.

(*ii*) Resistance accuracy. Composition, ± 5 per cent, ±10 per cent, ±20 per cent of the nominal batch resistance value during manufacture, the tolerances being wide because of the lack of precise control in composition. Film resistors are accurate to 0·1 to 2 per cent.

(*iii*) Maximum operating temperature. Composition, 115°C. Film, 150°C. Composition seriously affected by high temperature, mainly by changes in the structure of the binder in the resistance mix.

(*iv*) Frequency range. Composition, several Mc/s. Film, hundreds of Mc/s.

(*v*) Maximum operating voltage. Determined by physical shape. Much the same (about 1,600 volts) for insulated types. Non-insulated composition (about 1,500 volts) higher than film (about 800 volts).

Performance

(*i*) Stability. This is the permanent change in resistance under storage or working conditions. With normal working, composition is of the order of 5 per cent (but up to 25 per cent in more severe conditions). Film, 1 to 3 per cent. Storage (one year), composition = 5 per cent, film = 0·5 per cent. High temperature results in permanent change in resistance value; the composition change is much greater than the film.

(*ii*) Humidity. Causes increase in resistance, the effect being largely reversible and not permanent. Composition change is about seven times that of film.

(*iii*) Noise due to internal changes in the resistor when current flows. High level in composition, low level in film.

(*iv*) Temperature coefficient (the temporary change in resistance with temperature). Composition high compared with film.

(*v*) Voltage coefficient (the change, usually a decrease, in resistance when voltage applied). Composition has a 0·02 per cent change per volt d.c. compared with 0·001 per cent for film.

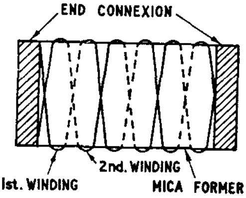
(*vi*) Solderability. Composition is more prone to relatively large percentage change in resistance due to overheating when soldering (about 6 to 1 change compared with film).

It is clear that the film type is of close tolerance and high stability, compared with composition.

Question 25.

Describe the general form of construction of a wire-wound non-inductive resistor and of a composition type of resistor for use at radio frequencies.

List the advantages and disadvantages of the composition type relative to the wire-wound type.

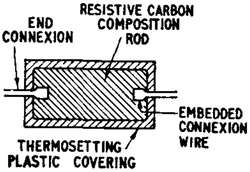


(*a*)

ANSWER. There are several methods of winding non-inductive resistors for use at radio frequencies. The Ayrton-Perry method is illustrated in sketch (*a*).

In this type of resistor a single wire is first wound on a thin sheet of mica leaving, at the edges of the mica, spaces between successive turns equal to the diameter of the wire. A second winding is then wound in the space, in a direction opposite to that of the first winding, and the two windings are connected in parallel. This results in the direction of the current in adjacent turns being always opposite, thus effecting an almost complete cancellation of the magnetic field in their vicinity; the self inductance of the winding is therefore very small. Self-capacitance is also small. The material used for the resistive element should have high resistivity, a melting point well above the operating temperature, and a low temperature coefficient of resistance. The most common wires are nichrome (alloy of nickel and chromium) and eureka (an alloy of copper and nickel).

Alternative methods of winding non-inductive wire-wound resistors are those known as fish-line and bifilar.



(*b*)

The method of construction of composition-type resistors varies among the different manufacturers. The general principle of the construction of one type is illustrated in sketch (*b*). In this resistor the constituents of the resistance element are carbon black, a resin binder and refractory filling. These are mixed, compressed into the required shape and then subjected to heat treatment which solidifies the unit. Connexions are made to the resistor by moulding the enlarged ends of copper wire directly into the carbon rod. A thermosetting plastic insulation is moulded around the resistance element.

The advantages of composition-type resistors, as compared with wire-wound types are:

(*a*) Low cost.
(*b*) Small size.
(*c*) Available in a very large range of values.

(*d*) Readily self-supporting.

(*e*) Lightweight.

The disadvantages of composition-type resistors as compared with the wire-wound types are:

(*a*) Noticeable decrease in resistance value as the applied voltage is increased.

(*b*) Resistance values do not remain stable with time.

(*c*) Operating temperature must be low and this limits the power-handling capacity.

(*d*) Inherently noisy.

Question 26.

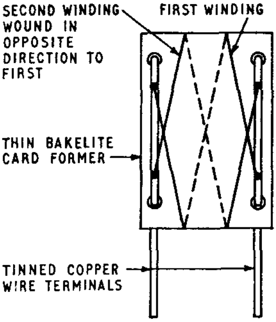
A wire-wound resistor for high-frequency application is required to have minimum self-inductance and minimum self-capacitance. Sketch and describe the construction of a suitable type, explaining how the self-inductance and self-capacitance are minimized.

Under what circumstances can carbon resistors be used for such applications? Explain why carbon resistors are not always used, the wire-wound resistor being preferred.

ANSWER. An ideal resistor for high-frequency application should be completely non-reactive and thus present the same resistance at all frequencies. If the resistor has inductance and capacitance, inductive and capacitive reactances will exist in addition to the ohmic resistance, and the effective resistance, or impedance, will be different with different frequencies. The resistor may then be unsatisfactory in application as its impedance will not be constant with frequency.

When a length of wire is wound in turns about a central non-magnetic core, a magnetic field is set up when current flows, and this changes when the current changes. The coil thus exhibits inductive reactance. This can only be reduced by reducing the magnetic field.

Adjacent turns, or adjacent sections of turns, of a resistor winding may be regarded as the electrodes of a capacitor, the dielectric being formed by the space, or insulation, between the turns. The winding therefore exhibits capacitive reactance when the current changes and is said to possess self-capacitance. This can be reduced by minimizing the potential between adjacent turns and separating the turns as widely as possible.



The sketch shows the construction of a typical resistor with an Ayrton-Perry winding, giving small inductance and capacitance. The former consists of a thin bakelite card with tinned copper-wire terminals. A single wire (eureka, nickel-chromium alloy, etc.) is wound so that the space between the turns is equal to the diameter of the wire, or a little more. A second wire is then wound in the opposite direction, in the space between the first turns, so that the magnetic effects of the two wires cancel out and the winding is almost non-inductive. The distributed capacitance is also very small as adjacent turns are at nearly the same potential. The single-layer winding, the low permittivity of the bakelite former, and the use of bare wire, which has no high-permittivity insulation, also contribute to low capacitance. The two windings are soldered to the wire terminals and so the windings are in parallel from the electrical point of view.

Thus, in general, the windings of non-reactive wire-wound resistors are arranged in two equal parts, a "go" section and a "return" section, but no matter how this fundamental method is varied, there always remains a small residual magnetic effect since the inductance can only be made zero if the go and return sections coincide exactly, and this is difficult to achieve in practice. The turns of each section are placed as close as possible to minimize this effect, but this, in turn, increases the self-capacitance. To reduce self-capacitance to a minimum, not only must the potential difference between turns be as low as possible but the turns should also be widely spaced and this conflicts with the non-inductive requirement. It follows, therefore, that a satisfactory resistor is a compromise between the effects of inductance and capacitance.

The carbon-composition type of resistor is not of solenoid construction and is thus non-inductive and non-capacitive for all practical purposes. There is a small capacitance between the two end-caps, which carry the wire terminals, but this is negligible. The carbon-film resistor which has a spiralled groove simulating a single-layer coil introduces a slight inductive and capacitive effect. This, however, is very small as the simulated coil is of single layer, and the "turns" are few and relatively widely spaced. Thus carbon resistors could be used for non-inductive and non-capacitive applications in high-frequency work.

The power ratings of carbon resistors are usually small and the resistance value is not always to close tolerances. Thus, in circumstances where a relatively high power rating, or a close-tolerance resistance value, or both, is required, the carbon resistor would not normally be used, a suitable wire-wound type being preferred.

Question 27.

What do you understand by the following terms with respect to resistors:
(a) Bifilar, (b) Ayrton-Perry, and (c) Fish-line?

Explain in some detail, how each arrangement achieves its purpose and comment on the relative efficiencies of the three arrangements.

ANSWER. The three terms relate to methods of winding wire-wound resistors to minimize reactance.

An ideal resistor for high-frequency applications should be non-reactive and thus present the same resistance at all frequencies. If the resistor has inductance and capacitance, inductive and capacitive reactances will exist in addition to the ohmic resistance and the effective resistance (impedance) will be different at different frequencies. The resistor may then be unsatisfactory in use.

If a length of wire is wound in turns, a magnetic field, similar to that of a bar magnet, is set up when current flows. When the current changes, the field changes and the coil exhibits inductive reactance. The coil is said to possess self-inductance, which can be reduced by reducing the magnetic field. This may be achieved by arranging for the field set up by one conductor to be cancelled out by an opposing field set up by an adjacent conductor.

Adjacent turns, or sections of turns, of a resistor may be regarded as the electrodes of a capacitor, the dielectric being formed by the space (or insulation) between turns. The winding exhibits capacitive reactance when the current changes and is said to possess self-capacitance. This can be reduced by minimizing the potential difference between adjacent turns and separating the turns as widely as possible.

(*a*) *Bifilar*

The wire is bent sharply back on itself and the double wire is wound on a former. This winding is virtually non-inductive since the magnetic effects of the "go" and "return" halves cancel out, but the distributed capacitance is relatively high as adjacent turns are at a relatively high potential difference.

(*b*) *Ayrton-Perry*

A single wire is wound, leaving space between turns a little more than the diameter of the wire. A second wire is then wound in the space between the first turns, in parallel with the first, but in the opposite direction so that the magnetic effects of the two wires cancel out, the resistor being almost non-inductive. The distributed capacitance is also very low as adjacent turns are virtually at the same potential.

(*c*) *Fish-line*

The wire is wound, in a single layer, around a silk cord with a relatively large space between the turns. This coil is then space-wound in a wide helix in grooves on a cylindrical former. The flux due to the turns is in concentric opposition relative to the "core" of the helix. The coil-turns on one side of the former thus magnetically phase-aid, and those on the other side phase-oppose. The "core" flux due to the helix and the resultant "bar magnet" type field is virtually zero. The self-capacitance is low due to the low potential difference, and the relatively wide spacing, between adjacent coil-turns. While there is a relatively large potential difference between the few turns of the helix, the capacitive effect is negligible due to the wide spacing between these turns.

The basis of (*a*) and (*b*), and in part that of (*c*), is to arrange the winding in two equal parts, a "go" and "return," but no matter how this fundamental method is varied, there always remains a small residual magnetic effect since inductance can only be made zero if the go and return sections coincide exactly. The turns of each section could be placed in close proximity to achieve this, but this in turn would introduce self-capacitance. To minimize self-capacitance, not only must the potential difference between adjacent turns be as low as possible, but the turns should also be widely spaced, which would increase the residual inductance. It follows, therefore, that no matter which winding method is adopted, a satisfactory resistor for high frequencies is a compromise between the effects of residual inductance and residual capacitance.

In theory, while the Bifilar method could approach the ideal of exact balance of go and return sections more than the other techniques, in that the self-inductance is virtually zero, the self-capacitance is high. In practice, the self-inductance would be much the same as the Ayrton-Perry, which technique has the additional advantage of negligible self-capacitance. The Fish-line technique has low self-inductance and low self-capacitance, but, in theory, both these residual effects could be made less by the Ayrton-Perry technique.

Question 28.

Describe any constructional features which may be adopted in the design of a magnetic-core inductor to reduce the losses when the inductor carries high-frequency currents.

ANSWER. The losses at high frequencies are as follows:

(*i*) Winding losses. These consist of the resistance of the winding and eddy currents in winding and screens.

(*ii*) Core losses. These consist of eddy currents flowing in the core and hysteresis effects.

(*iii*) Dielectric losses. These are due to the self-capacitance of the winding.

(*i*) Alternating current in a wire is accompanied by a changing electromagnetic field which links the wire. The resultant induced e.m.f. in the wire has the effect of causing the current to flow mainly near the outer surface, thus effectively reducing the cross-sectional area and increasing the resistance and the loss (skin effect). This loss may be reduced by increasing the effective surface area of the conductor by stranding, or by the use of copper tube or strip.

Eddy currents are set up in adjacent turns and screens when a.c. flows; these currents produce fields opposing that due to the current in the inductor and thus reduce the inductance. This loss may be reduced by stranding the conductor (insulated) and by mounting the inductor as far as possible from other conducting bodies.

(*ii*) The changing flux passing through the core produces eddy currents in it; these currents set up fields opposing the field due to the current in the winding and thus reduce the inductance. Core losses may be reduced by using high electrical-resistivity cores obtained by subdividing the core either by thin insulated laminations of high-permeability alloy or by using iron in the form of dust contained in a moulded insulating material.

Hysteresis in the core causes the magnetic flux to lag behind the magnetizing force and causes a loss due to power being expended during magnetization. This loss can be reduced by using low-hysteresis loss magnetic material and by working at low flux densities.

(*iii*) Dielectric loss results from solid dielectrics being subjected to alternating electric fields and power is dissipated in heat. This loss occurs in the former and in the insulating material on the wire. The loss in the former is minimized by avoiding the use of high-permittivity materials. The self-capacitance of the winding is effectively a shunt loss between the turns and causes a dielectric loss. The methods of avoiding excessive self-capacitance aim at minimum insulation on the wire and avoiding the use of high-permittivity materials for such insulation, using air separation where possible, and at reducing the stress on the dielectric by separating parts of the coil at different potentials. Winding methods to obtain low self-capacitance in this way are:

(*a*) Sectional winding. The turns are grouped into sections, each consisting of several layers with a small number of turns per layer.

(*b*) Bank winding. Alternate turns are wound on the top of the previous turn in a two-turn layer to ensure that the potential difference between adjacent turns is small.

(*c*) Spaced-layer winding. The turns of a multi-layer winding are wound backwards and forwards in the usual way, but layers are separated by air spaces.

(*d*) Basket winding. A single-layer winding in which adjacent turns cross at an angle.

(*e*) Spider-web winding. A coil of one turn per layer is formed by winding the wire in and out of a number of pins arranged radially in one plane around a central boss.

(*f*) Honeycomb or wave-winding. A multi-layer coil is obtained in which turns of one layer are separated by air spaces and the turns of adjacent layers cross at an angle. The effect is produced by winding in a zigzag manner from side to side of the winding surface.

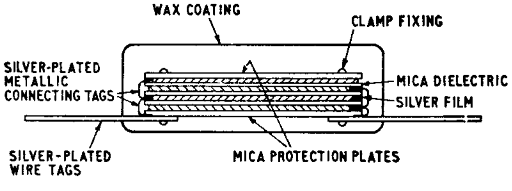
Question 29.

What do you understand by the term "high stability" with respect to capacitors?

Sketch and describe the construction of a capacitor of the high stability type. Give reasons for the choice of materials used and point out the features in the construction which contribute to high stability.

The smoothing arrangements of a power unit utilize an electrolytic capacitor of 40 *microfarads. Why is the type you have described not used for this purpose? Give brief reasons for your answer.*

ANSWER. High stability with respect to capacitors is the ability of a capacitor to maintain its stated characteristics, in particular the capacitance value and the maximum voltage, under storage or service conditions. This implies that there should be small power loss, negligible permanent change in this small loss, and thus negligible change in the capacitance and permissible voltage.



The silver-mica capacitor is a high-stability type. The sketch shows a simplified cross-section of a typical construction. The details of construction differ with different manufacturers. Mica is a most suitable dielectric because of its very low loss, high-voltage rating, and high stability over a wide range of frequencies and temperature. The electrodes consist of films of silver, fired on to the mica plates. The films are close grained, strongly adherent to the mica, and have accurately aligned areas with sharp, well-defined edges. The mica plates are usually 0·001in.thick. The capacitor may be single or multi-plate, and, when multi-plate, consists of a carefully lined-up stack of silvered-mica blades. Alternate silver electrodes are interconnected by silver-plated connecting tags on the respective sides, as shown. These tags connect to the respective silver-plated wire tags which form the two terminals of the capacitor. A thicker mica end-plate (or plates) is used as a strengthening member. Mica is used for these end plates as, particularly with smaller capacitance values, an electrically inferior material affects the electrical properties of the capacitor. The stack of mica blades is clamped and the fixings serve to attach the wire tags. The assembled stack is vacuum impregnated with a high melting-point wax, and is finally given a wax coating to prevent ingress of moisture which would cause loss due to leakage currents.

In some capacitors, in addition to the normal mica blades, a modified blade, known as the grid plate, is included at one end of the stack to permit the final capacitance value to be precisely adjusted. The silver film on this grid plate is in the form of a number of arms and the precise capacitance value is achieved by scraping across the arms, so reducing the effective area of the electrode.

Mica is used for the dielectric because it has the following characteristics:

(*a*) High permittivity with little change in value with life. The high permittivity facilitates the construction of capacitors of small physical size.

(*b*) High dielectric strength. This minimizes the danger of breakdown of the dielectric due to potential gradient across the capacitor.

(*c*) High specific resistance. This minimizes leakage currents and thus the losses.

(*d*) Low dielectric absorption. This minimizes reduction in capacitance at high frequencies.

(*e*) Low electrical loss with negligible change in the loss with life. This negligible change is due to mica being a chemically stable material.

(*f*) No discontinuities in the potential gradient, due to mica being a homogeneous material. Non-homogeneous materials would contain areas of different permittivities and as the potential gradient would be greater across a low permittivity area than across a higher permittivity area, the low permittivity area would tend to breakdown.

Silver is used for the electrodes as it has very low specific resistance. Resistance introduces a power loss in the capacitor and low resistance minimizes this loss. The low specific resistance also permits the use of small electrodes without introducing undue loss. Also, high-resistance surface films, which would give a power loss, do not form on silver under normal conditions.

Wax is used for the sealing and the outer covering, as, when applied in the molten condition, it covers every part of the capacitor to exclude air and moisture and thus protect it.

High stability is ensured by the use of mica and silver for the reasons stated above, and, in particular, because mica is a stable, electrically low-loss material. The almost perfect contact obtained by depositing the silver on to the mica, and the effective sealing by the wax, are features which resist permanent change of the electrical characteristics and also contribute to high stability.

It would be expensive to make a large capacitor by silvered-mica construction and for this reason this type of capacitor would not be used for power-unit smoothing. Also, silvered-mica construction gives a close tolerance capacitor which is unnecessary for smoothing. Electrolytic capacitors give large wide-tolerance capacitance (which is adequate for smoothing) in small volume, and require a polarizing voltage to maintain the anode positive relative to the cathode, a condition which is present in power-unit smoothing. These factors, combined with lower cost for a given large capacitance, make electrolytic capacitors most suitable for smoothing purposes.

Question 30.

Discuss briefly the factors which determine the choice of dielectric in the electrolytic, fixed and variable types of capacitors used in a radio receiver.

Quote typical capacitance values for (a) a preset trimming capacitor as used in a tuned radio circuit, and (b) an electrolytic capacitor. Mention two uses of an electrolytic capacitor.

What determines the shape of the plates required in a variable tuning capacitor?

ANSWER. The main factors which effect the choice of the dielectric in a capacitor are its electric strength, which determines both its thickness for a given working voltage and its size for a given capacitance, the losses in the dielectric (e.g. absorption loss), and the cost. The choice of the type of capacitor and dielectric is largely determined by the purpose for which the capacitor is to be used in the receiver.

In electrolytic capacitors the dielectric is usually aluminium oxide, the high permittivity and electric strength of which permits an extremely thin film of oxide to be used. In this way high value capacitors of small physical size can be made.

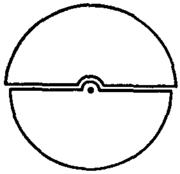
Ceramic dielectric is used in fixed capacitors of low capacitance. This dielectric is chosen because of its very high electric strength and permittivity which give low loss and high power ratings with comparatively small size. Fixed capacitors having larger values of capacitance use paper and mica dielectric. In the paper-type, insulating paper is impregnated with petroleum jelly or chlorinated napththalene which gives fairly high loss and low voltage rating but is relatively cheap and reliable for general use. Mica dielectric capacitors are relatively expensive and are only used where low loss and high electric strength are important.

Small variable capacitors use ceramic dielectric for similar reasons to those quoted above for the corresponding fixed type. Large variable tuning capacitors use air as dielectric. The constructional features of this type of capacitor are largely determined by their functional use, and air, as well as having little or no dielectric loss, is a very convenient form of dielectric.

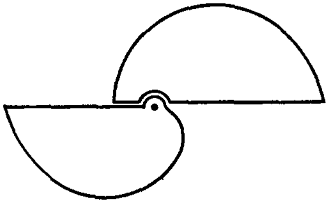
Typical capacitance ranges for a preset trimming capacitor as used in a tuned radio circuit are 2–7pF and 15–50pF. The typical capacitance range of electrolytic capacitors is 2–64μF but much larger values are possible.

Possible uses of an electrolytic capactior are (*i*) to by-pass the cathode bias resistor in an audio-frequency amplifier, (*ii*) to decouple an audio-frequency stage in a radio receiver, (*iii*) as a reservoir or smoothing capacitor in an a.c. power supply unit for a receiver and (*iv*) as the coupling capacitor in a RC-coupled transistor amplifier.

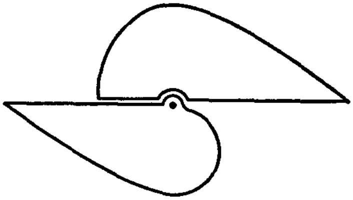
In a variable tuning capacitor, the capacitance is proportional to the area of the overlap of the fixed and moving plates and hence proportional to the angle of rotation. The shape of the plates is determined by the need to achieve linear calibration for the scale or dials in terms of capacitance, wavelength or frequency. Thus in sketches (*a*), (*b*) and (*c*) the angle of rotation is directly proportional to the capacitance, wavelength and frequency, respectively.



(*a*)



(*b*)



(*c*)

Question 31.

State, with regard to the dielectric of a capacitor:

(*a*) *its purpose,*

(*b*) *the desired properties of the material, and*

(*c*) *how its dimensions influence capacitor performance.*

Describe, in general terms, the construction of two capacitors having different dielectric materials. Comment on why each dielectric material has merit for the capacitors you describe.

ANSWER. (*a*). The dielectric, an insulator, enables the electric charge to be stored. A displacement of electrons occurs in the dielectric due to the two oppositely-charged electrodes producing an electric field in the dielectric separating them.

(*b*) The desired properties of a dielectric material are as follows:

(*i*) High permittivity with little change with life. This facilitates the construction of capacitors of small physical size.

(*ii*) High dielectric strength. This minimizes the danger of breakdown of the dielectric due to potential gradient across the capacitor.

(*iii*) High specific resistance. This minimizes leakage current and losses.

(*iv*) Low dielectric absorption. This minimizes reduction in capacitance at high frequencies.

(*v*) Low electrical loss with negligible change in loss as the material ages.

(*vi*) The material should be homogeneous as non-homogeneous materials would contain areas of different permittivities. The potential gradient would be greater across a low permittivity area and this area would tend to break down.

(*c*) The capacitance value is proportional to the effective surface area of the dielectric on contact with the electrodes. It is inversely proportional to the distance of separation of the electrodes, and thus to the thickness of the dielectric.

The silvered-mica and the foil-type dry-electrolytic capacitors will be described.

In the silvered-mica capacitor, the electrodes consist of films of silver deposited on the micas by firing. This process results in a capacitor of high stability, producible to close limits of capacitance. The capacitor may be single-plate or multi-plate; when multi-plate, it consists of a lined-up stack of silvered-mica blades. Alternate silver electrodes are interconnected by silver-plated connecting tags on respective sides. These tags connect to the respective silver-plated wire tags which form the two main terminals of the capacitor. The stack of mica blades is clamped, and the fixings serve to attach the wire tags. Mica protection end-plates ensure mechanical rigidity. The assembled stack is vaccum impregnated in high-melting-point wax to prevent ingress of moisture and consequent loss due to leakage currents. The wax coating forms the outer covering of the capacitor.

Mica has merit in this type of capacitor for all the reasons stated as desired properties in (*b*), and in particular because of its high permittivity (6–7) and high stability.

In the foil-type dry-electrolytic capacitor, two strips of aluminium foil are used. One, the positive, or anode, has a very thin film (a few millionths of an inch) of aluminium oxide, the dielectric, formed on both sides. The second foil is not formed and functions as the contact electrode for the electrolyte cathode. The two foils are separated by two layers of porous paper soaked with the electrolyte, which is usually a mixture paste of glycol and ammonium tetraborate. This electrolyte is the negative, or true, cathode. In addition to carrying the electrolyte the paper also functions as a spacer to separate the anode and cathode foils from direct contact. This assembly is rolled up and the ends closed with wax, and then sealed into an aluminium container having a bakelite end-disk carrying the external soldering tags. Tabs on the anode and cathode foils are connected to the external soldering tags by aluminium rivets.

Aluminium oxide has merit as the dielectric in this type of capacitor because it can be formed in an extremely thin film, and thus a large capacitance can be obtained in a small volume capacitor.

Question 32.

Discuss the main differences in the constructional features of inductors used in the audio and radio-frequency stages of a radio receiver.

A tuned circuit comprises an inductor and capacitor in series and is tuned to a resonant frequency of 1 *Mc/s.*

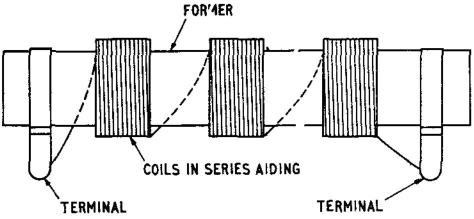
If the value of the inductance is increased by 21 *per cent, what is then the frequency of resonance?*

Answer. The main differences in the constructional features of inductors used in the audio-frequency and radio-frequency stages of a radio receiver relate to the core, former and winding of the inductor.

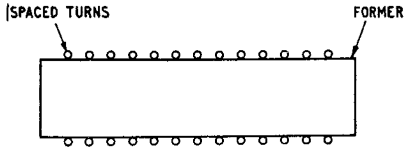
The core of an audio-frequency inductor will be of magnetic material, taking the form of either laminated iron, powdered iron or a rod of the high-permeability material known as ferrite. For audio-frequency inductors carrying d.c. an air-gap is usually included to prevent magnetic saturation. Radio-frequency inductors usually have no core, although in the lower regions of the h.f. band a ferrite rod may be used.

No special consideration is necessary for the formers of audio-frequency inductors, other than low cost and physical strength, and materials such as paxolin or resin-bonded hard-compressed paper may be used. However, at high radio-frequencies, in order to reduce the losses, it is necessary to use low-permittivity formers of materials such as polythene and steatite.

The windings of audio-frequency inductors are usually made with enamelled copper wire, the layers being separated by oil impregnated paper. In large inductors the wire may be further insulated with silk or cotton covering. The only important constructional feature is to ensure that the thickness of the wire is sufficient to carry the required current without overheating. High-frequency inductors have to be wound in such a way that the self-capacitance and the high-frequency resistance effect, known as "skin-effect", are kept to a minimum. For this reason enamelled copper wire is wound into the form of pies, as shown in sketch (*a*), or the coil is wound as a long single-layer solenoid, as shown in sketch (*b*). Litz wire would be preferred but solid copper is usually used because it is cheaper.



(*a*)



(*b*)

In the numerical part of the question, the approximate frequency of resonance is given by $f = \frac{1}{2\pi\sqrt{LC}}$ c/s, where L is in henrys and C is in farads.

Since C remains constant and L increases by 21 per cent,

$$\text{then } f_1 = \frac{1}{2\pi\sqrt{LC}}, \quad \ldots \quad (1)$$

$$\text{and } f_2 = \frac{1}{2\pi\sqrt{1{\cdot}21LC}}, \quad \ldots \quad (2)$$

$$\text{Dividing (2) by (1), } \frac{f_2}{f_1} = \frac{2\pi\sqrt{LC}}{2\pi\sqrt{1{\cdot}21LC}} = \frac{1}{\sqrt{1{\cdot}21}} = \frac{1}{1{\cdot}1}$$

$$\therefore f_2 = \frac{f_1}{1{\cdot}1} = \frac{1{\cdot}0}{1{\cdot}1}\text{ Mc/s} = \underline{0{\cdot}909\text{ Mc/s}}.$$

Therefore, the new resonance frequency is 0·909 Mc/s, or the original resonance frequency is reduced by a factor of 1·1.

Question 33.

Why are inductors sometimes iron-cored and sometimes air-cored? Explain, in general terms, why different inductance values are likely to result from two types.

Explain, with reference to that part of the construction of an iron-cored inductor concerned with the magnetic path only, how good performance may be obtained.

ANSWER. Inductance results when a magnetic flux links electrical conductors. Circular lines of flux are produced when a current flows through a straight conductor. This flux links adjacent conductors to give inductance. The linkage is considerably increased when the conductor is wound as a coil, but despite the increased flux linkage, the inductance value is relatively small due to the small flux value, which, in turn, is due to the low permeability of the air core.

When the coil is wound on an iron core, the flux, the flux linkage, and thus the inductance value, are very much greater than those of an air-cored inductor because of the very high magnetic permeability of the iron.

Thus air-cored inductors give a relatively small and precise inductance value. Iron-cored inductors give a relatively large inductance value in a small volume.

Both air-cored and iron-cored inductors give losses, the greater the frequency the greater the loss. These losses arise from the self-capacitance of the coil, the dielectric loss of any coil-supporting structure, the skin effect and eddy-current losses of the winding, the ohmic resistance of the winding, and the eddy-current and hysteresis losses in the core.

Air-cored inductors can be designed to give less total loss than iron-cored inductors (e.g. the core losses do not arise). Thus air-cored inductors are usually more suitable for very high frequency applications, iron-cored inductors being used at low frequencies.

Good performance of the magnetic path of inductors is achieved by high flux density for a given current and number of turns, with minimum magnetic and power losses. The constructional features to achieve this will depend upon particular inductors, but the following factors should be taken into account.

(*a*) High flux density is achieved by:

(*i*) Using high permeability material.

(*ii*) Minimizing air-gaps in the magnetic path, as the magnetic reluctance of air is considerably greater than that of the magnetic metal parts. Some inductors (carrying both d.c. and a.c. in the winding) include an air-gap to prevent d.c. saturation. The air-gap should then be the minimum consistent with the performance required from the inductor.

(*iii*) Keeping the length of the magnetic path short and the cross-sectional area large for minimum total reluctance, as magnetic reluctance is proportional to the length and inversely proportional to the cross-sectional area of a magnetic part.

(*iv*) Winding the coil as closely as possible to the core to minimize this air-gap and thus reduce the reluctance.

(*b*) Low loss is achieved by the following:

(*i*) Small eddy-current loss. These losses can be reduced by using cores of high resistivity and by sub-dividing the core, either by using laminations of high-permeability alloys (e.g. silicon steel, nickel-iron, etc.), or by using compressed powder magnetic material (e.g. powdered molybdenum alloy). The insulated sheets of the laminated core, and the insulating binder of the powder core confine the eddy currents to separate paths, increase the electrical resistance and reduce the eddy currents. On the other hand. these arrangements tend to reduce the permeability and while this in turn reduces the eddy currents, it also reduces the inductance. Ferrite cores (oxides of iron, zinc and manganese) are sometimes used to overcome this limitation. These cores have no binding agent, nor air-gaps between particles, and for a given volume contain more magnetic material than do cores of magnetic powder or very thing laminations. Thus they have a high permeability and at the same time a low eddy-current loss.

(*ii*) Small hysteresis loss. By using low hysteresis-loss magnetic material and, where possible, working at a low flux density, hysteresis losses may be minimized.

7—MICROPHONES, RECEIVERS AND LOUDSPEAKERS

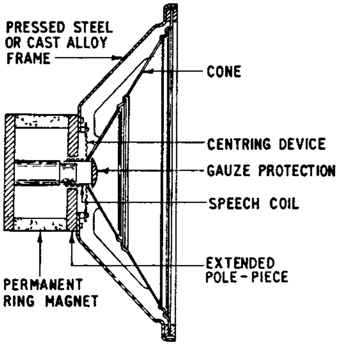
Characteristics and performance of carbon, crystal and moving-coil microphones. Moving-iron and moving-coil loudspeakers and telephone receivers.

Question 34.

With the aid of a sketch, describe a moving-coil loudspeaker and explain its operation. Why are baffle boards normally used with such loudspeakers?

An output tetrode valve is designed to work into an anode load of 5,000 *ohms. What turns ratio is required in order to match a* 3-*ohm moving-coil cone loudspeaker?*

Answer. The construction of a moving-coil loudspeaker is shown in the sketch. The moving (or speech) coil, which usually consists of a few turns of a non-magnetic conductor wound on a light cylindrical former, is suspended so that it can travel backwards and forwards, but is not capable of movement in any other direction. It lies in the field of a permanent magnet, whose field is radial and therefore at right-angles to the moving coil at every point, and is rigidly secured to a light cylindrical cone, which is usually made of paper or treated linen. A flexible self-centring device is attached to the apex of the cone.



The moving coil, when carrying alternating current, is acted on by an axial force (as determined by Fleming's left-hand rule) varying in accordance with the magnitude and duration of the currents. As a result, the coil vibrates backwards and forwards in the air-gap, and these vibrations are directly transmitted to the cone which sets up sound waves in the air.

A baffle is used because it is necessary to isolate the front of the cone from the back to prevent the serious reduction of radiation which would otherwise occur. For example, if no baffle was employed, when the coil moves forward the compressed air at the front of the cone would pass round to the rear of the cone, where the air is rarified, and so the full effect of the sound would not be obtained.

A transformer with a turns ratio of n will be required to match the anode load of 5,000 ohms to a 3-ohm moving-coil cone loudspeaker,

$$\text{where } n = \frac{\text{number of turns in the primary winding}}{\text{number of turns in the secondary winding}}$$

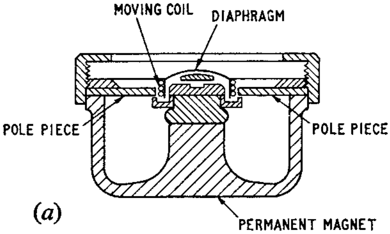
$$= \sqrt{\frac{5{,}000}{3}} \simeq 41.$$

Question 35.

Describe, with the aid of sketches, the construction and operation of: (a) a moving-coil telephone receiver and (b) a moving-iron telephone receiver.

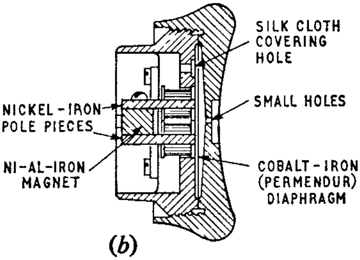
Briefly explain the effect on the operation of each type if the permanent magnet is removed.

ANSWER. (*a*) Sketch (*a*) shows a cross-sectional view of a moving-coil receiver. It consists of a powerful permanent magnet fitted with circular pole pieces to produce a radial field across the air-gap occupied by the moving-coil. The moving-coil, consisting of a large number of turns of fine wire, is rigidly fixed to the diaphragm so that it moves axially between the circular pole-pieces. In operation, the signal from the transmission line passes through the coil and sets up a magnetic field which tends to move the coil relative to the permanent field, as in an electric motor. This movement of the coil causes the diaphragm to move in sympathy, so reproducing the original sound waves.



(*a*)

If the permanent magnet were removed from the moving-coil receiver it would cease to operate, because the operation of this type of receiver depends upon the interaction of the permanent magnet and the moving-coil fields.



(*b*)

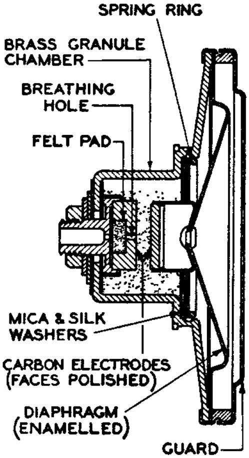
(*b*) Sketch (*b*) shows a cross-sectional view of a modern moving-iron telephone receiver. The polarizing magnet is a powerful permanent magnet of 33 per cent cobalt steel. It carries two soft-iron pole pieces upon each of which is fitted a coil wound with many turns of fine gauge copper wire, the two coils being connected in series (aiding). A circular diaphraghm made of stalloy, a silicon-iron alloy, is rigidly clamped around its periphery between the moulded plastic earcap and the metal case of the receiver. The latter is made of a non-magnetic material, usually aluminium. The size of the air-gap between the normal position of the diaphragm and the pole faces is usually about 0·01 in. In the operation of the receiver the signal from the transmission line passes through the pair of coils and produces small changes in the intensity of the much larger steady magnetic flux set up by the permanent magnet. These changes cause the diaphragm to move in sympathy with the signal and the corresponding vibrations of the diaphragm create the sound waves which are received by the listener.

If the permanent magnet were removed from the moving-iron receiver, frequency doubling would result, because the diaphragm would make one complete vibration for each half-cycle of the alternating current in the coil. The sensitivity of the receiver would also greatly decrease.

Question 36.

Describe with the aid of diagrams the construction and method of operation of a carbon-granule microphone. Explain clearly why a direct current is essential to its operation.

ANSWER. A modern carbon-granule microphone is shown in the sketch. Sound waves consist of alternate compressions and rarefactions in the air.



When a thin flexible diaphragm is placed in the path of such a train of waves it vibrates under the stimulus of the varying air pressure, and the frequency and amplitude of the waves is converted into vibrations of the diaphragm of corresponding frequency and amplitude. The diaphragm is arranged so that these movements alter the pressure on a small quantity of carbon granules, thereby altering the electrical resistance of the conducting path presented by the carbon granules. A unidirectional current, which is passed through the carbon granules, then varies at a rate corresponding to the frequency of the impressed sound wave, and with a magnitude proportional to the amplitude of the waves.

If a direct current is passed continuously through the carbon granules, the current will vary in sympathy with the sound waves; the frequency of the sound creates the same frequency of current changes and the loudness of the sound controls the magnitude of the variation. The current nevertheless remains a direct current, which rises and falls in value but never changes direction. It is equivalent to a direct current of constant value with a superimposed alternating current whose frequency and amplitude are controlled by the sounds. A transformer is used to separate this alternating component and transmit it to the outgoing transmission line, a battery being included in the local circuit to provide the direct current. The transformer usually has a fairly high ratio of secondary to primary turns to match the low-impedance transmitter to the higher impedance of the outgoing line.

Let R ohms be the normal resistance of the quiescent transmitter and its circuit,

I amperes be the steady d.c. produced in the circuit by a battery of V volts,

r be the reduction in resistance produced by a given sound wave, and

i be the corresponding change produced in I.

Then, in the absence of sound, $I = V/R$.

When the sound deflects the diaphragm, a change of current i is produced.

$$\text{Therefore, } I + i = \frac{V}{R - r},$$

$$\text{Hence, } i = \frac{V}{R - r} - \frac{V}{R} = V\frac{r}{R(R - r)} = I\frac{r}{R - r}.$$

If r is small compared with R,

$$i \simeq I\frac{r}{R}.$$

The amplitude of the a.c. component produced by a given sound wave is therefore proportional to

(*a*) the quiescent d.c. in the circuit,

(*b*) the ratio of the change of carbon-granule resistance to the resistance of the transmitter circuit and the quiescent transmitter.

8—TUNED CIRCUITS

Series and parallel tuned circuits; approximate frequency of resonance (without derivation). Use in selection of narrow bands centred on carriers of different frequencies. Bandwidth, half-power (— 3db) points.

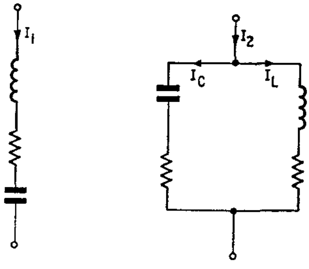
Question 37.

Explain what is meant by resonance in a tuned circuit.

A tuned circuit comprises an inductor and capacitor in series. The inductor has a value of 50 *microhenrys and the frequency of resonance is* 1,500 *kc/s.*

If the capacitance is increased by 100 *picofarads, at what frequency does the circuit resonate ?*

Answer. A tuned circuit may be arranged either in the series form shown in sketch (*a*) or the parallel form shown in sketch (*b*).



(*a*) (*b*)

In the series circuit, at frequencies below resonance the capacitive reactance predominates and current I_1 is very small. At frequencies above resonance the inductive reactance predominates and current I_1 is again small. At some intermediate frequency called the resonant frequency the capacitive and inductive reactances are equal in magnitude but opposite in sign and their effects cancel, so current I_1 is limited only by the resistance. Thus, at resonance the overall impedance becomes purely resistive and has its minimum value, whilst the current has its maximum value.

In the parallel circuit, the line current, I_2 divides between the inductive and capacitive branches. At frequencies below resonance $I_L > I_C$ so that I_C is a relatively large lagging current. At frequencies above resonance $I_C > I_L$ so that I_2 again is relatively large, but now is a leading current. At some intermediate frequency, called the resonant frequency, I_L is exactly 180° out of phase with I_C so that they nearly cancel, leaving only a small in-phase residual current flowing from line. Usually the resistance in the capacitive branch can be neglected, and the line current at resonance is determined solely by the series resistance of the coil.

When the Q-factor of the coil is sufficiently high, the coil resistance also can be ignored (so far as its effect on the resonant frequency is concerned) and then the frequency of parallel resonance is determined solely by the values of L and C and is equal to the series resonance frequency for the same values of L and C.

$$\text{For series resonance, } f = \frac{1}{2\pi\sqrt{LC}}$$

$$\therefore C = \frac{1}{\omega^2 L}, \; (\omega = 2\pi f)$$

$$= \frac{10^{12}}{(2\pi \times 1{\cdot}5 \times 10^6)^2\, 50 \times 10^{-9}} \text{ pF}$$

$$= 225 \text{ pF.}$$

The new value of C is therefore 325 pF.

$$\text{Thus, the new frequency} = \frac{1}{2\pi\sqrt{50 \times 10^{-6} \times 325 \times 10^{-12}}} \text{ c/s}$$

$$= 1{\cdot}25 \times 10^6 \text{ c/s}$$

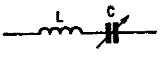
$$= \underline{1{\cdot}25 \text{ Mc/s.}}$$

Question 38.

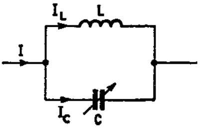
Explain what is meant by "resonance" in a tuned circuit. Briefly discuss the variation of impedance with frequency of a tuned circuit near resonance.

An inductor is tuned to series resonance at 1,500 *kc/s by a capacitor of* 1,600 *pF. What is the new frequency of resonance if the capacitance is increased by* 4,025 *pF?*

ANSWER. A tuned circuit may be arranged either in the series form shown in sketch (a) or the parallel form shown in sketch (b).



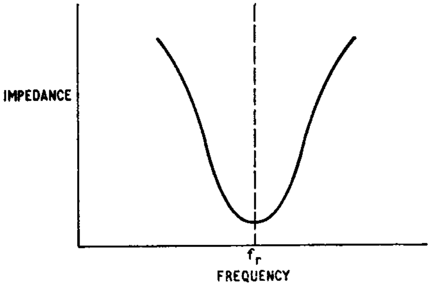
(a)



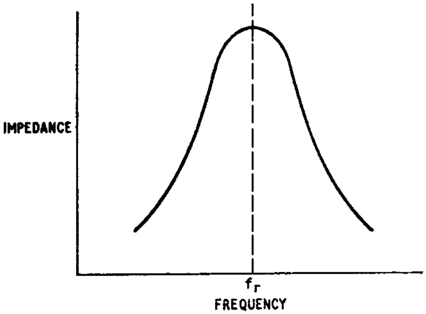
(b)

In the series circuit, the capacitive reactance is large at the lower frequencies and decreases with increasing frequency. On the other hand, the inductive reactance is low at the lower frequencies and increases with an increase of freqnency. At some intermediate frequency capacitive and inductive reactances are equal in magnitude and since they are opposite in sign the effective reactance of the circuit is zero. The overall impedance of the circuit is, therefore, determined by the resistive elements of the circuit and has its minimum value. This is known as the condition of resonance of the tuned circuit and the frequency at which it occurs is the resonant frequency.

In the parallel case this is best considered by reference to the currents flowing in the various parts of the circuit. The line current I divides between the inductive and capacitive branches. At the lower frequencies, because the capacitive reactance is larger, $I_L \gg I$ so that I_C is a relatively large lagging current. At the higher frequencies, because the inductive reactance is large, $I_C \gg I_L$ so that I is again relatively large but is now a leading current. At some intermediate frequency I_L and I_C are equal in magnitude and being 180° out of phase they tend to cancel and leave a small in-phase residual current flowing from the line due to the resistive elements of the circuit. The overall impedance of the circuit, therefore, becomes purely resistive and due to the configuration of the circuit has its maximum value. This is known as the condition of resonance of the tuned circuit and the frequency at which it occurs is the resonant frequency.



(*c*)



(*d*)

Sketches (*c*) and (*d*) show the variation of impedance of a series-tuned circuit and a parallel-tuned circuit, respectively, close to the frequency of resonance. The slope of these impedance-frequency curves on either side of the resonant frequency, f_r, determines the ability of a tuned circuit to select the desired signal at or near its frequency of resonance and to discriminate against signals removed from its frequency of resonance. This property is known as the selectivity of the circuit. The use of either the series-tuned or parallel-tuned circuit for such discrimination depends largely in practice upon the impedance of the source to which the tuned circuit is connected.

For a series-tuned circuit, the frequency of resonance is given by:

$$f_r = \frac{1}{2\pi\sqrt{LC}}\ \text{c/s},$$

where L is in henrys and C is in farads.

In the question,

$$f_{r1} = 1{,}500\ \text{kc/s} = 1{,}500 \times 10^3\ \text{c/s} = \frac{1}{2\pi\sqrt{L \times \frac{1{,}600}{10^{12}}}}$$

$$= \frac{10^6}{2\pi\sqrt{L \times 1{,}600}} \quad .. \quad (1).$$

When the capacitance is increased by 4,025 pF then C_2 becomes 1,600 + 4,025 = 5,625 pF.

$$\therefore\ f_{r2} = \frac{1}{2\pi\sqrt{L \times \frac{5{,}625}{10^{12}}}} = \frac{10^6}{2\pi\sqrt{L \times 5{,}625}} \quad .. \quad (2).$$

Dividing equation (2) by equation (1),

$$\frac{f_{r2}}{1{,}500 \times 10^3} = \frac{\dfrac{10^6}{2\pi\sqrt{L \times 5{,}625}}}{\dfrac{10^6}{2\pi\sqrt{L \times 1{,}600}}} = \frac{\sqrt{L \times 1{,}600}}{\sqrt{L \times 5{,}625}},$$

$$= \frac{\sqrt{1{,}600}}{\sqrt{5{,}625}} = \frac{40}{75}.$$

$$\therefore f_{r2} = \frac{1{,}500 \times 10^3 \times 40}{75}\ \text{c/s}.$$

$$= \frac{1{,}500 \times 40}{75}\ \text{kc/s},$$

$$= \underline{800\ \text{kc/s}}.$$

Question 39.

The anode load of a radio-frequency amplifier consists of a parallel-tuned circuit, the inductor of which has a value of 150 μH. *Neglecting circuit resistance, what value of capacitance will be required to tune the circuit to a frequency of* 1 *Mc/s?*

Give a circuit diagram of such an amplifier with typical component values.

State briefly your reasons for the type of valve chosen.

ANSWER. The impedance of the parallel-tuned circuit will be a maximum at an angular frequency ω, given by

$$\omega^2 = \frac{1}{LC},$$

where L = inductance in henrys
C = capacitance in farads.

The above formula neglects circuit losses.

Now, $\omega = 2\pi \times 10^6$ rad/s
$L = 150 \times 10^{-6}$ henrys.

$$\therefore (2\pi \times 10^6)^2 = \frac{1}{150 \times 10^{-6} \times C}$$

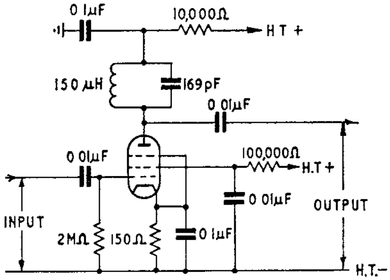
$$\therefore C = \frac{1}{150 \times 10^{-6} \times (2\pi \times 10^6)^2}$$

$$= 169 \times 10^{-12}\,\text{F}$$

$$= \underline{169\,\text{pF.}}$$

The circuit diagram of a typical amplifier is given in the sketch. A pentode valve is used for the following reasons:

(*i*) No neutralization is necessary. The screen grid, being earthed to r.f., acts as an efficient screen between the grid and anode. The grid–anode capacitance is reduced to negligible proportions and feedback between the input and output circuits is avoided.



(*ii*) In general, a r.f. amplifier employing a pentode valve gives a higher gain than one employing a triode valve.

(*iii*) The high anode-slope resistance of a pentode results in a selectivity curve approaching the impedance/frequency curve of the tuned circuit.

Question 40.

If one section of a two-gang variable tuning capacitor is used to tune the aerial circuit to the incoming signal, calculate the maximum and minimum values of the capacitor required to cover the frequency range 500–1,500 *kc/s when tuned with an inductance of* 150 *μH. Hence write down the range of the second section required to tune the frequency-changer oscillator over the range* 1,000 *kc/s to* 2,000 *kc/s, if the same value of inductance is used to tune the oscillator circuit.*

ANSWER. The resonant frequency, f_0, of a tuned circuit having capacitance C and inductance L, is given by

$$f_r = \frac{1}{2\pi\sqrt{LC}}, \text{ i.e. } C = \frac{1}{4\pi^2 f_0^2 L}.$$

Thus, to tune the signal circuit to resonance at 500 kc/s,

$$\begin{aligned} C &= \frac{1}{4\pi^2 \times (500 \times 10^3)^2 \times 150 \times 10^{-6}} \text{ farad} \\ &= \underline{678 \text{ pF.}} \end{aligned}$$

With the inductance, L, constant,

$$f_r \propto \frac{1}{\sqrt{C}}, \text{ or } C \propto \frac{1}{f_r^2}.$$

This relationship may be used to calculate the capacitance required for resonance at 1,500 kc/s and 2,000 kc/s in the following manner:

$$\begin{aligned} \text{Capacitance at 1,500 kc/s} &= \text{Capacitance at 500 kc/s} \times \frac{1}{\left(\frac{1{,}500}{500}\right)^2} \\ &= \text{Capacitance at 500 kc/s} \times 1/9 \\ &= \frac{678}{9} \text{ pF} \\ &= 75{\cdot}3 \text{ pF.} \end{aligned}$$

$$\begin{aligned} \text{Capacitance at 1,000 kc/s} &= \text{Capacitance at 500 kc/s} \times \frac{1}{\left(\frac{1{,}000}{500}\right)^2} \\ &= \frac{678}{4} \text{ pF} \\ &= 169{\cdot}5 \text{ pF.} \end{aligned}$$

$$\begin{aligned} \text{Capacitance at 2,000 kc/s} &= \text{Capacitance at 500 kc/s} \times \frac{1}{\left(\frac{2{,}000}{500}\right)^2} \\ &= \frac{678}{16} \text{ pF} \\ &= \underline{42{\cdot}5 \text{ pF.}} \end{aligned}$$

Thus, the range of capacitance in the aerial circuit is, say, 70–700 pF, and the range of oscillator capacitance is, say, 40–170 pF.

Question 41.

Explain, by reference to a frequency response curve, how a tuned circuit may be used to provide selectivity in a radio frequency amplifier.

The measured response of a parallel tuned circuit is as shown in Table I.

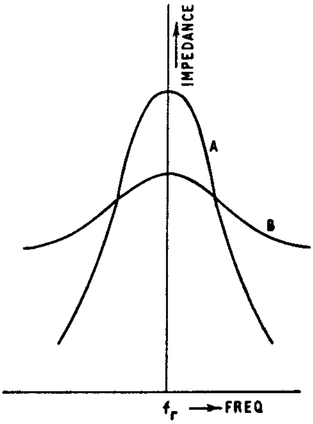
Table I.

Frequency in kc/s	245	246	248	249	250	251	252	254	255
Voltage	35	55	83·5	96	100	96	83·5	55	35

Plot the response curve and use it to determine the bandwidth of the tuned circuit at the half power $(-3db)$ *points.*

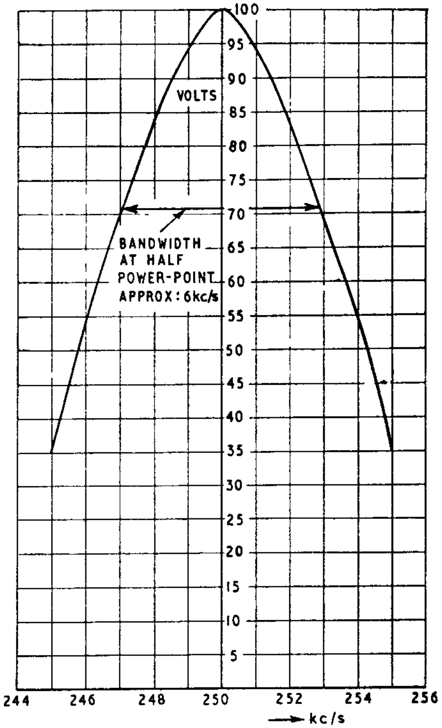
Briefly comment on the suitability of such a circuit for use in a medium-wave broadcast receiver.

Answer. Two examples of the variation of impedance with frequency for a parallel-tuned LC circuit are shown in sketch (*a*). These curves show that the impedance of a parallel-tuned LC circuit is a maximum at the frequency of resonance, f_r, and decreases in value on either side of f_r. This characteristic of a parallel-tuned LC circuit may be used in a receiver by connecting such a circuit as the anode load in the radio frequency amplifier stage of the receiver. Since the voltage amplification factor of a radio frequency amplifier is almost directly proportional to the value of its anode load impedance, a desired signal at the resonance frequency of the anode load will be amplified more than undesired signals received at frequencies off resonance. This property of the tuned circuit, known as selectivity, is dependent upon the slope of the curve on either side of the resonance frequency. Thus, referring to sketch (*a*), curve A has a greater selectivity than curve B.



(*a*)

The response curve is given in sketch (*b*).



(*b*)

The half-power (−3 db) point may be found by using the relationship that

$$N = 10 \log_{10} \frac{P_1}{P_2} \text{ decibels} = 20 \log \frac{V_1}{V_2} \text{ decibels.}$$

For the half-power (−3 db) point,

$$-3 = \log 20 \frac{V_1}{V_2}$$

$$\log \frac{V_1}{V_2} = \frac{-3}{20} = -0{\cdot}15$$

$$\text{or } \log \frac{V_2}{V_1} = 0{\cdot}15.$$

$$\therefore \quad \frac{V_2}{V_1} = \text{anti-log } 0{\cdot}15 = 1{\cdot}413.$$

$$\text{Since } V_2 = 100 \text{ volts then } V_1 = \frac{100}{1{\cdot}413} = \underline{70{\cdot}7 \text{ volts.}}$$

Referring to the response curve, the bandwidth at a voltage of 70·7 volts is given by AB. This bandwidth = <u>6 kc/s.</u>

Alternatively:

$$\text{Since } P \propto V^2$$

$$\text{then } V \propto \sqrt{P}$$

$$\text{Thus, if } \frac{P_1}{P_2} = \frac{1}{2}$$

$$\text{then } \frac{V_1}{V_2} = \frac{1}{\sqrt{2}} = 0{\cdot}7071$$

$$\therefore V_1 = 100 \times 0{\cdot}7071 = \underline{70{\cdot}7 \text{ volts,}} \text{ as before.}$$

In order to accommodate a reasonable number of radio broadcast transmissions in the long and medium wavebands it has been agreed internationally that the carrier frequency spacing shall be 9 kc/s. Hence, the highest audio frequency transmitted is 4·5 kc/s; this gives reasonable quality when music is broadcast. Since the response curve shown in figure (*b*) only has a total bandwidth of 6 kc/s at the half-power points, such a circuit would give rather poor quality reproduction when used in a broadcast receiver, particularly for the reception of music.

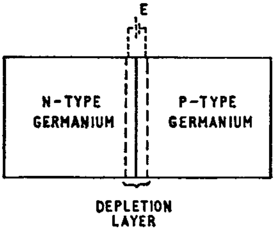
9—THERMIONIC VALVES AND SEMICONDUCTOR DEVICES

Characteristics and essential features of semiconductor diodes and transistors, thermionic diodes, triodes, tetrodes, beam tetrodes, and pentodes.

Question 42.

By reference to the formation of a potential barrier and to a current/voltage characteristic explain the rectifying action of a p–n *junction.*

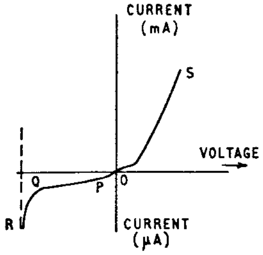
ANSWER. If a crystal of n-type germanium and a crystal of p-type germanium are joined, the junction is known as a p–n junction and has properties which enable it to be used as a rectifier. In practice it is not possible to join two separate germanium crystals and form a perfect junction but it is possible to prepare a single crystal which has n-type characteristics at one end and p-type characteristics at the other and which behaves as a perfect junction.



(*a*)

Sketch (*a*), which is for explanatory purposes only and should not be taken as a sketch showing the construction of the device, shows a p-n junction with n-type germanium on the left and p-type germanium on the right. N-type germanium has an excess of electrons which act as negative charge carriers and p-type germanium has an excess of positive charge carriers known as "holes". At the junction electrons from the n-type material tend to move into the p-type area and "holes" from the p-type area into the n-type area. This movement of "holes" and electrons across the p-n junction causes a thin layer known as the depletion layer, to be set up which consists of n-type germanium positively charged and p-type germanium negatively charged. This condition is equivalent to a source of potential and may be represented by an imaginary battery, E.

If now an actual battery is connected across the p–n junction in such a direction that it assists the barrier potential the strengthening of the barrier has the effect of increasing the junction resistance. However, due to thermal agitation there is a flow of minority carriers which causes a small reverse current to flow, and this remains relatively steady until the breakdown voltage is reached. These conditions may be represented by part OPQR of the graph in sketch (*b*). The reverse-current scale is different from the forward-current scale in the graph.



(*b*)

If the battery is connected across the junction to oppose the potential barrier then the effective resistance of the junction is lowered allowing a flow of majority carriers, which gives rise to a large current flow. This condition is represented by OS of the graph in sketch (*b*).

When an alternating voltage is applied across such a junction, current will flow during alternate half-cycles, resulting in a rectifying action.

Question 43.

Measurements made on a triode valve are as follows:

Anode Volts (V_a)	*Anode Current* (*mA*)					
	$V_g = 0$	$V_g = -1$	$V_g = -1$	$V_g = -3$	$V_g = -4$	$V_g = -6$
100	8·2	3·6	0·8	—	—	—
150	15·2	7·6	2·4	0·4	—	—
200	22·8	13·2	5·6	2·0	—	—
250	32·0	20·0	10·0	5·0	2·0	—
300	—	26·8	16·7	9·0	4·8	0·4

Plot the mutual characteristics for $V_a = 200$, 250 *and* 300 *volts and the anode characteristics for* $V_g = 0$, -1 *and* -2 *volts. Use these curves to determine the mutual conductance, anode slope resistance and the amplification factor of the valve over the straight part of its characteristics.*

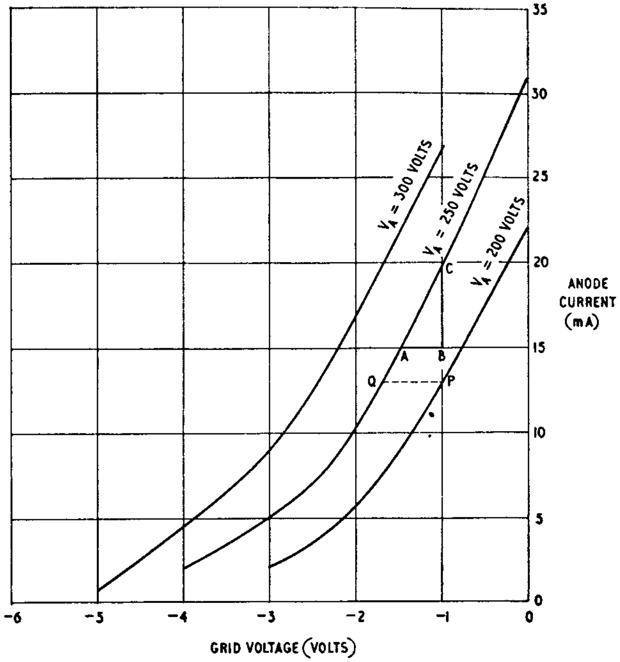
ANSWER. The mutual and anode characteristics for the triode valve are given in sketches (*a*) and (*b*), respectively.

The mutual conductance, g_m, is defined as:

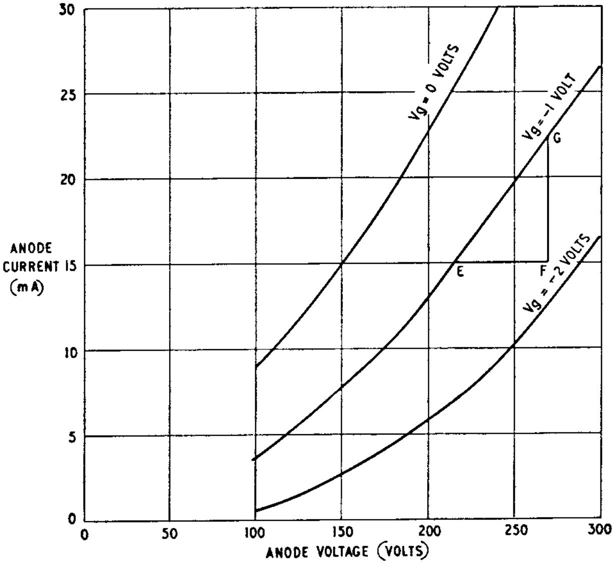
$$g_m = \frac{\text{Change in anode current}}{\text{Change in grid voltage}},$$

the anode voltage remaining constant. From sketch (*a*) it is seen, when the anode voltage is 250 volts, that a change in grid voltage from A to B causes the anode current to change from B to C.

$$\text{Hence, } g_m = \frac{(20 - 15)\text{ mA}}{(1\cdot5 - 1\cdot0)\text{ volts}} = \frac{5\text{ mA}}{0\cdot5\text{ volts}} = \underline{10\text{ mA/volt.}}$$


$V_A = 300$ VOLTS
$V_A = 250$ VOLTS
$V_A = 200$ VOLTS
C
A
B
Q
P
35
30
25
20
15
10
5
0
ANODE CURRENT (mA)
−6
−5
−4
−3
−2
−1
0
GRID VOLTAGE (VOLTS)

(a)


Vg = 0 VOLTS
Vg = −1 VOLT
Vg = −2 VOLTS
G
E
F
30
25
20
ANODE CURRENT 15 (mA)
10
5
0
0
50
100
150
200
250
300
ANODE VOLTAGE (VOLTS)

(b)

The anode slope resistance, r_a, is defined as;

$$r_a = \frac{\text{Change in anode voltage}}{\text{Change in anode current}},$$

the grid voltage remaining constant. From sketch (*b*) it is seen, when the grid voltage is -1 volt, that an increase in anode voltage from E to F causes the anode current to change from F to G.

$$\text{Hence, } r_a = \frac{(270 - 215)\text{ volts}}{(22{\cdot}5 - 15)\text{ mA}} = \frac{55\text{ volts}}{7{\cdot}5 \times 10^{-3}\text{ amp}} = \underline{7{,}340\text{ ohms}},$$

The amplification factor, μ is defined as:

$$\mu = \frac{\text{Change in anode voltage}}{\text{Change in grid voltage}},$$

for the same change in anode current. From sketch (*a*) it is seen that a change in anode current CP is produced by a change in anode voltage from 250 to 200 volts or by a change in grid voltage of QP.

$$\text{Hence, } \mu = \frac{(250 - 200)\text{ volts}}{(1{\cdot}65 - 1{\cdot}0)\text{ volts}} = \frac{50}{0{\cdot}65} = \underline{77.}$$

Question 44.

Sketch sets of characteristics curves for the following:

(*a*) *I_a against V_g for various values of V_a for a triode valve.*

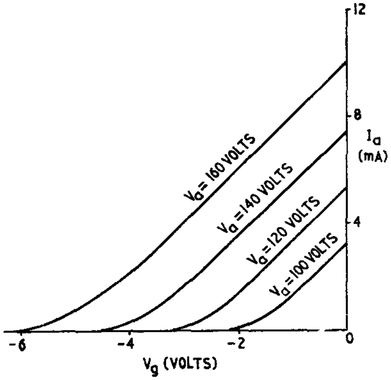
(*b*) *I_a against V_a for various values of V_g for a pentode valve.*

(*c*) *I_c against V_c for various values of I_b for a transistor in the common emitter connexion.*

(*d*) *I_c against I_e for a given value of V_c for a transistor in the common-base connexion.*

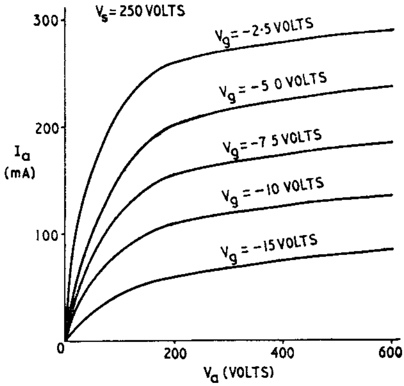
State what information may be derived from the slope of the straight portion of each of these curves.

ANSWER. The curves showing the required characteristics are given in sketches (*a*), (*b*), (*c*) and (*d*).



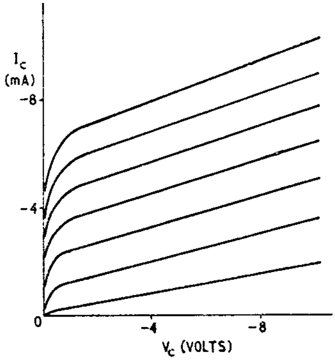
(*a*)

(*a*) The curves shown in sketch (*a*) are known as the triode mutual characteristics. The slope of the straight portion of these curves determines the control which the grid has on the anode current. This control is usually quoted in milliamperes of anode current change for one volt change in grid potential and is called the mutual conductance of the valve.



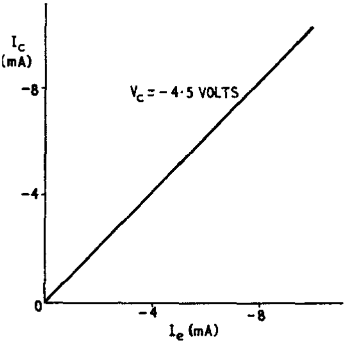
(*b*)

(*b*) The curves shown in sketch (*b*) are known as the pentode anode characteristics. The slope of the straight portion of the curves gives the control which the anode potential has on the anode current for the particular values of control and screen grid potential. This slope is called the anode conductance but its reciprocal, the anode a.c. resistance of the valve, is more widely used.



(*c*)

(*c*) The curves shown in sketch (*c*) are known as the output characteristics for the transistor in the common-emitter connexion. Just as in (*b*), the reciprocal of the slope of the straight portion of these curves gives a resistance. This resistance is the effective internal resistance of the transistor when it is acting as a source of a.c. supply to a load circuit.



(*d*)

(*d*) The curve shown in sketch (*d*) is known as the transfer characteristic for the transistor in the common-base connexion. The slope of this line indicates the current-gain factor of the transistor.

Question 45.

Discuss the shortcomings of triode valves and explain why pentode valves are commonly preferred to triodes in the high-frequency sections of medium-wave radio receivers.

ANSWER. The principal difficulty of radio-frequency amplification by means of triodes arises from the capacitance that exists between the control grid and the anode, and which becomes of increasing importance at the higher frequencies. As a result of this inter-electrode capacitance, which may amount to several picofarads, the valve input impedance becomes to some extent dependent on anode-load impedances. Thus, at frequencies at which the anode-load impedance becomes inductive, positive feedback of energy from the anode to the grid circuit may take place. When this positive feedback becomes sufficient it will cause the stage to oscillate. Alternatively, the load impedance may become capacitive, resulting in negative feedback of energy from anode to grid with a tendency to suppress the input signal.

There are three principal reasons why pentode valves are preferred to triodes in the high-frequency sections of medium-wave radio receivers, namely, better stability, increased amplification and improved selectivity.

The cause and effect of instability has already been referred to above. Pentode and tetrode valves each have a screening grid, located between the control grid and anode, which is effectively at earth potential to the signal frequencies. This additional grid reduces the control-grid–anode capacitance, so greatly reducing the unwanted coupling and improving the stability of an amplifier using such valves.

Pentode valves commonly have much higher amplification factors than triode valves and this factor, coupled with the improved stability possible with amplifiers employing pentode valves, enables an increased amplification to be achieved.

Finally, the anode impedance of a pentode valve used in the high-frequency section of an amplifier is much higher than that of a triode valve. Since this anode impedance is effectively in parallel with the tuned-anode circuit of the amplifier then it follows that the pentode valve will have far less effect in reducing the selectivity of the tuned-anode circuit than would a triode valve.

Question 46.

The data given in Tables A and B refer to a transistor in the common-emitter configuration.

Table A

Collector voltage V_c		− 2	− 4	− 6	− 8	− 10
Collector current I_c (*mA*)	*Base current* − 120μA	− 6·4	− 7	− 7·6	− 8·2	− 8·8
	Base current − 80μA	− 4·4	− 4·8	− 5·2	− 5·6	− 6·0
	Base current − 40μA	− 2·2	− 2·4	− 2·6	− 2·8	− 3·0

Table B

Collector voltage $V_c = -4{\cdot}5$ *V*					
Base current I_b (μA)	0	− 5	− 10	− 15	− 20
Collector current I_c (*mA*)	− 0·15	− 0·45	− 0·75	− 1·1	− 1·4

Use the data in Table A to plot the collector voltage/collector current characteristics for $I_b = -40$, -80 *and* -120 μA, *and from the characteristic* $I_b = -80$ μA *deduce the output resistance of the transistor. Use the data in Table B to plot the collector current/base current characteristic for* $V_c = -4{\cdot}5$ *volts and from the graph deduce the current gain.*

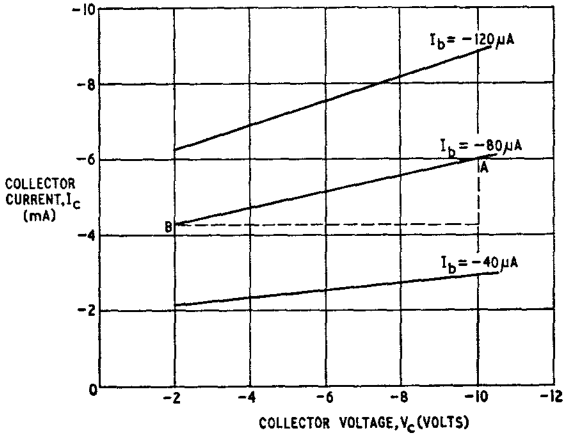
ANSWER. (*a*) The output characteristics for the base current, I_b = 40, 80 and 120 μA are given in sketch (*a*).

The output resistance of the transistor may be found from the reciprocal of the slope of the straight portion of the characteristic for $I_b = 80\ \mu A$. Thus, between points A and B,

$$\text{Output resistance} = \frac{\text{Change in } V_c}{\text{Change in } I_c},$$

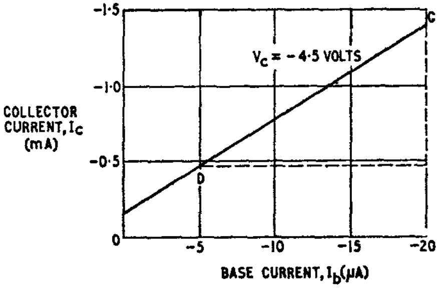
$$= \frac{(10 - 2)\text{ V}}{(6 - 4{\cdot}4)\text{ mA}} = \frac{8 \times 10^3}{1{\cdot}6}\text{ohms},$$

$$= \underline{5{,}000\text{ ohms.}}$$



(*a*)

(*b*) The transfer characteristic (i.e. the collector current/base current relation) for $V_c = -4{\cdot}5$ volts is given in sketch (*b*).



(*b*)

The current gain of the transistor may be found from the slope of the straight portion of this characteristic.

Thus, between points C and D,

$$\text{The current gain} = \frac{\text{Change in } I_c}{\text{Change in } I_b},$$

$$= \frac{(1{\cdot}4 - 0{\cdot}45)\ \text{mA}}{(20 - 5)\ \mu A},$$

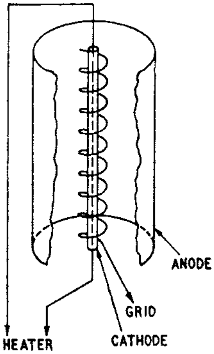
$$= \frac{0{\cdot}95 \times 10^3}{15} = \underline{63{\cdot}3}.$$

Question 47.

Outline the functions of the electrodes in a triode valve when used as an amplifier and explain the process of amplification. Define the terms "mutual conductance" and "anode a.c. resistance."

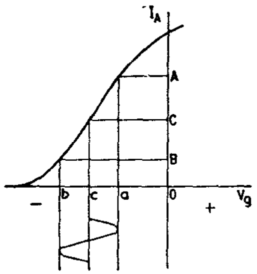
Derive an expression for the amplification of a single-stage triode valve amplifier with resistance as anode load.

ANSWER. The triode valve, shown in sketch (*a*), has a cathode, a grid and an anode as its three electrodes, with a heater wire within the cathode and insulated from it. The whole is contained in an evacuated glass bulb. The oxide-coated cathode is maintained at a temperature of about 1,000°K by the heater and emits copious supplies of electrons. These, being negatively charged, are attracted to the surrounding anode which is maintained at a positive potential relative to the cathode. The anode is connected back to the cathode via the external anode load circuit. The grid is an open spiral of wire coaxial with the cathode and situated in the space between it and the anode. Any potential applied to the grid will affect the electrons passing from cathode to anode, and provided this potential is negative and relatively small it will hinder electrons, without collecting them, in proportion to its potential. Variations of grid-cathode voltage will, therefore, appear as similar variations in the number of electrons passing from cathode to anode, i.e. as anode current variations. As the anode current can be made fairly large, a considerable a.c. voltage can be developed across an anode load by a small alternating grid-cathode potential. The valve, therefore, amplifies.



(*a*)

The anode-current/grid-voltage curve for the triode, sketch (*b*), shows how the amplification can be found from the valve characteristic.



(*b*)

When V_g varies from *a* to *b* around a mean value of grid voltage, *c*, the anode current varies from A to B around C. Typical values might require *ab* to be a 2-volt swing for an anode current swing of 20 mA in a load of 5,000 ohms. The output signal is, therefore, 100 volts for an input signal of 2 volts.

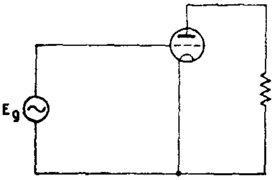
Mutual conductance is a measure of the amplifying property of the valve. It is the anode current change (in mA) for a one volt swing of the grid voltage.

∴ Mutual conductance $g_m = \dfrac{\delta I_g}{\delta V_g}$ mA per volt when the anode voltage is held constant.

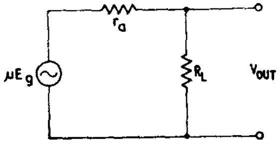
The anode a.c. resistance is the apparent internal resistance of the valve between cathode and anode and is given by

$$r_a = \frac{\delta V_a}{\delta I_a} \text{ ohms.}$$

The simple amplifier circuit of sketch (*c*) may be represented by the equivalent circuit of sketch (*d*). The grid generator, E_g, in sketch (*c*) becomes μE_g, in sketch (*d*) where μ is the amplification factor of the valve.



(*c*)



(*d*)

r_a = anode a.c. resistance of valve, R_L = load resistance,

$$\mu = r_a \times g_m.$$

If I be the r.m.s. value of the alternating current round the circuit of sketch (*d*) and if E_g, be the alternating voltage on the grid then

$$I = \frac{\mu E_g}{r_a + R_L},$$

$$V = \text{Output Voltage} = IR_L = \frac{\mu E_g R_L}{r_a + R_L},$$

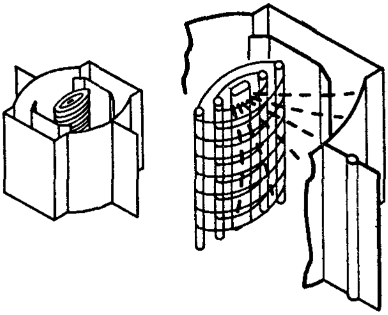
$$\therefore \text{ Voltage amplication } = \frac{V}{E_g} = \underline{\frac{\mu R_L}{r_a + R_L}}.$$

Question 48.

Describe, with sketches, the construction of either a beam tetrode valve suitable for use in the output stage of a domestic radio receiver, or a junction transistor suitable for use in a low-power audio amplifier.

Say what materials are used for the various parts and sketch a typical family of characteristic curves for the device you have described.

ANSWER. *Beam Tetrode Valve.* Sketch (*a*) shows the constructional

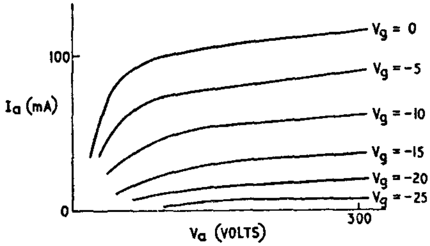


(*a*)

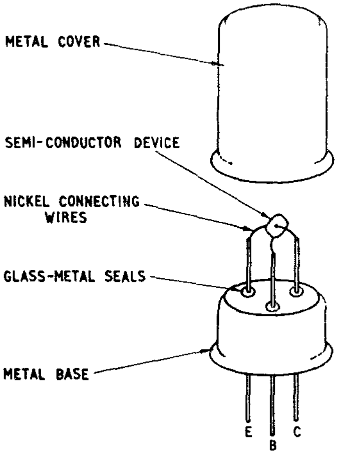
features of a beam tetrode valve. The cathode comprises a nickel tube coated with a rare-earth oxide or mixture of oxides. This is heated by a heater wire inserted within the cathode tube and insulated from it by means of an aluminium oxide. Surrounding the cathode is the control grid, which may consist of any type of open-mesh structure which provides holes of ample size for the passage of electrons and which, at the same time, has an influence on the electrostatic field near the cathode. Commonly, it consists of a coil of fine molybdenum wire with widely spaced turns, attached to nickel support wires. A second, or screen, grid surrounds the first, and is of similar construction; its function is to reduce the anode control-grid capacitance. Surrounding this is the anode, which is a cylinder or similarly shaped structure of molybdenum.

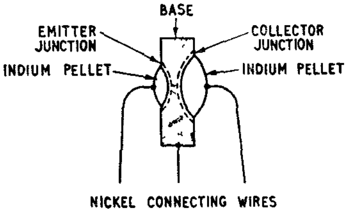
The electron stream from the cathode to the anode is in the form of a flat beam. This is achieved by a combination of suitably placed deflecting electrodes, sometimes called beam-forming plates, which are maintained at cathode potential, and the alignment of the control-grid and screen-grid wires. This causes the electron beam to be focused at a point between the screen and anode so that secondary-emission electrons are repelled back to the anode.

The whole structure is mounted inside an evacuated glass envelope. A typical family of characteristic curves is given in sketch (*b*).



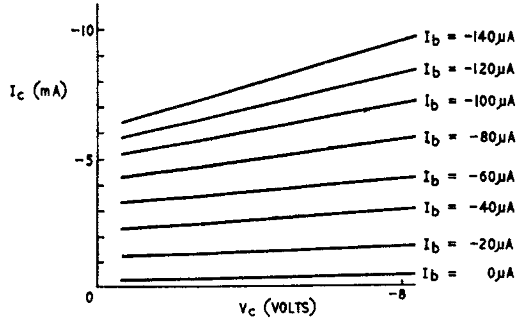
(*b*)





(*c*) (*d*)

Junction Transistor. Sketch (*c*) shows the constructional features of a typical junction transistor as used in a low-power audio amplifier. The semiconductor device is soldered to nickel connecting wires which, in turn, are spot-welded to the support wires. These are taken through glass-metal seals in the glass plug of the metal base of the transistor capsule. The semiconductor is protected by the metal cover which is cold-welded to the flange on the capsule base. An enlarged view of the semiconductor device is given in sketch (*d*). The base consists of a square or circular slice of n-type germanium which is pure germanium doped with a small amount of arsenic or antimony. The emitter and collector consists of layers of p-type germanium formed by the alloying of indium on to the germanium. The case is usually filled with dry air.



(*e*)

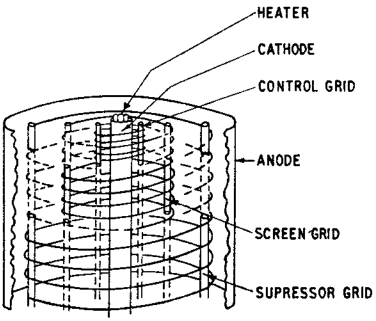
A typical family of output-characteristic curves is given in sketch (*e*). These static characteristic curves show the variation of output current with output voltage for a series of fixed input currents for a transistor used in the common-emitter configuration. Particular attention is drawn to the signs of the scales.

Question 49.

By reference to a sketch, explain the purpose of each of the three grids in a pentode valve.

Briefly discuss the reasons for using pentode valves rather than triode valves in the high-frequency stages of medium-wave radio receivers.

Answer. The electrode structure of an indirectly heated pentode valve



is shown in the sketch. Closely surrounding the cathode is the control grid which may consist of any type of open-mesh structure made of nickel or molybdenum wire. Because of its closeness to the cathode, any changes in the potential of the control grid are able to control the anode current. The measure of such control is called the mutual conductance of the valve. A second, or screen grid, surrounds the first and is of similar construction. This screen grid is earthed via a capacitor and is given a positive potential by connecting it, usually via a resistor, to the h.t. line. Its function is to minimize feedback from anode to grid circuits via the inter-electrode capacitance of the valve. The third, or suppressor grid, is a wide-mesh grid of similar construction to the control and screen grids. It is usually connected internally to the cathode electrode and is thereby effectively biased to prevent the interchange of secondary emission electrons between the screen grid and anode.

There are three principal reasons why pentode valves are commonly preferred to triodes in the high-frequency sections of medium-wave radio receivers, namely better stability, increased amplification and improved selectivity.

The principal difficulty of radio-frequency amplification by means of triodes arises from the capacitance that exists between control grid and anode. As a result of this inter-electrode capacitance, which may amount to several picofarads, the valve input impedance becomes to some extent dependent on the anode load impedance. Thus, at frequencies at which the anode load impedance becomes inductive, positive feed-back of energy from anode to grid circuit may take place causing the stage ultimately to oscillate. Alternatively, with a capacitive load impedance, negative feed-back of energy may result with a tendency to suppress the input signal. Pentode valves, by having a screening grid located between the control grid and anode, effectively reduce the control grid-to-anode capacitance, so greatly reducing the unwanted coupling and improving-the stability of an amplifier using such valves.

Pentode valves commonly have much higher amplification factors than triode valves and this fact, coupled with the improved stability possible with amplifiers employing pentode valves, enables an increased amplification to be achieved.

Finally, the anode impedance of a pentode valve used in the high-frequency section of an amplifier is much higher than that of an equivalent triode valve. Since this anode impedance is effectively in parallel with the tuned anode circuit of the amplifier it follows that the pentode will have far less effect in reducing the selectivity of the tuned anode circuit than would a triode valve.

Question 50.

Explain the following terms with reference to sketches of typical I_a/V_a *and* I_a/V_g *curves for a thermionic triode valve:*

(*a*) *the anode slope resistance (anode a.c. resistance),*

(*b*) *the mutual conductance,*

(*c*) *the amplification factor.*

Draw the circuit of a single valve amplifier with a resistance as anode load. Derive an expression for the voltage amplification of this stage, and hence show why this is less than the amplification factor of the valve.

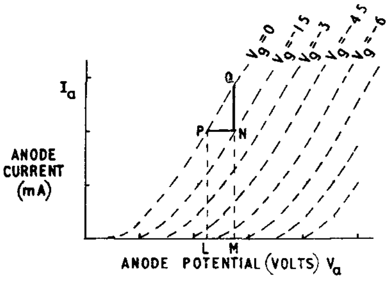
ANSWER. If in a thermionic triode valve the grid–cathode potential difference is denoted by V_g, the anode–cathode potential difference by V_a and the anode–cathode current by I_a, the following definitions can be written down in terms of small changes, denoted by δ, in V_g, V_a, I_a.

(*a*) Anode slope resistance, r_a, $= \dfrac{\delta V_a}{\delta I_a}$, for a fixed grid voltage V_g,

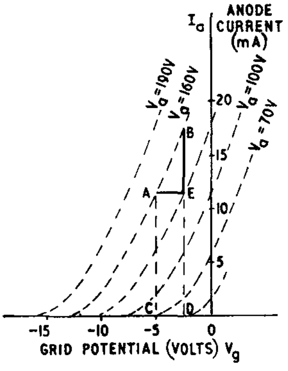
(*b*) Mutual conductance, g_m, $= \dfrac{\delta I_a}{\delta V_g}$, for a fixed anode voltage V_a,

(*c*) Amplification factor, μ, $= \dfrac{\delta V_a}{\delta V_g}$, where V_g produces a given small change in I_a, with V_a constant and V_g produces the same change in I_a with V_a constant.

Typical families of I_a/V_a and I_a/V_g curves for a triode are shown in sketches (*a*) and (*b*).



(*a*)



(*b*)

The I_a/V_a curves are almost straight over much of their length, so that, given a fixed value of grid voltage, the anode-current change is proportional to the anode-voltage change producing it. In sketch (*a*) this means that QN/PN is constant. The inverse of this, PN/QN, has the dimensions of resistance, i.e. voltage ÷ current, and is known as the anode slope resistance, r_a.

The I_a/V_g curves are also straight over most of their length, V_g being negative. The ratio BE/AE $= I_a/V_g$ is the gradient of the curve for a given anode voltage. This is the mutual conductance, g_m.

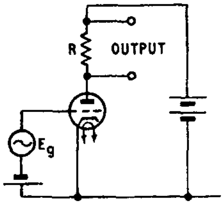
The amplication factor (μ), defined as in (*c*), can be written as follows:

$$\frac{\delta V_a}{\delta V_g} = \frac{\delta V_a}{\delta I_a} \times \frac{\delta I_a}{\delta V_g}$$

= anode slope resistance × mutual conductance

or $$\mu = r_a \times g_m.$$

The simplest basic circuit of a single-valve triode amplifier is given in sketch (*c*). Let *R* be the anode load resistance and r_a the anode slope resistance of the valve. Then the change of the anode current I_a due to an alteration in the grid voltage E_a will be



(c)

$$I_a = \frac{\text{change of anode voltage produced by } E_g}{\text{the total resistance of the anode circuit}}$$

$$= \frac{\mu E_g}{R + r_a}$$

The change in voltage across the load R ohms, i.e. output voltage V_{out}, due to a change in voltage E_g between the grid and cathode is I_aR.

$$V_{out} = I_aR = \frac{\mu E_g R}{R + r_a}.$$

The voltage amplification

$$= \frac{\text{Output voltage across load } R}{\text{Input voltage grid-cathode}} = \frac{V_{out}}{E_g}$$

$$= \frac{\mu R}{R + r_a}.$$

Now, since $(R + r_a)$ must always exceed R, the voltage amplification $\frac{\mu R}{R + r_a}$ must always be less than μ, the amplification factor of the valve.

Question 51.

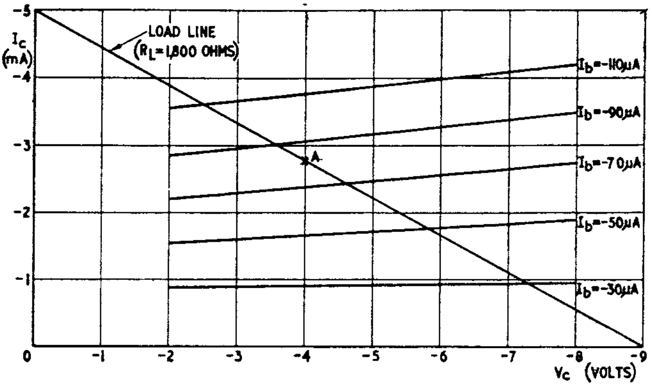
For a transistor used in the common-emitter configuration the relationships between collector current and collector voltage, with various fixed values of base current, are given in the table.

Collector Voltage (volts)	*Collector Current (mA)*				
	Base Current $-30\ \mu A$	*Base Current* $-50\ \mu A$	*Base Current* $-70\ \mu A$	*Base Current* $-90\ \mu A$	*Base Current* $-110\ \mu A$
−2	−0·9	−1·55	−2·2	−2·85	−3·55
−4	−0·92	−1·65	−2·4	−3·05	−3·77
−6	−0·95	−1·77	−2·55	−3·25	−4·0
−8	−0·98	−1·9	−2·75	−3·5	−4·2

Draw the static characteristics of the transistor and use these to determine the current gain when the collector voltage is -5 *volts.*

The transistor is to be used as a common-emitter amplifier with a load resistor of 1,800 *ohms, and collector battery voltage of* -9 *volts. Draw the load line and use this to find the base current for a collector voltage* of -4 *volts.*

ANSWER. The sketch shows the static characteristics of the transistor, plotted from the data given.



The current gain of the transistor is given by:

$$\alpha' = \frac{\delta I_C}{\delta I_B}$$

At $V_c = -5$ volts; when $I_B = -70\,\mu A, I_C = 2{\cdot}46$ mA;
and when $I_B = -50\,\mu A, I_C = 1{\cdot}72$ mA.

$$\therefore \text{Gain} = \frac{(2{\cdot}46 - 1{\cdot}72) \times 10^{-3}}{(70 - 50) \times 10^{-6}}$$

$$= \frac{0{\cdot}74 \times 10^{-3}}{20 \times 10^{-6}} = \underline{37.}$$

When the load is 1,800 ohms and the collector current is zero, the voltage at the collector will be -9 volts. When all of the battery voltage is dropped across the load the collector current will be $\frac{9 \times 10^{-3}}{1{,}800} = 5$ mA. Using these two points the load line may be drawn, as shown on the sketch.

For a collector voltage of -4 volts, the base current will be that corresponding to point A on the load line, i.e. $I_B = \underline{-82\,\mu A.}$

10—AMPLIFIERS

Descriptive treatment of Class-A, Class-B and Class-C operation of simple tuned transistor and valve amplifiers. The principle of operation of simple resistance-loaded small-signal transistor and valve amplifiers. Use of load lines. Simple equivalent circuits. Factors affecting stage amplification. Qualitative consideration of the effect upon frequency response of the interstage couplings, and of the input impedance of the subsequent stage.

Question 52.

Characteristics of a junction transistor are given in the following table:

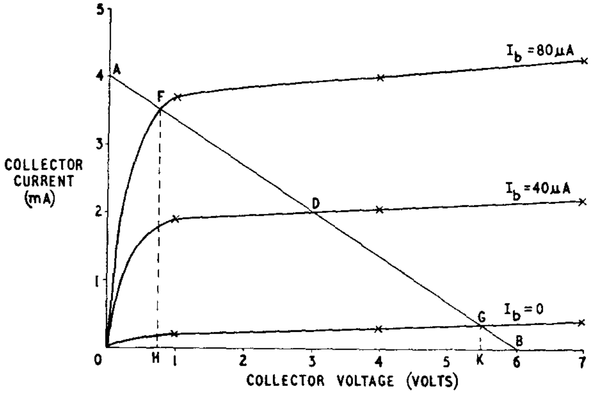
Collector volts (V_{ce})	*Collector current* (I_c *mA*)		
	$I_b = 0$	$I_b = 40\ \mu A$	$I_b = 80\ \mu A$
1·0	0·20	1·90	3·7
4·0	0·30	2·05	4·0
7·0	0·40	2·20	4·3

The transistor is connected in a common emitter with a collector load of 1,500 *ohms, a supply voltage of* 6 *volts and a d.c. bias of* 40 *microamperes.*

Plot the characteristics and draw the appropriate load line. Calculate the power dissipated in the transistor.

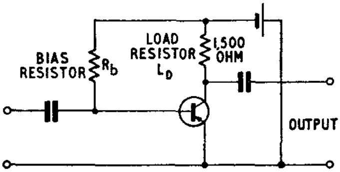
What will be the total voltage swing at the collector for an a.c. input signal current of 40 *microamperes peak in the base?*

ANSWER. The collector-current/collector-voltage characteristics are plotted in sketch (*a*).



(*a*)

The basic circuit of a common, i.e. grounded, emitter transitor stage is shown in sketch (*b*), with a load resistance of 1,500 ohms. The value of resistor R_b would be chosen to give the desired bias current, and with this arrangement only one battery is needed to operate the circuit.



(*b*)

The load line is a straight line with a gradient which is the inverse of the collector-load resistance, and passes through points that represent the extreme working conditions. Thus, at the point B, where the potential of the collector with respect to the emitter is the same as the battery voltage, there can be no voltage drop in the collector load, and, therefore, at this point the collector current is zero. The voltage and current co-ordinates of the point B are thus 6 volt, 0 mA. When the load current is the greatest possible, i.e. so that all the battery voltage is dropped across the collector load, the collector-emitter voltage is zero. The collector current is thus 6/1,500 = 4 mA. Hence, point A has the co-ordinates 0 volt, 4 mA. Then AB is the load line for a resistive collector load of 1,500 ohms, since its inverse slope is given by

$$6/(4 \times 10^{-3}) = 1{,}500 \text{ ohms.}$$

The quiescent working point is at D, where the load line cuts the 40 μA characteristic. When an input signal of 40 μA peak current is applied, the peak-to-peak input signal will be 80 μA and the current in the base will vary between 0 and 80 μA. The working condition is up-and-down the load line centred about D, and the extremes of the working range for a 1,500-ohm collector load will be at F and G, where F and G are the points at which the load line cuts the characteristic curves for base currents of 80 and 0 μA, respectively. The limits of collector-emitter voltage swing will be the points H and K, the abscissae of F and G. The peak-to-peak collector–emitter voltage excursion, HK, is then 4·9 volts.

When the quiescent condition pertains, the base current is 40 μA and the power taken from the battery is dissipated in the 1,500-ohm load and the transistor. This corresponds to the steady state at point D in sketch (*a*). At D, the collector current is 2·05 mA, which is therefore the current drawn from the battery and also the current in the 1,500-ohm load.

The power supplied by the battery $= 1 \times V = 2{\cdot}05 \times 6$,
$= 12{\cdot}3$ milliwatts.

The power dissipated as heat in the 1,500 ohm load
$= (2{\cdot}05)^2 \times 10^{-6} \times 1{,}500$ watts,
$= 6{\cdot}3$ milliwatts.

Therefore, the power dissipated in the transistor itself
$= 12{\cdot}3 - 6{\cdot}3 = 6{\cdot}0$ milliwatts.

Question 53.

A single-valve triode amplifier has a resistive anode load. Explain how the anode-current/anode-volts, (I_a/V_a) characteristics of the valve can be used to calculate the voltage amplification of the stage.

The characteristics of a particular triode are given in the following table:

Grid Volts	0				−4·4				−8·8		
Anode current I_a milliamps	40	54	62	70	30	45	49	54	27	34	36
Anode volts V_a	40	90	150	250	75	150	200	300	100	200	300

This triode is to operate from a 350-*volt anode supply with a grid bias of* −4·4 *volts. From your curves determine the value of anode load resistance that will give as high a gain as possible consistent with low distortion, when the value of the grid is* ± 4·4 *volts peak-to-peak.*

ANSWER. The anode-current/anode-voltage characteristics of a triode valve consist of a family of curves, each of which is drawn for a constant value of grid–cathode voltage. A swing in grid voltage can therefore be represented by a line drawn across the family to cut the curves which represent the desired grid-voltage limits. Such a line is called a load line, because its gradient (given by I_a/V_a) is the inverse of the resistance in the anode circuit of the valve. (This assumes a load which is purely resistive in the anode circuit.)

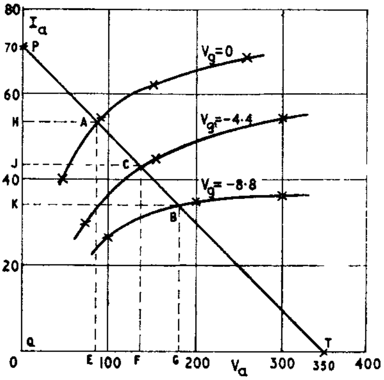
The conditions of operation for a given anode load resistance are given by the points at which the line of appropriate slope resistance cuts the curves of the anode-current/anode-voltage family at the limits of the grid-voltage swing. The amplification is then the ratio of the change of anode voltage caused by the applied grid-voltage swing. For freedom from distortion it is necessary that the anode-voltage changes on each side of the value corresponding to the mean of the grid-voltage swing should be equal. The mean value of the grid voltage is the grid-bias voltage required.

The load line can be drawn as described below.

When a cut-off voltage is applied to the grid, $I_a = 0$. There will be zero voltage drop in the anode load and so the full h.t. voltage will appear at the anode. This fixes point T in the sketch.

If now the anode load resistance is known, a line can be drawn through this point T with an inverse gradient equal to the anode load resistance. If it is not known in value a gradient must be chosen which satisfies the specified condition. In the given problem, the intercepts AC and CB must be as nearly equal as possible and yet such as to give the best amplification, measured by the grid-voltage swing AB divided into the resulting anode-voltage swing EG. In using the method care must be taken to measure the intercepts on their correct scales.

The sketch shows the conditions for the problem. T is fixed at 350 volts, and the line TP is drawn by swinging a straight edge around T



until the intercepts AC and CB appear to be equal. This equality ensures minimum distortion because it leads to equality of the anode-voltage swings EF and FG on each side if the quiescent point F. The grid bias of $-4{\cdot}4$ volts is at C, which is the member of the family drawn for this value of grid voltage.

By measurement, the anode load = 1/slope of PT

$$= \text{OT/PO} = \frac{350 \times 1{,}000}{70}$$

$$= \underline{5{,}000 \text{ ohms.}}$$

Question 54.

An audio-frequency amplifier uses a triode valve with an anode-slope resistance of 10,000 *ohms and an amplification factor of* 50. *What value of anode load resistor will be required to give a voltage amplification of* 40 *times.*

If the direct current taken by the valve is 5 *mA, what should be the power rating of the anode load resistor?*

ANSWER. Voltage gain of amplifier $= \dfrac{\mu R_L}{R_L + r_a}$,

where μ = amplification factor of valve
r_a = anode-slope resistance
R_L = anode load resistance.

Hence $$40 = \frac{50 \times R_L}{R_L + 10{,}000}$$

$$\therefore R_L + 10{,}000 = \frac{50}{40} \times R_L$$

$$= 1{\cdot}25\ R_L$$

$$\therefore 0{\cdot}25\ R_L = 10{,}000$$

$$\therefore R_L = \underline{40{,}000 \text{ ohms.}}$$

Power dissipated in anode load

$$= (\text{d.c. anode current})_2 \times R_L$$
$$= (5 \times 10^{-3})^2 \times 40{,}000$$
$$= 25 \times 10^{-6} \times 4 \times 10^4 = 1 \text{ watt.}$$

$\therefore$ Power rating of anode load resistor = <u>1 watt.</u>

Question 55.

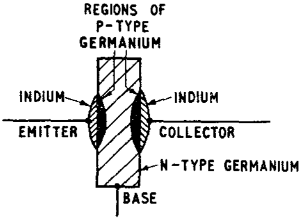
With the aid of sketches describe any one type of transistor, and explain briefly why it can act as an amplifier.

Give a circuit of a single-stage amplifier using a transistor.

What effect has temperature change on the operation of such an amplifier?

ANSWER. The type of transistor likely to be most generally used is the junction transistor. This is a later development than the point-contact transistor which was the original semiconductor triode.

A thin plate of n-type germanium forms the base on which the transistor is built. Two pellets of indium are attached on opposite sides of the germanium and opposite each other, as shown in sketch (*a*). The plate is then heated until the indium and germanium alloy, the indium migrating part way into the germanium. The heating process is stopped before the alloy regions from each side quite meet inside the plate of germanium. When the assembly is cooled, the whole forms a continuous wafer of n-type germanium sandwiched between the regions of p-type germanium. The central region is known as the base, one of the added regions is the emitter and the other is the collector.



(*a*)

The whole is mounted in a hermetically-sealed capsule from which the three connecting wires emerge. The semiconductor pellet measures only a few millimetres in each dimension, the completely-sealed unit being of the order of 1 cm long.

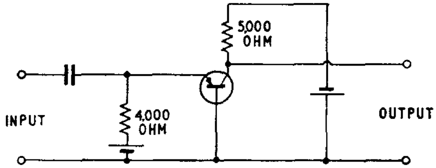
Germanium is a semiconductor, its resistance to current depending upon the nature of the impurities in the crystal. Conduction in normal metals is by the passage of the free electrons which occur in molecules, and if the impurity in the germanium produces n-type conductivity there will be enough free electrons for these to become the majority carriers. If a p-type impurity is present in the germanium, electrons will be missing from some molecules, leaving holes. These holes are mobile but, because they represent the absence of negative charges, are equivalent to positive charges and appear as a positive current. According to the impurities in the germanium the predominating current can be electrons giving n-type conductivity, or holes, giving p-type.

In a p–n–p junction transistor, the collector electrode is biased with respect to the base so as to repel electrons approaching from the base, the only collector current then being that corresponding to the few residual holes in the n-type germanium. These not only pass through the collector barrier but are even assisted on their way from base to collector. This current is the collector back-leakage current.

If now the emitter is biased with respect to the base in the direction of easy current flow, the current from the emitter into the base consists mainly of holes. These holes will diffuse across the base region to the collector which is biased to repel electrons but attract holes.

Under ideal conditions, the whole of the emitter current would pass through the base to the collector. Only a very small voltage (e.g. 0·1 volt) across the base–collector junction is required to collect all the available holes from the base region. Increasing this voltage results in only a small increase in current. The output impedance of the transistor is therefore high. On the other hand, the emitter-base junction is biased in the direction of easy current flow and the input impedance is therefore low.

There are three basic circuits in which the transistor can be connected as an amplifier; grounded emitter, grounded collector and grounded base. The grounded-base configuration is shown in sketch (*b*). If an input current of say, 1 mA is sent into the emitter, then about 0·95 mA will appear at the collector, and the remaining 0·05 mA will go through to the base. The input circuit is of low impedance and a potential difference between the emitter and base of about 0·1 volt will produce this input current. Since the collector potential will be about −5 volts, the power in the collector circuit has been increased by 0·95 × 5 = 4·5 mW. As the input power was 0·1 × 1 = 0·1 mW, the gain in power is 45.



(*b*)

Transistors are sensitive to temperature because they depend on a balance of electron and hole movements which are also temperature dependent. The temperature must not be allowed to rise beyond about 70°F for operation to continue satisfactorily.

Question 56.

Draw the equivalent circuit diagram for the resistance-capacitance-coupled audio-frequency amplifier shown in Fig. 1 at low, middle and high frequencies.

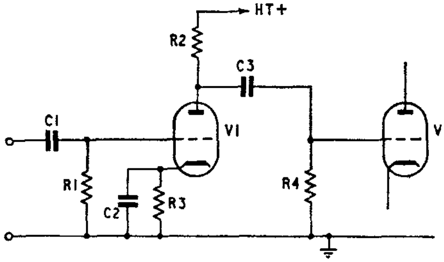
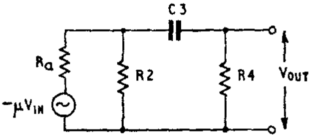


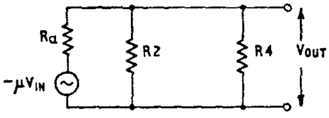
Fig. 1

Use these diagrams to explain the gain/frequency characteristics of such an amplifier. Show that at middle frequencies the gain is dependent upon the parallel combination of R2 and R4.

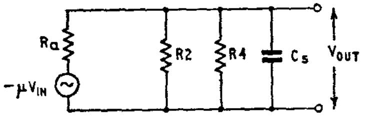
ANSWER. The equivalent circuit diagrams for the resistance-capacitance-coupled audio-frequency amplifiers at low, middle and high frequencies



(*a*)



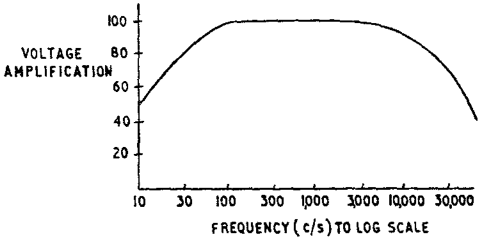
(*b*)



(*c*)

are given in sketches (*a*), (*b*) and (*c*), respectively. In these circuits it is assumed that valve V1 has an anode slope resistance equal to R_a and an amplification factor equal to μ.

At the low frequencies, sketch (*a*), the shunt capacitance effects of the valves and wiring may be neglected. The effect of the coupling capacitor C3 is, however, not negligible compared with resistor R4, and its impedance increases with decrease of frequency. Thus, the voltage applied to the grid of valve V2 decreases with decrease of frequency, and this accounts for the fall of gain at the low-frequency end of the range in the gain/frequency curve shown in sketch (*d*).



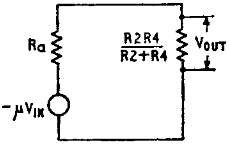
(*d*)

Over the middle frequencies, sketch (*b*), the shunting capacitances have little effect and the coupling capacitor, C3, has negligible reactance in comparison with the resistance of resistor R4. Hence, over this range of frequencies the gain is substantially constant, as shown in sketch (*d*).

At high frequencies, sketch (*c*), the reactance of capacitor C3 is negligible compared with the resistance of resistor R4, but the output capacitance of valve V1 plus the input capacitance of valve V2 and the wiring capacitances between valves V1 and V2 all add up to give an overall effective shunting capacitance C_S. The effect of this capacitance becomes greater as the frequency is increased (i.e. the capacitive reactance decreases with increase of frequency) and, hence, the gain of the amplifier will decrease as the frequency is increased.

From sketch (*b*), it may be seen that the effective anode load, R_L of valve V1 at the middle frequencies consists of resistors R2 and R4 connected in parallel,

$$\text{i.e. } R_L = \frac{R_2R_4}{R_2 + R_4}.$$



(*e*)

Hence, sketch (*b*) may be redrawn as shown in sketch (*e*).

$$\text{Thus, } V_{out} = \mu V_{in} \frac{\dfrac{R_2R_4}{R_2 + R_4}}{R_a + \dfrac{R_2R_4}{R_2 + R_4}},$$

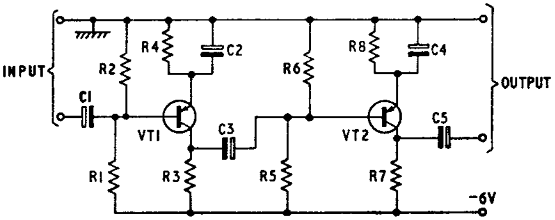
$$\text{and the gain} = \frac{V_{out}}{V_{in}} = \mu \frac{\dfrac{R_2R_4}{R_2 + R_4}}{R_a + \dfrac{R_2R_4}{R_2 + R_4}}.$$

Question 57.

Draw the circuit diagram of a two-stage RC-coupled audio-frequency amplifier using transistors. Show typical values for the components and suitable bias and stabilization arrangements.

What factors influence the frequency response of the amplifier you have described?

Answer. The sketch shows the circuit diagram of a two-stage RC-coupled audio-frequency amplifier using transistors in the common-emitter arrangement. The first stage is biased and d.c. stabilized by the potential-divider resistors, R1 and R2, and the emitter resistor, R4. Resistors R5, R6, and R8 perform similar functions for the second stage.



Typical components values are:

C1, C3, C5	10 μF, electrolytic	R3, R5	3,900 ohms
C2, C4	100 μF, electrolytic	R4, R8	1,200 ohms
R1	56,000 ohms	R7	1,000 ohms
R2, R6	10,000 ohms		

As the input impedance of common-emitter transistor stages is comparatively low, the low-frequency response is largely determined by the value of the coupling capacitors C1 and C3. Common values for these capacitors are between 10 and 25 μF in order to give, at a frequency of 50 c/s, a reactance comparable with the input resistance of the next stage, thereby reducing the approximate current loss to a tolerable 3 db, at this frequency.

The response at the higher audio frequencies is largely determined by the self-capacitance of the transistor and the transit time of the majority carriers. These factors are usually incorporated in what is referred to as the cut-off frequency response of the transistor. This is the frequency at which the current gain is reduced by 3 db relative to the gain at the medium audio frequencies.

Question 58.

Draw simple circuit diagrams for single-stage transistor amplifiers with resistive input and output terminations, using:

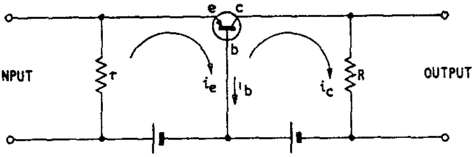
(a) the common-base connexion

(b) the common-emitter connexion.

What is the relationship between the current gains of the transistor in common-base and common-emitter connexion?

How is the operating temperature likely to affect the gain of a transistor amplifier?

ANSWER. A transistor can be connected as an amplifier in three ways, depending on which electrode is made common to the input and output circuits.

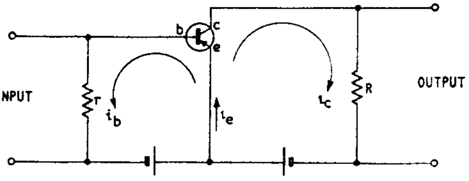


(*a*)

(*a*) The common-base or grounded-base connexion, which corresponds to the earthed-grid circuit in a thermionic-valve amplifier, is shown in sketch (*a*). The input-signal current flows between the emitter, e, and common base, b, the emitter being biased positively with respect to the base. The output current flows from the collector, c, through the load resistor, R, back to the battery and the common base. The input resistance of the transistor in the common-base circuit is low, of the order of 100 ohms. The output impedance of the transistor is then high, e.g. over 100,000 ohms. The output impedance of the complete circuit is therefore virtually given by the value of resistor R.

The current gain, α, for small signals in the common-base circuit is equal to the ratio of the alternating collector current to the alternating emitter current; thus, $\alpha = i_c/i_e$.

The value of α is always less than unity, a typical figure being 0·98. Ideally, all the emitter current would travel on to the collector, which would give a current gain of unity. But some of the minority carriers, during their passage from the emitter to the collector, are lost in the base region due to re-combination with majority carriers. The circuit can, however, give appreciable power gain because the resistance in which the alternating current flows from the collector is very much greater than that in which the alternating emitter current flows. The power output is, of course, drawn from the batteries, the current in each being almost the same in the simple circuit of sketch (*a*).



(*b*)

(*b*) The common-emitter or grounded-emitter circuit is shown in sketch (*b*). This is the most used form of amplifier circuit because it gives the greatest power gain obtainable from the possible transistor configurations. The input impedance of the transistor in this circuit is of the order of 1,000 ohms or more. The output impedance of the transistor is likely to be of the order of 25,000 to 50,000 ohms so that the value of resistor R can provide effective control of the output impedance of the circuit. The base is biased a few volts negative with respect to the emitter, and the emitter is biased a few volts positive with respect to the collector.

The current gain, α', for small signals is equal to the ratio of the alternating collector current to the alternating base current; thus $\alpha' = i_e/i_b$.

Since, by Kirchoff's laws, the current flowing into the transistor must equal the current flowing out, so the alternating base current is equal to the difference between the collector and emitter alternating currents, giving

$$i_b = i_e - i_c.$$

But i_e has been shown to equal αi_e, so by substitution

$$i_b = i_e\,(1 - \alpha)$$

$$\text{and } \alpha' = i_c/i_e\,(1 - \alpha) = \underline{\alpha/(1 - \alpha).}$$

For a typical transistor in which $\alpha = 0{\cdot}98$, the current gain in common-emitter connexion is thus

$$\alpha' = 0{\cdot}98/0{\cdot}02 = \underline{49}.$$

The gain of a grounded-base transistor amplifier is likely to remain substantially constant at temperatures up to 50°C and to fall rapidly as the temperature rises above this. In contrast, the gain of a grounded-emitter amplifier, while remaining fairly constant up to 50°C, will increase somewhat at higher temperatures, until the transistor becomes hot enough to be damaged by the internal temperature rise.

Question 59.

Draw the equivalent circuit diagrams for the choke-capacitor coupled audio-frequency amplifier shown in Fig. 1 at low, middle and high frequencies.

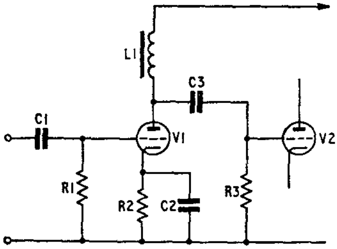
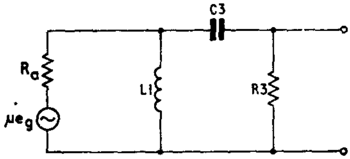


Fig. 1

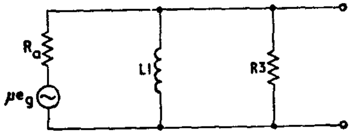
By reference to gain-frequency response curves, briefly discuss the relative advantages and disadvantages of (a) resistor-capacitor, (b) transformer, and (c) choke-capacitance, coupled audio-frequency thermionic amplifiers.

Answer. The equivalent circuit diagrams for the choke-capacitance, coupled audio-frequency amplifier at low, middle and high frequencies are given in sketches (*a*), (*b*) and (*c*), respectively. In these circuits it is assumed that valve V1 has an anode slope resistance, R_a, and an amplification factor μ.



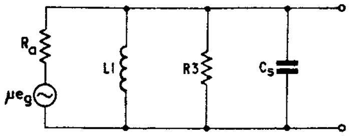
(*a*)

At low frequencies the shunt-capacitance effects of the valves and wiring may be neglected. The reactance of the coupling capacitor C3 is not, however, negligible compared with resistor R3 and increases with decrease of frequency. This effect combined with the small value of the reactance of the choke at low frequencies causes a falling-off in the gain of this type of amplifier at low audio frequencies.



(*b*)

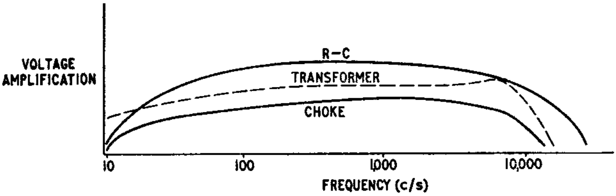
Over the middle frequencies the stray shunt capacitances still have little effect and the coupling capacitor C3 has negligible reactance in comparison with resistor R3. Hence, over this range of frequencies the gain has its optimum value and is substantially constant.



(*c*)

At high frequencies the reactance of capacitor C3 is still negligible compared with resistor R3 but the output capacity of valve V1 plus the input of valve V2 and the wiring capacitances between valves V1 and V2 all add up to give an overall effective shunting capacitance C_s whose effect becomes greater as the frequency is increased. Hence, the gain of the amplifier decreases at the higher audio frequencies.

Sketch (*d*) gives the gain-frequency response of resistance-capacitor, transformer and choke-capacitance coupled amplifiers.



(*d*)

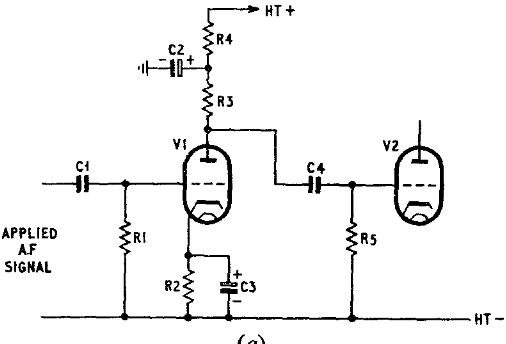
At the low-frequency end, the gain of the choke-capacitor coupled amplifier tends to fall off earlier than in the RC-coupled amplifier. This is because the reduction in the reactance of the choke occurs before the reduction of the gain due to the coupling capacitor. On the other hand, the transformer-coupled amplifier can be arranged to give a slightly better performance than the other two types of coupling at the low-frequency end.

At the high-frequency end the shunt-capacitance effect causes the gain of the choke-capacitor coupled amplifier to fall off earlier than in the case of the RC-coupled amplifier. In the transformer-coupled amplifier the shunt capacitance produces a series-resonance effect, giving rise to the undesirable peak in the gain-frequency characteristic.

Question 60.

Describe briefly, with reference to circuit diagrams, two methods of interstage coupling used in audio-frequency amplifiers. Sketch typical gain/frequency characteristics for each type, and explain why a logarithmic frequency scale is normally used for this purpose.

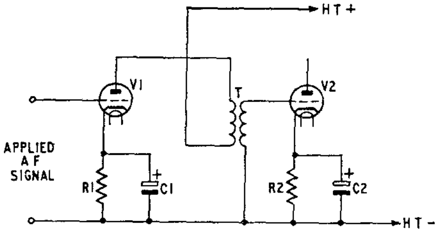
ANSWER. Sketch (*a*) gives the circuit diagram of a resistor-capacitor-coupled audio-frequency amplifier.



(*a*)

Capacitor C1 isolates the valve grid from any d.c. voltages which may be associated with the a.f. input signal. The network C1, R1 acts as a potential divider, and to avoid a loss of signal the a.f. reactance of C1 should be small compared with the resistance of R1; similar remarks apply to C4, R5. Further, the network C4, R5 which shunts the audio load resistor R3 should have a large impedance compared with R3 in order to avoid loss of gain. Grid-bias voltage is supplied by resistor R2 and is applied to the grid by resistor R1. The capacitor C3 acts as the bias decoupling capacitor and prevents an a.f. voltage being developed across R2, which would result in the gain of the amplifier being reduced. Resistor R3 is the anode load which, in association with the coupling capacitor C4, gives this type of amplifier its name. Resistor R4 and capacitor C2 act as a decoupling network to by-pass the a.f. component of the anode-current to earth, so preventing it from flowing through the h.t. supply and thereby causing instability.

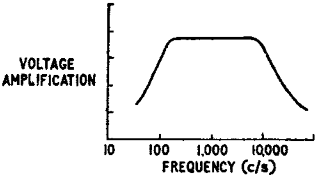
Sketch (*b*) gives the circuit diagram of a transformer-coupled audio-frequency amplifier. Grid bias voltage is supplied by resistor R1. The capacitor C1 acts as the bias decoupling capacitor and prevents an a.f. voltage being developed across R1, which would reduce the gain of the amplifier. The step-up transformer, T, acts as the load impedance of the valve V1 and provides an amplified voltage at the grid of valve V2.



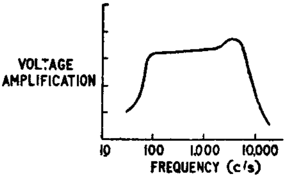
(*b*)

Sketch (*c*) gives a typical gain-frequency characteristic for a resistor-capacitor-coupled amplifier. The notable features of this curve are the substantially constant amplification over a wide range of frequencies and the fairly rapid fall away at both the very low and very high frequencies.

Sketch (*d*) gives a typical gain/frequency characteristic for a transformer-coupled audio-frequency amplifier. The notable features of this curve are the relatively constant amplification over the middle range of frequencies, a falling off at low frequencies similar to that for the resistor-capacitor coupled amplifier but a much steeper cut-off at the high frequency end, following a slight rise.



(*c*)



(*d*)

The frequency scales used in sketches (*c*) and (*d*) are set out on a logarithmic basis, that is to say, the distance between two frequencies on that scale does not depend on the number of cycles separating them but on the ratio of the frequencies, i.e. the space between 10 and 100 c/s is the same as that between 100 and 1,000 c/s. This system is normally used because the ear appreciates relative frequencies in a similar manner, i.e. it appreciates a similar interval between each note and its octave.

Question 61.

For each of the two circuit diagrams given, draw an equivalent circuit diagram.

In Fig. 1, *which single component could be modified in value to reduce the gain at low frequencies relative to the gain at higher frequencies?*

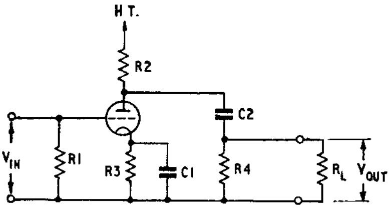


Fig. 1.

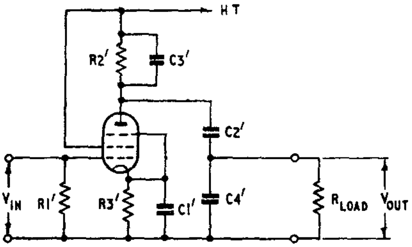


Fig. 2.

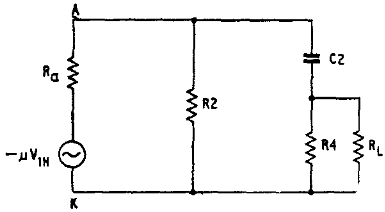
ANSWER. In order to draw the equivalent diagram circuit of a triode-valve circuit, the following procedure will be found helpful.

(*i*) Mark on the actual diagram circuit the grid (G), anode (A) and cathode (K).

(*ii*) Start the equivalent circuit diagram between A and K with a resistor R_a and a generator of potential $-\mu e_{gk}$, where R_a is the anode slope resistance of the valve, μ its amplification factor, and e_{gk} the input voltage to the circuit measured between grid and cathode.

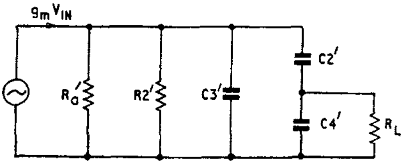
(*iii*) Complete the equivalent circuit diagram by transferring all circuit elements from the actual to the equivalent circuits but omitting the valve and all d.c. sources.

For the circuit diagram of Fig. 1, for frequencies at which capacitor C1 has negligible reactance compared with that of resistor R3, e_{gk} is equal to V_{in}. The equivalent circuit therefore becomes as shown in sketch (*a*).



(*a*)

For the pentode valve (Fig. 2), $R_a \gg R_L$ in normal circuits, and the current-source equivalent circuit is usually more convenient. This is drawn in a similar manner to that already described except that the valve is replaced by a current generator which supplies a current $g_m e_{gk}$ in the direction from anode to cathode within the valve, and with the anode slope resistance placed across this generator's terminals. The equivalent diagram for Fig. 2 drawn in this way is shown in sketch (*b*). As before, it is assumed that $1/\omega C1' \ll R3'$.



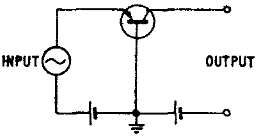
(*b*)

In Fig. 1 of the question, if capacitor C2 is made smaller in value, its rising reactance at low frequencies would cause the voltage developed across resistor R4 to fall. Alternatively, if capacitor C1 is reduced in value, the gain of the stage will be reduced as the frequency is reduced, because of negative-feedback action.

Question 62.

With the aid of diagrams showing suitable biasing arrangements, briefly explain the three ways in which a junction transistor may be connected in a small signal amplifier. Compare the current gain input impedance and output impedance of the three circuit arrangements.

ANSWER. There are three ways in which a transistor may be connected in a circuit and they are usually described by naming that electrode of the transistor which is common to both input and output circuits. The three methods of connexion are known as common-base, common emitter and common-collector.



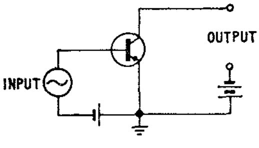
(*a*)

Sketch (*a*) shows a p–n–p transistor connected with a common base and it can be seen that the base connexion is common to both input and output circuits. The emitter is biased positively with respect to the base, which tends to reduce the effect of the emitter–base potential barrier, and the collector is biased negatively with respect to the base, which tends to assist the base-collector potential barrier. The current gain,

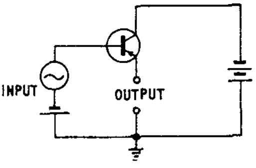
$$\alpha = \frac{\text{change in } i_c}{\text{change in } i_e},$$

must be less than unity since the change in collector current is less than the change in emitter current.

Sketch (*b*) shows a p–n–p transistor connected with a common emitter and it can be seen that the emitter connexion is common to both input and output circuits. The bias batteries again assist the base–



(*b*)



(*c*)

collector potential barrier and reduce the effect of the emitter–base potential barrier. A current gain may be obtained with this mode of connexion.

Sketch (*c*) shows a p–n–p transistor used with a common collector and it can be seen that the collector connexion is common to both input and output circuits. Again the bias batteries are connected to give the correct voltage relationship between emitter and base, and base and collector.

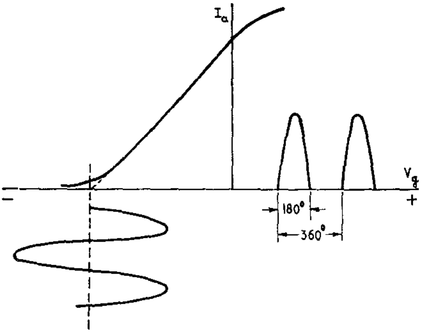
The current gain, input impedance and output impedance characteristics of the three circuit arrangements are summarized in the table given below.

Characteristic	Common-Base	Common-Emitter	Common-Collector
Current Gain	<1 (Typically 0·98)	High (Typically 50)	High (Approximately the same as common-emitter
Input Impedance	Low	Medium	High
Output Impedance	High	Medium	Low

Question 63.

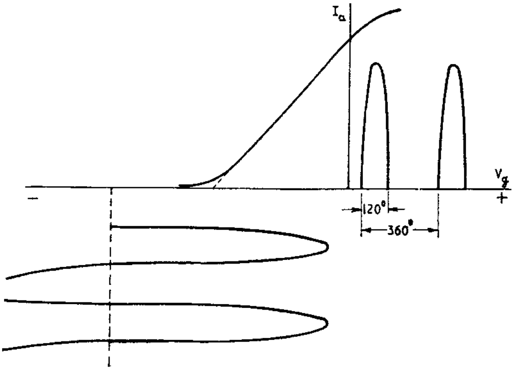
Explain the distinction between Class-B and Class-C operation of a transmitter valve.

ANSWER. Class-B operation of a transmitter valve is obtained when the valve's grid bias is adjusted approximately to the anode-current cut-off point, as shown in sketch (*a*). Under this condition the valve passes anode current only during the positive half-cycles of the alternating grid voltage. The drive may or may not take the grid positive, according to conditions; thus with audio-frequency amplification the grid would probably not be driven positive but in this case a Class-B push-pull stage would be used.



(*a*)

Class-C operation of a valve amplifier is obtained when the valve's grid-bias voltage is adjusted to a value usually two or three times greater than the anode cut-off point, as shown in sketch (*b*). In this condition the valve anode current flows in the form of pulses lasting less than half a



(*b*)

cycle of the alternating grid voltage, about 120° being a typical value. The drive voltage is generally much larger than that for Class-B operation and in high-power stages grid current would flow.

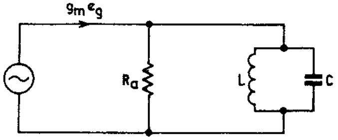
Question 64.

A variable-mu pentode valve has a mutual characteristic expressed by the figures given in the table.

The valve, whose anode slope resistance is 1 *megohm, is used with a* 530 μH *inductor, of Q-factor* 300 *in a* 1 *Mc/s tuned r.f. amplifier.*

Draw the equivalent circuit, and calculate the stage gain for small signals when the grid bias is (*a*) −2·5 *volts and* (*b*) −20 *volts.*

Grid volts	−25	−20	−15	−10	−7·5	−5	−2·5	0
Anode current (mA)	0·2	0·5	1·0	1·8	2·6	4·0	6·2	10·4



(*a*)

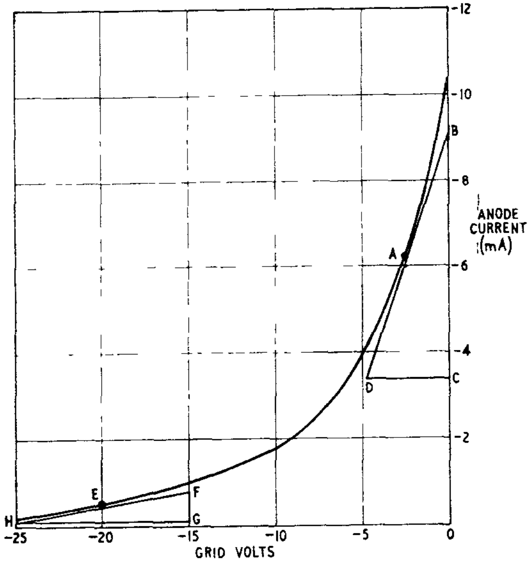
ANSWER. The equivalent circuit is given in sketch (*a*). Note that the shunt form of equivalent circuit is used owing to the high internal impedance of the valve.

The effective impedance of the tuned circuit at resonance is given by

$$\begin{aligned} Z &= Q\omega L \\ &= 300 \times 2\pi \times 10^6 \times 530 \times 10^{-6} \\ &= 1 \text{ megohm.} \end{aligned}$$

With the tuned-circuit impedance Z in parallel with the 1 megohm anode impedance the valve is therefore supplying current to a load of 0·5 megohms, i.e. $Z_{eff} = 0{\cdot}5$ megohms.

The valve characteristic curve, plotted from the table of values, is shown in sketch (*b*). If tangents to this curve drawn at $V_g = -2{\cdot}5$ volts



(*b*)

and $V_g = -20$ volts, the slope of these tangents gives the two values of mutual conductance required, which are 1·2 and 0·07 mA/volt, respectively.

The stage gain is given by

$$\frac{V_{out}}{V_{in}} = \frac{g_m e_g Z_{eff}}{e_g} = g_m Z_{eff}$$

$$\begin{aligned} \therefore \text{Gain at } -2{\cdot}5 \text{ volts} &= 1{\cdot}2 \times 0{\cdot}5 \times 10^6 \times 10^{-3} \\ &= \underline{\underline{600.}} \\ \text{Gain at } -20 \text{ volts} &= 0{\cdot}07 \times 0{\cdot}5 \times 10^6 \times 10^{-3} \\ &= \underline{\underline{35.}} \end{aligned}$$

Question 65.

Explain, by reference to waveform diagrams, what is meant by (a) Class A (b) Class B and (c) Class C operation in a tuned transistor or valve amplifier.

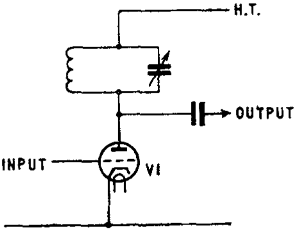
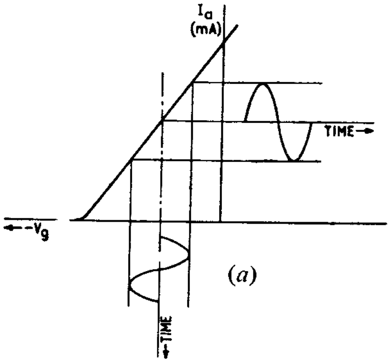


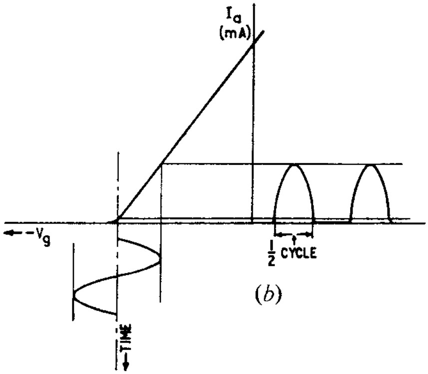
Fig. 1.

State the drawbacks of using a triode valve in the radio-frequency amplifier circuit shown in Fig. 1. Draw an alternate circuit using a pentode valve and briefly explain how this avoids these drawbacks.

ANSWER. *Class A valve operation.*



(*a*)



(*b*)

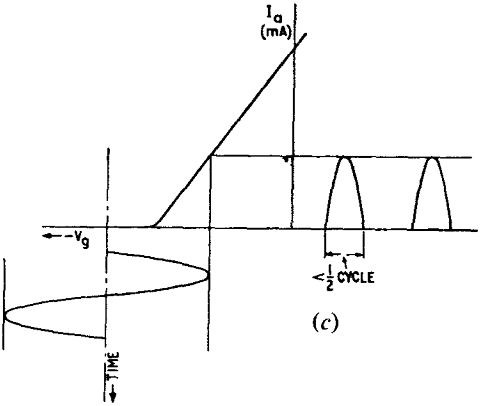
In Class A valve operation the operating point and the amplitude of the input are so adjusted that anode current flows at all times during the entire electrical cycle as shown in figure (*a*).

Class B valve operation

If the bias voltage is made such that anode current just ceases to flow in the absence of an input signal the valve is said to be biased to cut off. In this condition a sinusoidal input signal produces approximately half sine-wave anode current pulses and the valve is operating in Class B. This type of operation is illustrated in figure (*b*).

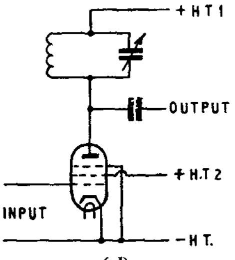
Class C valve operation

In this type of operation the valve is biased well beyond cut-off and when a sinusoidal input of adequate amplitude is applied, the anode current consists of a series of pulses each having a duration of less than half a cycle. This type of operation is illustrated in figure (*c*).



(c)

The principal drawback of using a triode valve in a radio-frequency amplifier circuit arises from the capacitance that exists between the control grid and the anode. As a result of this inter-electrode capacitance, which may amount to several picofarads, the valve input impedance becomes to some extent dependent on the anode-load impedance. Thus, at frequencies at which the anode-load impedance becomes inductive, positive feed-back of energy from anode to grid circuit may take place, causing the stage to oscillate. Alternatively, the load impedance may become capacitive, resulting in negative feed-back of energy from anode to grid, with a tendency to suppress the input signal. Further drawbacks are the low amplification and poor selectivity obtainable when using a triode in an r.f. amplifier.



(d)

An alternative circuit, using a pentode valve is given in figure (*d*). When using a pentode valve the cause and effect of the instability referred to above is largely eliminated. This is effected by the screen grid, located between the control grid and anode, which is effectively at earth potential to the signal frequencies. This additional grid reduces the control grid to anode capacitance, so greatly reducing the unwanted coupling and improving the stability of an amplifier using a pentode valve. Further, a pentode valve commonly has a much higher amplification factor than a triode and this, coupled with the improved stability, enables increased amplification to be obtained. Finally, the anode impedance of a pentode valve used in the high-frequency section of an r.f. amplifier is much higher than in the corresponding case of a triode valve. Since this anode impedance is effectively in parallel with the tuned anode circuit of the amplifier it follows that the pentode valve will have far less effect in reducing the selectivity of the tuned anode circuit than in the case when using a triode valve.

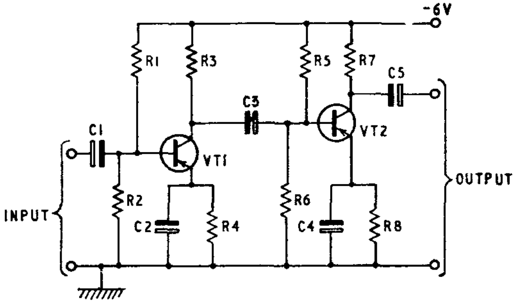
Question 66.

Sketch a circuit and describe the operation of a two-stage RC-coupled audio-frequency amplifier using transistors in the common-emitter configuration.

State approximate values of the load resistors and coupling capacitors.

Discuss any factors which affect the stage amplification.

ANSWER. The sketch shows the circuit diagram of a two-stage RC-coupled audio-frequency transistor amplifier using transistors in the common-emitter configuration. The first stage is biased and d.c. stabilized by the potential divider resistors, R1 and R2 and the emitter resistor, R4. Resistors R5, R6 and R8 perform similar functions for the second stage. For each stage, the base–emitter junction is biased in the forward direction and the collector–base is biased in the reverse direction. A signal applied to the input of the first stage will cause an increase in the base current, resulting in an increase in the voltage across the emitter–base junction and a corresponding change in the collector current. The current gain of the common-emitter circuit is given by



$$\alpha^1 = \frac{\text{change in } I_c}{\text{change in } I_b}$$

and typical current gains of 30–50 are possible with this type of configuration. This current gain represents a voltage gain when considering the changing collector current passing through the output resistor R3. This amplified signal voltage is passed via capacitor C3 to the second stage of the amplifier where further amplification will take place.

Common values for the coupling capacitors C3 and C5 are 10–25μF while typical values for the load resistors R3 and R7 are 3,900 and 1,000 ohms, respectively.

The low frequency response is largely determined by the need to match the low input resistance of the common-emitter transistor which has a value of the order of 1,000 ohms. Hence, the values for C3 and C5, stated above, will give, at a frequency of 50 c/s, a reactance comparable with the input resistance of the transistor. The response at the higher audio frequencies is largely determined by the self-capacitance of the transistor and the transit time of the majority carriers. These factors are usually incorporated in what is referred to as the cut-off frequency response of the transistor. This is the frequency at which the current gain is reduced to 3 db relative to the gain at the medium audio frequencies.

Question 67.

The data given in Table I refer to a transistor in the common emitter configuration.

Table I

Collector Volts	Collector Current (mA)			
	Base Current −20μA	Base Current −40μA	Base Current −60μA	Base Current −80μA
−3	−0·91	−1·6	−2·3	−3·0
−5	−0·93	−1·7	−2·5	−3·25
−7	−0·97	−1·85	−2·7	−3·55
−9	−1·0	−2·05	−3·0	−4·05

Plot the collector voltage/collector current characteristics for base currents of −20, −40, −60, *and* −80 *μA, and use these characteristic curves to determine (a) the current gain when the collector voltage is* −6 *volts, (b) the output resistance of the transistor for* $I_b = -60\ \mu A$.

The transistor is to be used as a common-emitter amplifier with a load resistor of 2,500 *ohms and a collector battery voltage of* −10 *volts. Draw the load line and use this to find the base current for a collector voltage of* −5 *volts.*

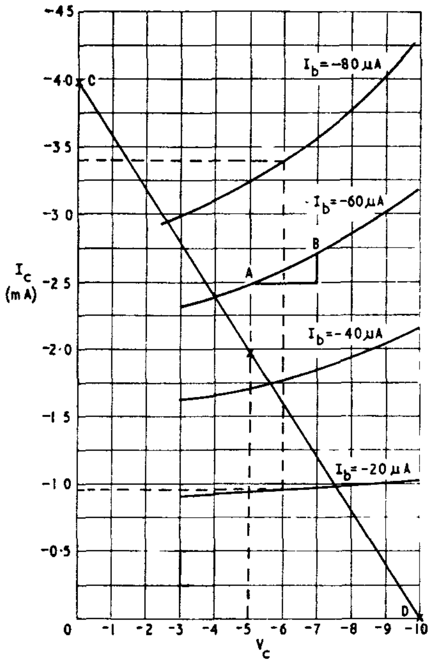
ANSWER. The output characteristics (collector voltage/collector current) for base current $I_b = -20, -40, -60$ and $-80\ \mu A$ are given in the sketch.

$$\text{The current gain} = \frac{\text{change in } I_c}{\text{change in } I_b}, \; V_c \text{ constant}$$

$\underline{\text{For } V_c = -6 \text{ volts}}$

$$\text{Current gain, } \alpha = \frac{(3{\cdot}4 - {\cdot}95)\text{ mA}}{(80 - 20)\ \mu A}$$

$$\frac{2{\cdot}45}{60} \times 10^3 = \underline{40{\cdot}8}$$



The output resistance of the transistor may be found from the reciprocal of the slope of the straight portion of the characteristic for $I_b = -60\,\mu A$. Thus, between points A and B:

$$\text{Output resistance} = \frac{\text{change in } V_c}{\text{change in } I_c} .$$

$$= \frac{(7-5)\text{V}}{(2{\cdot}7 - 2{\cdot}5)\text{ mA}} = \frac{2 \times 10^3}{0{\cdot}2}\text{ ohm}$$

$$= \underline{10{,}000 \text{ ohms}}$$

When the load is 2,500 ohm, and the collector current is zero, the voltage at the collector will be -10 volts. When all the battery voltage is dropped across the load the collector current will be $\frac{-10}{2{,}500}$ amp $= -4$ mA. Using these two points the load line CD may be drawn, as shown on the sketch.

Using this load line the base current, when $V_c = 5$ volts, is approximately $\underline{-47\,\mu A}$.

11—OSCILLATORS

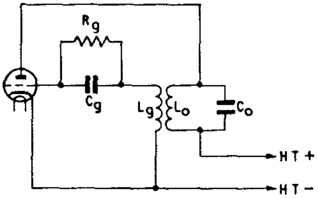
Descriptive treatment of simple triode-valve oscillators with tuned circuit in anode or in grid. Simple mutual inductance-coupled transistor oscillators.

Question 68.

Draw the circuit of an inductance-capacitance valve oscillator for use at 1,200 *kc/s, indicating suitable values for the components.*

Explain the purpose of the various components and the factors which determine their values.

ANSWER. The sketch gives the circuit diagram of a tuned-anode oscillator. The operation of the circuit can be explained as follows:



If the tuned circuit, L_0C_0, is given a pulse, for example, that furnished by applying the anode voltage to the valve, it will be shock excited into oscillation and energy will be transferred to and fro between the inductor and capacitor. These oscillations would normally slowly decrease in amplitude and eventually die out, due to losses in the coil and capacitor. Energy is, however, supplied to the tuned circuit by the valve anode current and the oscillations are thereby maintained. When the circuit is oscillating a sinusoidal current, much larger than the anode current, circulates in the anode-tuned circuit. As the anode inductor, L_0, is inductively coupled to the grid inductor, L_g, a voltage is induced in the latter which is applied to the grid of the valve, and this can be made adequate to maintain the anode current.

Grid bias is obtained from the d.c. voltage developed across the capacitor, C_g, as a result of the valve drawing grid current which flows across resistor R_g, and its value therefore is chosen so that its reactance at the working frequency is small compared with that of R_g. Suitable values for oscillator frequency of 1,200 kc/s would be 2 megohms and 500 pF.

The frequency of oscillation is very nearly that of the tuned circuit L_0C_0 which is given by

$$f = \frac{1}{2\pi\sqrt{L_0 C_0}}$$

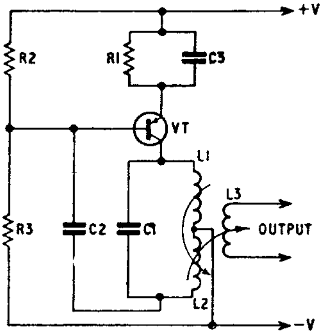
where f is in c/s, L_0 is in henrys and C_0 is in farads. For 1,200 kc/s, suitable values would be 300 pF for C_0 and 58·5 μH for L_0.

Question 69.

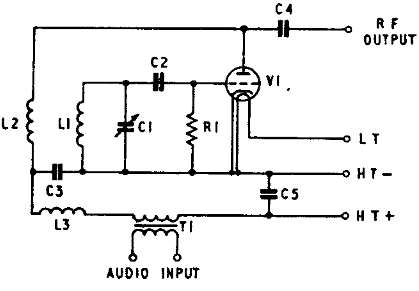
Draw the circuit of a simple medium-frequency LC oscillator using either a transistor or a triode valve, and explain how its output may be amplitude-modulated.

If such an oscillator has a fixed inductance of 60 *microhenry and it is required to tune over the band* 1–2 *Mc/s, calculate the range of the variable capacitor to be used.*

ANSWER. A circuit diagram of a medium-frequency LC Hartley-type oscillator, using a transistor, is shown in sketch (*a*). The tuned circuit L1, L2, and C1, is connected in the collector circuit of the transistor, VT. Oscillations are maintained by inductive coupling between L1 and L2, and the feedback via C2 to the base circuit. Stabilization of the d.c. operating point is provided by the potential divider circuit, R2 and R3, and the emitter resistor, R1.



(*a*)



(*b*)

Sketch (*b*) is a circuit diagram of an anode-modulated radio-frequency oscillator using a thermionic valve. The tuned circuit L1, C1 is connected to the grid of the triode (*b*) valve V1, and oscillations are maintained by inductive feedback from coil L2, coupled to coil L1. The grid capacitor C2 and leak resistor R1 provide self-bias. The output is taken through an h.t. blocking capacitor, C4. The output is amplitude-modulated by applying an audio-frequency signal to the primary of the audio transformer T1, the secondary being connected in series with the h.t. supply to the anode of V1. The radio-frequency choke L3 and coupling capacitor C3 prevent radio-frequency currents entering the audio circuits; C5 is an audio-frequency decoupling capacitor which keeps audio-frequency currents out of the h.t. supply unit.

The output of such an oscillator may be amplitude modulated by applying an audio-frequency signal in the base circuit by means of an audio-frequency transformer.

The frequency of oscillation is very nearly that of the resonant frequency of the tuned circuit, which is given by

$$f = \frac{1}{2\pi\sqrt{LC}},$$

where f is in c/s, L is in henrys and C is in farads.

Rearranging the above formula,

$$C = \frac{1}{4\pi^2 L f^2}.$$

$$\therefore \quad C_1 \text{ at } 1 \text{ Mc/s} = \frac{1}{4\pi^2(60 \times 10^{-6})(1 \times 10^6)^2} \text{ farads}$$

$$= \frac{10^{12}}{4\pi^2 \times 60 \times 10^6} \text{ pF} \simeq 420 \text{ pF}.$$

At 2 Mc/s, since $C \propto \dfrac{1}{f^2}$ then,

$$C_2 \text{ at } 2 \text{ Mc/s} = 420 \times \frac{1}{(2/1)^2} = 105 \text{ pF}.$$

The variable capacitor must therefore have a capacitance range of 105–420 pF.

12—DETECTORS

Descriptive treatment of the detection of amplitude-modulated waves by semiconductor and thermionic devices.

Question 70.

Briefly explain why it is necessary to include a detector stage in a receiver for amplitude-modulated signals.

Discuss the characteristics of thermionic and semiconductor diodes which make them suitable for the detection of a.m. signals.

ANSWER. After amplification by the radio-frequency stages of a radio receiver, an amplitude-modulated radio wave consists of a high-frequency oscillatory current with the audio-frequency modulation impressed upon it. If this current were applied directly to the headphones or loudspeaker, no audible sound would result because:

(*i*) The relatively high inductance of the loudspeaker voice coil and its high shunt stray capacitance would prevent the flow of sufficient current in the voice coil for effective operation.

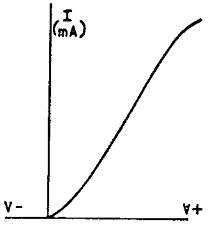
(*ii*) Even if sufficient high-frequency current could be made to flow through the voice coil the inertia of the coil and the cone would prevent the loudspeaker from responding.

(*iii*) Even if radio-frequency sounds could be emitted by the loudspeaker they would be above the range of frequencies that can be heard.

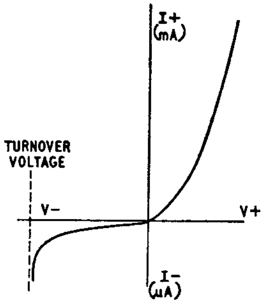
It is necessary, therefore, to provide a device that responds not to the individual cycles of the radio-frequency oscillatory current but only to changes in its amplitude. Such a device is called a detector and in practice, detection of amplitude-modulated waves is usually achieved by rectification of the modulated carrier wave. Such detectors are described as envelope detectors, and should be distinguished from synchronous detectors, which are used in certain types of line transmission equipment.

Circuits employing thermionic and semiconductor diodes are classed as linear detectors although with small signals this is not strictly the case. Detection in both cases is effected by the uni-directional properties of the devices.

The voltage/current characteristics of the thermionic diode and the semiconductor diode are illustrated in sketches (*a*) and (*b*), respectively.



(*a*)



(*b*)

The relative merits of detector circuits may be assessed under four headings:

(*i*) The degree of distortion introduced by the detector.
(*ii*) The effect of the detector on the preceding circuit.
(*iii*) The ability of the detector to handle small signals.
(*iv*) The ability of the detector to handle large signals.

The thermionic diode can handle large signals with little distortion but small signals tend to be distorted owing to the bottom-bend curvature of the diode characteristic. Damping of the preceding circuit may usually be avoided by careful choice of the load resistor.

Semiconductor diodes tend to introduce a greater degree of damping of the preceding circuit, but their extremely small self-capacitance and their ability to work into low-resistance loads makes them superior to thermionic diodes for certain applications. They also have advantages where size, weight and absence of heater connexions are important considerations.

Question 71.

Fig. 1 shows the circuit of a leaky-grid detector. By reference to an amplitude-modulated signal applied to the input of the circuit, explain the operation of the detector, mentioning particularly the function of each of the lettered components.

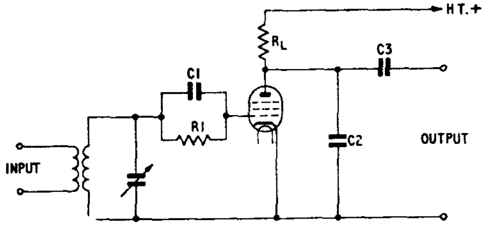
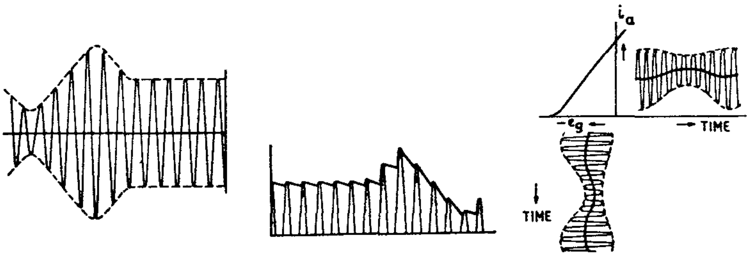


Fig. 1

Answer. Consider an unmodulated carrier-frequency applied to the detector circuit. At the peak of each positive half-cycle a pulse of grid current flows charging capacitor C1 to a voltage approximately equal to the peak value of the input signal. During the remainder of each cycle no grid current flows because the grid is negative with respect to the cathode. Between charging pulses, capacitor C1 discharges through resistor R at a rate dependent upon the time constant of the R, C1 combination. If this time constant is large compared with the periodic time of the carrier frequency then a d.c. voltage is developed across resistor R, the grid being made negative with respect to the cathode.

If now, an amplitude-modulated carrier wave is applied to the detector circuit, see sketch (*a*), the voltage drop across resistor R will vary at the modulating frequency, providing the time constant of the R, C1 combination is comparable with the periodic time of the highest modulating frequency. Thus, the negative bias voltage on the grid of the valve varies at the modulating frequency in the manner shown in sketch (*b*).



(*a*) (*b*) (*c*)

The actual voltage between the grid and cathode of the valve consists of the input signal plus the voltage across resistor R and this may be seen in the lower part of sketch (*c*). The upper waveform in sketch (*c*) shows the resultant vairation of anode current flowing through the anode load resistor, R_L, the mean value of the anode current varying at the modulating frequency. This audio-frequency component is passed to the next stage via capacitor C3 while the carrier-frequency component is by-passed by capacitor C2.

Question 72.

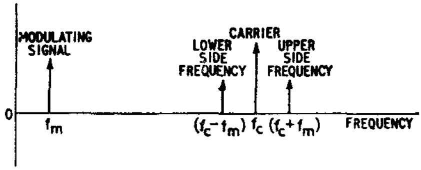
Explain the meaning of the term "sideband" in connexion with an amplitude-modulated wave.

Describe a simple way of demodulating such a modulated wave. Illustrate your answer with waveform diagrams.

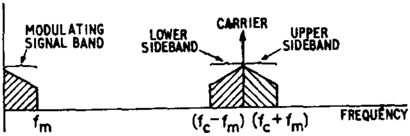
ANSWER. When a carrier wave frequency f_c, is modulated by an audio-frequency f_m, the modulated output wave contains three components:

(*a*) the original carrier frequency, f_c,
(*b*) the summation frequency $(f_c + f_m)$ and
(*c*) the difference frequency $(f_c - f_m)$.

This is illustrated in sketch (*a*) where the frequency scale is the horizontal axis, the vertical axis being purely diagrammatic to represent the presence of a wave. The sum and difference frequencies are known as the side frequencies of the modulated wave. They are actually single frequencies, and there would be no frequency components at all in the gaps above and below the carrier. If the carrier were modulated with a band of speech signals, however, the sum and difference signals would



(*a*)

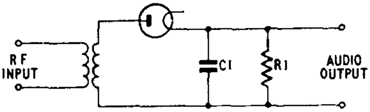


(*b*)

themselves be bands of frequencies of the same width above and below the carrier as the original modulating band of speech. These are known as the sidebands, as shown in sketch (*b*).

With a modulating band of frequencies, the lower sideband is "inverted" with respect to the original audio-frequency band, i.e. the lowest frequency in the speech band is nearest to the carrier f_c in both the upper and lower sidebands.

To demodulate a modulated wave it is necessary to use a circuit that will respond only to the frequency of the original modulating signal, which is usually at an audio-frequency, while eliminating the high-frequency carrier wave.

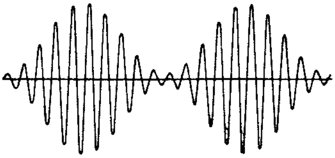


(*c*)

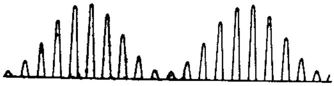
For this purpose, a rectifier is used, the simplest form being a single diode rectifier circuit as shown in sketch (*c*). The diode valve, V1, connects one side of the input circuit to a load resistor R1 shunted by a capacitor, C1.

The diode conducts only in one direction, so that it passes current at every positive peak of the carrier f_c. These peaks of uni-directional current charge the capacitor C1, and the charge then drains away continuously through the load resistor R1. The variation of the carrier amplitude due to the modulation f_m is relatively slow compared with the periodic time of f_c, with the result that if the time-constant of the R1, C1 combination is suitably chosen, the modulating frequency appears faithfully reproduced across resistor R1. The voltage across R1, varying now only at the modulating frequency, provides an output that can be carried on to further amplifying stages as required.

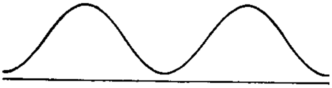
The waveform of the modulated input wave is shown in sketch (*d*). Sketch (*e*) shows the peaks of uni-directional current passed by the diode; current can only pass when the instantaneous r.f. voltage across the diode exceeds that across the R1, C1 load, so that this current appears as a series of short bursts which charge capacitor C1. Sketch (*f*) shows the final modulating frequency as it appears across resistor R1, where all the carrier component is removed.



(*d*)



(*e*)

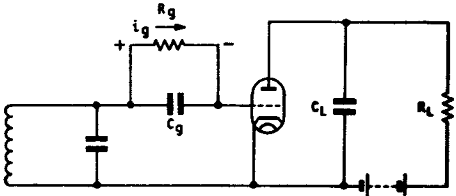


(*f*)

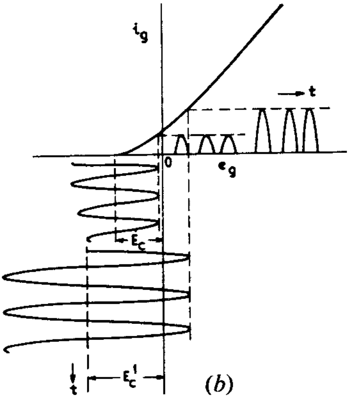
Question 73.

Explain, with the aid of diagrams, the action of either a leaky-grid detector or an anode-bend detector when used for the detection of amplitude-modulated waves.

ANSWER. The leaky-grid detector depends for its action on the curvature of the grid-voltage/grid-current characteristic of the valve. A typical circuit diagram is shown in sketch (*a*). When a continuous-wave r.f.

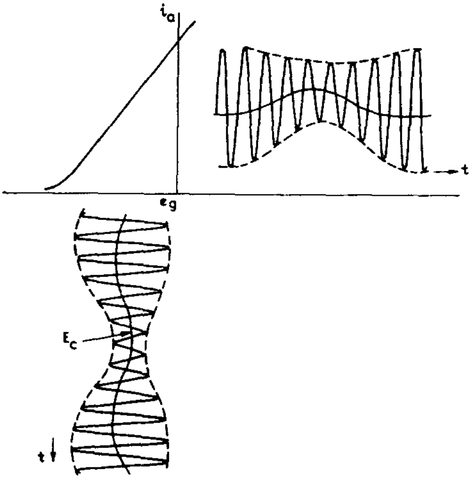


(*a*)



(*b*)

signal is applied to the grid, as shown in sketch (*b*), pulses of grid current flow and in passing through the resistor R_g, bias the valve negatively. The capacitor C_g becomes charged to the mean value of the voltage drop across resistor R_g thus providing a steady bias voltage E_c. An r.f. signal of larger amplitude results in an increased bias E_c. Referring now to sketch (*c*); when a modulated signal is applied to the grid the voltage E_c will vary as shown. The reactance of capacitance C_g is high at a.f., and the a.f. component of the average value of the grid current flows through resistor R_g. The r.f. components of grid current, however, pass through C_g, with negligible voltage drop. The mean anode current varies as indicated and an a.f. voltage is developed across the anode load resistor R_L. Since r.f. signals are applied to the grid of the valve and appear in the anode circuit, R_e is by-passed by the capacitor C_L. At low signal levels the leaky-grid detector gives an a.f. output voltage which is proportional to the square of the amplitude of the r.f. signal. This results in serious distortion of the modulation depth is large. The anode-current/grid-voltage characteristic should be as linear as possible to avoid anode rectification, which tends to offset the effects of grid detection.



(*c*)