SUPPLEMENT

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QUESTIONS AND ANSWERS

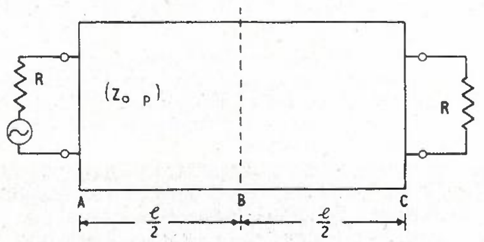
To conserve paper the answers to a few questions from each examination are omitted, the selection being made to cover as wide a field as possible.

LINE TRANSMISSION II, 1952

Q. 1. *A uniform transmission line of length l has a characteristic impedance Z_o and propagation coefficient p; the line is connected at one end to a generator having an e.m.f. E and internal resistance R and is terminated in an equal resistance R at the receiving end. By consideration of multiple reflections at the ends of the line show that the current halfway along the line is given by*

$$\frac{E}{2\left(R\cosh\frac{pl}{2} + Z_o\sinh\frac{pl}{2}\right)}$$

A. 1. The sketch shows the first two reflections of a unit wave of current originating at A. k is the reflection coefficient, $\left(\frac{R - Z_o}{R + Z_o}\right)$



Original wave	$1 \rightarrow$	$e^{-\frac{pl}{2}} \rightarrow$	$e^{-pl} \rightarrow$
1st reflection	$\leftarrow ke^{-2pl}$	$\leftarrow ke^{-\frac{3pl}{2}}$	$\leftarrow ke^{-pl}$
2nd reflection	$k^2e^{-2pl} \rightarrow$	$k^2e^{-\frac{5pl}{2}} \rightarrow$	$k^2e^{-3pl} \rightarrow$

The total current at B is obtained as the sum of an infinite series of the form

$$I_B = e^{-\frac{pl}{2}}\,(1 - ke^{-pl} + k^2e^{-2pl} - ke^{-3pl} + \text{etc.})$$

the alternating signs being introduced to take into account the phase reversal which occurs at reflection.

This is a geometric series with a common ratio $r = -ke^{-pl}$ and a first term $a = e^{-\frac{pl}{2}}$.

The sum to n terms is $\frac{a(1 - r^n)}{1 - r}$

$$= e^{-\frac{pl}{2}}\frac{[1 - (-ke^{-pl})^n]}{1 + ke^{-pl}}$$

As n tends to infinity, $(-ke^{-pl})^n$ tends to zero, so that the sum to infinity is

$$I_B = \frac{e^{-\frac{pl}{2}}}{1 + ke^{-pl}} = \frac{1}{e^{\frac{pl}{2}} + ke^{-\frac{pl}{2}}}$$

The actual initial current is not unity but $\frac{E}{R + Z_o}$ so that the current at B becomes

$$I_B\left(\frac{E}{R + Z_o}\right) = \left(\frac{E}{R + Z_o}\right)\frac{1}{e^{\frac{pl}{2}} + ke^{-\frac{pl}{2}}}$$

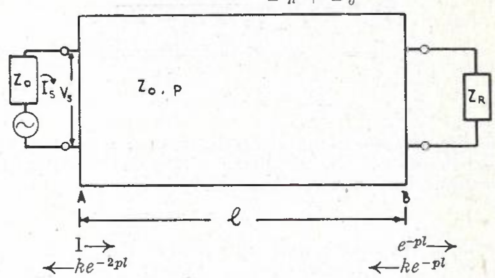
$$= \frac{E}{e^{\frac{pl}{2}}(R + Z_o) + e^{-\frac{pl}{2}}(R - Z_o)} \quad \left(\text{since } k = \frac{R - Z_o}{R + Z_o}\right)$$

$$= \frac{E}{R\,(e^{\frac{pl}{2}} + e^{-\frac{pl}{2}}) + Z_o\,(e^{\frac{pl}{2}} - e^{-\frac{pl}{2}})}$$

$$= \frac{E}{2\left(R\cosh\frac{pl}{2} + Z_o\sinh\frac{pl}{2}\right)}$$

Q. 2. *Explain the formation of a standing wave in a quarter-wavelength lossless transmission line. Find the equivalent T and π circuits for such a line and show that it can be used to transform a constant-voltage (low internal resistance) source to a constant-current (high internal resistance) source and vice versa.*

A. 2. Sketch (a) represents a section of a uniform line with a characteristic impedance Z_o and propagation coefficient p per unit length. The arrows refer to a unit current wave originating at the transmitting end and being reflected at an impedance mismatch at the receiving end. k is the reflection coefficient, $\frac{Z_R - Z_o}{Z_R + Z_o}$



(a)

The total current at A will be given by

$$I_S = 1 - ke^{-2pl}$$
$$= 1 - ke^{-2j\beta l} \quad (\text{since } p = j\beta \text{ for a loss-free line})$$
$$\text{or } I_S = 2e^{-j\beta l}\left(\frac{e^{j\beta l} - ke^{-j\beta l}}{2}\right)$$

Considering the particular cases where the line is either open- or short-circuited at B, i.e. where $k = 1$ or -1, respectively, and making use of the identities

$$\tfrac{1}{2}(e^{jx} + e^{-jx}) = \cos x$$
$$\tfrac{1}{2}(e^{jx} - e^{-jx}) = j\sin x$$

it is seen that

$$I_S \text{ (open circuit)} = 2je^{-j\beta l} \sin \beta l$$
$$\text{and } I_S \text{ (short circuit)} = 2e^{-j\beta l} \cos \beta l.$$

These expressions show that, if the line is open- or short-circuited, the amplitude of the current varies sinusoidally along its length. This condition is described as a standing wave and is explained by the interaction of two waves of equal amplitude, travelling in opposite directions.

The initial voltage wave, corresponding to the unit current wave, will be Z_o and will be reflected as $-kZ_oe^{-pl}$. The reflected wave travels in the opposite direction to the initial one so that the total voltage at A will be

$$V_S = Z_o(1 + ke^{-2pl})$$
$$= Z_o(1 + ke^{-2j\beta l}).$$

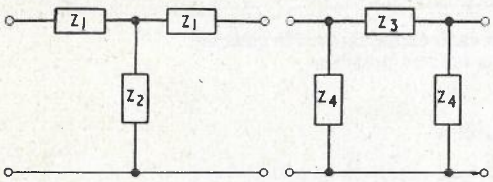
Proceeding in exactly the same way as for the current, it is found that

$$V_S \text{ (open circuit)} = 2Z_o e^{-j\beta l} \cos \beta l$$
$$\text{and } V_S \text{ (short circuit)} = 2jZ_oe^{-j\beta l} \sin \beta l$$

showing that voltage standing waves are also produced. The impedance at A is obtained by dividing the voltage by the current

$$Z_S \text{ (open circuit)} = -jZ_o \cot \beta l$$
$$Z_S \text{ (short circuit)} = jZ_o \tan \beta l.$$

Now, in the particular case where the length of the line is a quarter-wavelength, $\tan \beta l$ and $\cot \beta l$ will be respectively infinity and zero.



(b) (c)

In sketches (b) and (c) which represent, respectively, the equivalent τ and π circuits for a $\frac{1}{4}$-wavelength line,

$$Z_1 + Z_2 = Z_S \text{ (open circuit)} = 0$$
$$\text{and } Z_1 + \frac{Z_1Z_2}{Z_1 + Z_2} = Z_S \text{ (short circuit)} = \infty.$$

These two equations are satisfied if $Z_1 = -Z_2$. If the network is closed with Z_o the sending end impedance must also be Z_o.

$$\text{Thus } Z_1 + \frac{(Z_o + Z_1)Z_2}{Z_1 + Z_2 + Z_o} = Z_o$$

Substituting $Z_1 = -Z_2$ gives

$$Z_1 - \frac{Z_1(Z_o + Z_1)}{Z_o} = Z_o$$

$$\text{whence } Z_1^2 = -Z_o^2$$
$$\text{or } Z_1 = \pm jZ_o$$
$$Z_2 = \mp jZ_o$$

Working in the same way, it is found that

$$Z_3 = \pm jZ_o$$
$$Z_4 = \mp jZ_o$$

Either equivalent circuit can be used to find Z_o for any terminating impedance. Taking the T network,

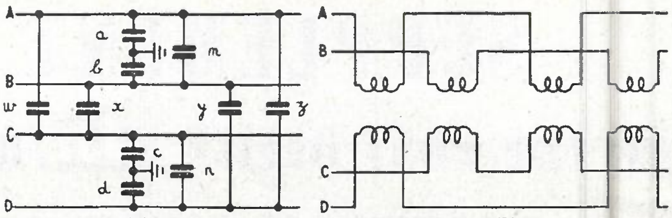
$$Z_S = Z_1 + \frac{(Z_R + Z_1)Z_2}{Z_1 + Z_2 + Z_R}$$
$$= \pm jZ_o \mp \frac{jZ_o(Z_R \pm jZ_o)}{Z_R}$$
$$= \frac{Z_o^2}{Z_R}$$

This shows that the sending end impedance of a $\frac{1}{4}$-wavelength line is always the inverse of the terminating impedance with respect to the characteristic impedance. Thus if Z_R is small, Z_S is large and vice-versa.

Q. 3. *Explain how electric and magnetic crosstalk arise in a multi-pair cable and discuss the importance of each type of crosstalk and the methods employed for their improvement in—*

(a) a large audio-frequency cable used for bothway transmission,
(b) a carrier-frequency cable used for unidirectional transmission.

A. 3. The main sources of crosstalk are capacitance unbalances and mutual inductance between pairs. The conditions for zero coupling between pairs AB and CD (see sketch (a)) are that the capacitance unbalances $(w - x)$, $(w - z)$, $(z - y)$, $(x - y)$, $(a - b)$ and $(c - d)$ shall all be zero and also that the total mutual inductance between the loops formed by AB and CD shall be zero. Inductive coupling (sketch (b)) is kept low by twisting the wires together into pairs or quads and then twisting these together to form the cable. This ensures that the magnetically-induced E.M.F.s in one pair, due to



(a) (b)

current flowing in any other pair, will tend to cancel out over the whole cable. A further improvement can be obtained by arranging that all the pairs do not have the same length of lay. Two different lays are generally sufficient for an audio cable, the pairs in each layer being arranged so that any two adjacent ones have different lays. In a carrier cable, this may still not reduce the mutual inductances to the required level. In such cases, it may be necessary to give all the pairs different lays and also to space the metal sheath away from the wires to reduce mutual coupling via the sheath.

Capacitance unbalance is more serious and cannot generally be kept within the required limits merely by ensuring the greatest possible uniformity of cable construction. On an audio cable, a sufficient degree of capacitance balance can be achieved by the use of "test-selected" joints. At such a joint, measurements of capacitance unbalance are first made and the pairs then selectively jointed in such a way that the unbalances of the portions of cable on either side of the joint tend to cancel out. The selected joints usually occur at about 1,000-yard intervals. On a carrier cable, the balancing problem is more severe. In this case there has to be a selected joint for each manufactured length of 176 yards. The cable is made up of unit "balancing sections" of eight lengths each. Each section is formed by first jointing the eight lengths in four pairs, in such a way that the unbalances tend to cancel out in each pair. The latter are then jointed to form two groups of four lengths which are then selectively jointed together to form the unit section. These sections of about 1,400 yards are then, in turn, selectively jointed in pairs, groups of four and so on until a complete repeater section length of cable has been formed.

Even this process is generally not sufficient and it is necessary to provide "balancing-frames" at intervals along the cable (usually one per repeater section). Each frame contains a number of variable capacitors with a suitable cross-connection field which enables a capacitor to be connected between any two wires of the cable. The capacitors are adjusted to reduce the residual unbalances to a satisfactory level.

Q. 4. *Describe the frequency grouping of telephone channels in a typical coaxial-cable system. Indicate what carrier-frequency supplies are required for the system described.*

Outline arrangements for generating and stabilising the necessary carrier and pilot frequencies.

Q. 5. *Discuss the essential performance characterics of a typical coaxial line amplifier, giving approximate quantitative requirements.*

Outline the principles involved in relating the number of channels and signal levels handled by such an amplifier to its non-linear and overload characteristics.

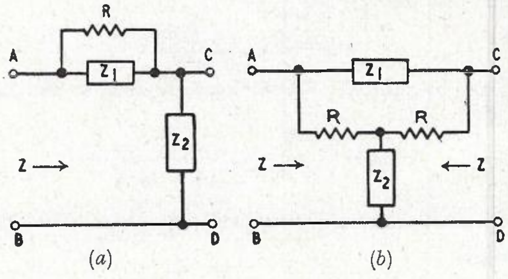
Q. 6. *Explain what is meant by "inverse impedances" and show how networks having inverse impedances can be arranged to form a four-terminal attenuation equaliser having (a) constant input impedance only, and (b) constant input and output impedances.*

Explain the advantages of such equalisers compared with a two-terminal equaliser and indicate the circumstances in which condition (b) above is desirable.

A. 6. Two impedances Z_1 and Z_2 are said to be inverse with respect to a resistance R if they satisfy the equation

$$Z_1Z_2 = R^2$$

The circuits of two types of "constant resistance" equaliser are shown in the sketches.



(a) (b)

Suppose that terminals C and D of type (*a*) are closed with R. The impedance measured at terminals A and B will be

$$Z = \frac{RZ_1}{R + Z_1} + \frac{RZ_2}{R + Z_2}$$
$$= R\left(\frac{RZ_1 + RZ_2 + 2Z_1Z_2}{RZ_1 + RZ_2 + Z_1Z_2 + R^2}\right)$$
$$= R, \text{ when } Z_1Z_2 = R^2$$

It can be shown that the impedance presented at CD when AB are closed with R will *not* be equal to R.

In the symmetrical type (*b*), the image impedance Z_o is given by

$$Z_o^2 = Z \text{ open} \cdot Z \text{ closed}$$
$$= \left(Z_2 + \frac{R(Z_1 + R)}{Z_1 + 2R}\right)\left(\frac{Z_1R(R + 2Z_2)}{Z_1R + Z_1Z_2 + R^2 + 2RZ_2}\right)$$
$$= \frac{Z_1R^2 + 2Z_1Z_2R}{Z_1 + 2R}$$
$$= R^2 \text{ since } Z_1Z_2 = R^2.$$

Thus, in this case, if either pair of terminals is closed with R, the impedance presented at the other pair will also be R.

It can be shown that the insertion loss of either type of equaliser in a matched circuit of impedance R is 20 log $(1 + \sqrt{Z_1/Z_2})$ db. Thus the product of the impedances Z_1 and Z_2 is determined by the circuit impedance, and the ratio of Z_1 to Z_2 is determined by the required insertion loss characteristic.

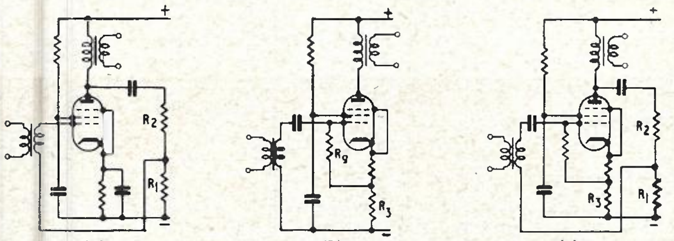
Equalisers of this type not only have the advantage of providing constant resistive impedances which can be used to terminate filters, coaxial lines, etc., but their design is simplified by the fact that the total insertion loss of a number of sections in tandem is the sum of the insertion losses of the individual sections. The symmetrical type is useful where it is necessary to present a constant impedance in both directions. Such a situation may arise, for example, on a 2-band system where the equalisers are required to present a constant impedance to a pair of directional filters on one side and a negative feedback amplifier on the other.

Q. 7. *Give typical circuit arrangements of a single valve pentode amplifier in which negative feedback is derived from (a) the output voltage, (b) the output current, and (c) both the output voltage and the output current.*

Discuss the relative advantages of the three methods and mention one application of each type.

What is the voltage gain of a cathode-follower stage employing a pentode valve of mutual conductance 8 mA/volt and a cathode resistance of 250 ohms.

A. 7. In the voltage feedback arrangement (sketch (*a*)), the feedback voltage is a fraction $R_1/(R_1 + R_2)$ of that developed across the primary of the output transformer. In the current feedback amplifier,



(*a*) (*b*) (*c*)

(sketch (*b*)) the feedback voltage is R_3 multiplied by the current flowing in the anode load impedance. The mixed feedback circuit (sketch (*c*)) is merely a combination of the other two.

The main difference in behaviour between the three circuits is in the output impedance presented to the load. Voltage feedback, by tending to keep the output voltage constant, produces a low output impedance, whilst current feedback tends to keep the load current constant, thus apparently increasing the output impedance. Voltage feedback has an advantage when applied to an amplifier with an output transformer, since the reduction in effective output impedance facilitates the design of the transformer. Current feedback is used in the output stage of an oscillator which is required to give a constant current output irrespective of the load impedance into which it works. Another application for current feedback is to the stabilising of D.C. power supply units such as those used for submerged repeater systems. Mixed feedback combines the two effects and by a suitable choice of the amount of each type of feedback, it is possible to fix both the total feedback and the effective output impedance independently. The output impedance then tends to be independent of the internal impedance of the output valve. This facility is useful where the amplifier output impedance has to be matched accurately to the load, for example, when the amplifier feeds a transmission line or a wave filter.

In a cathode-follower, the output voltage is taken across a resistance in the cathode circuit, with the result that the whole of the output voltage is fed back directly into the grid circuit. If the mutual conductance of the valve is g_m and the cathode resistance R, the effective voltage gain is $\frac{g_mR}{1 + g_mR}$

In the example given, this is $\frac{8 \times 250 \times 10^{-3}}{1 + (8 \times 250 \times 10^{-3})} = \frac{2}{3}$

Q. 8. *A submarine coaxial cable having a paragutta core 0·62 in. in diameter and optimum diameter ratio has the following primary coefficients at a frequency of 1 Mc/s; R = 54Ω; L = 0·52 mH; G = 8,000 μ mhos; C = 0·202 μF, all per nautical mile. Calculate the components of the attenuation due to resistance and leakance and hence estimate the permissible reduction in diameter for the same attenuation if the paragutta is replaced by a loss-free dielectric having the same permittivity.*

A. 8. The attenuation is given by

$$\alpha = \frac{R}{2}\sqrt{\frac{C}{L}} + \frac{G}{2}\sqrt{\frac{L}{C}} \text{ nepers/naut. mile.}$$

In this expression, the first term represents the component due to resistance and the second that due to leakance. Substituting given values:—

$$\alpha = 27\sqrt{\frac{0{\cdot}202 \times 10^{-6}}{0{\cdot}52 \times 10^{-3}}} + 4000 \times 10^{-6}\sqrt{\frac{0{\cdot}52 \times 10^{-3}}{0{\cdot}202 \times 10^{-6}}}$$
$$= 0{\cdot}532 + 0{\cdot}203 \text{ nepers/naut. mile.}$$

If the dielectric were perfect, the resistance loss could be allowed to increase from 0·532 to (0·532 + 0·203) = 0·735 nepers/naut. mile.

Now, R, L and C are given by formulae of the following forms;

$$L = 2 \log_e \frac{b}{a}$$
$$C = \frac{k}{2 \log_e \frac{b}{a}}$$
$$R = \left(\frac{1}{a} + \frac{1}{b}\right)\sqrt{\frac{\mu f}{\rho}}$$

where b and a are the inner radius of the outer conductor and outer radius of the inner conductor, respectively, f is the frequency, μ and ρ are respectively the permeability and resistivity of the material forming both inner and outer conductors and k is the dielectric permittivity.

$$\text{Thus } \alpha = \frac{R}{2}\sqrt{\frac{C}{L}} = \frac{1}{4b}\sqrt{\frac{\mu k f}{\rho}}\left(1 + \frac{b}{a}\right)\left(\log_e \frac{b}{a}\right)^{-1}$$

For given materials, the resistance loss is proportional to

$$\frac{1}{b}\left(1 + \frac{b}{a}\right)\left(\log_e \frac{b}{a}\right)^{-1}$$

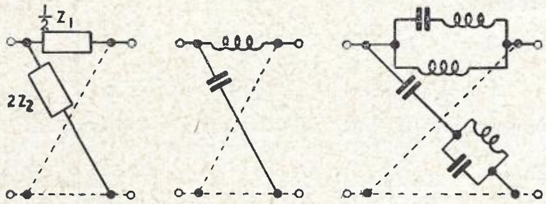
If the outer radius b is fixed it can be shown (by differentiation with respect to (b/a)) that this expression reaches a minimum when (b/a) is about 3·5. This represents the optimum diameter ratio for cables having inner and outer conductors of the same material. Once the ratio (b/a) has been fixed, the resistance loss is proportional to $1/b$. The diameter of the given cable, assuming the optimum ratio to be maintained, could thus be reduced in the ratio 0·735 to 0·532, i.e., by about 27½ per cent.

Q. 9. *Explain what is meant by group delay and group-delay distortion and discuss their importance in (a) telephony, (b) music transmission, (c) V.F. telegraphy, (d) facsimile telegraphy, (e) television.*

Sketch typical networks suitable for correction of group-delay distortion.

A. 9. Suppose that the signal applied to a transmission line consists of a large number of sinusoidal voltages, of equal amplitude but with values of ω distributed uniformly over a narrow frequency band $\delta\omega$. If the envelope of the waveform, corresponding to such a frequency group, is examined at various points along the line, it will be found that pulses of energy are being propagated with a constant velocity. The time taken for any such pulse to reach the receiving end is called the "group delay" of the line and is given by $\delta\beta/\delta\omega$ where $\delta\beta$ is the difference in the total phase shift along the line for frequencies at the two extremes of the transmitted group. If the bandwidth of the group is made infinitesimally small, the group delay becomes equal to the slope of the curve of the phase-shift β, plotted against ω. The frequency spectrum of any signal waveform can be regarded as made up of elementary frequency groups, each of which will be subjected to a delay $\delta\beta/\delta\omega$. If $\delta\beta/\delta\omega$ is not constant over the whole transmitter frequency spectrum, the various components of the signal will not arrive together at the receiving end and "group delay distortion" will result. This type of distortion cannot be detected by the ear unless it is very severe. Generally speaking, more distortion can be tolerated on speech than on high-quality music but it is not usually necessary to provide delay equalisation on normal music transmission circuits. In a multi-channel V.F. telegraph system waveform distortion is important, but the amount of delay distortion occurring over the frequency range covered by each channel is not serious. For a facsimile telegraph circuit, however, delay distortion over the whole band must be taken into account and it is usually necessary to introduce delay-equalising networks. On a television link, the requirements are fundamentally the same as for facsimile telegraphy but are much more difficult to meet in practice because of the very wide frequency bandwidth which has to be covered.

Delay equalisers generally consist of one or more lattice sections



(a) (b) (c)

of the basic form shown in sketch (*a*). If Z_1 and Z_2 are pure reactances which are inverse with respect to a resistance R, i.e., if $Z_1Z_2 = R^2$, then the lattice section has a constant image impedance R and zero attenuation at all frequencies. Sketches (*b*) and (*c*) show possible inverse reactance arms which may be used. There is no limit to the complexity of the lattice arms but, in practice, it is usually convenient to use a number of simple sections in tandem rather than one complicated one. Since all the sections can be arranged to have the same image impedance, R, the total phase characteristic will be the sum of those of the individual sections.

Q. 10. *Give an account of the losses which occur in transformers used in line transmission equipment and discuss the factors which determine—*

(*a*) *the choice of core size, core material and, where appropriate, lamination thickness, and*
(*b*) *the gauge and degree of stranding of the windings.*

A. 10. The main sources of loss in communication transformers are:—

(*a*) conductor loss,
(*b*) core loss,
(*c*) dielectric loss.

The dielectric loss in the insulating materials can generally be kept small by the use of low-loss insulants and by excluding moisture from the windings. The conductor loss includes components due to normal magnetically-induced eddy-currents and also to displacement currents in the conductor, which arise as a result of the distributed capacitance of the windings. The latter may become troublesome at high frequencies (say above about 1 Mc/s) and may call for special design techniques which will not be considered further here. Core losses include components due to eddy-currents, hysteresis and residual loss although, in communication transformers, the required freedom from non-linear distortion generally means that hysteresis loss forms only a small proportion of the total. For laminated cores, eddy-current losses predominate but residual loss becomes important in high-frequency powder-core materials and in ferrites.

The core size is often determined by distortion requirements although it may be fixed by the ratio of inductance to D.C. resistance which is necessary in order to obtain the required freedom from shunt loss at the lowest transmitted frequency without, at the same time, producing an excessive loss due to the D.C. resistance of the windings. If the windings have to carry D.C. the resulting voltage drop and heat dissipation may not only place a further restriction on the winding resistances but will necessitate more turns for a given inductance, as a result of the lowering of core permeability by the D.C. magnetising force and by the necessity for an airgap.

For a laminated core, the choice of material will depend on whether a D.C. current flows in the windings or not. This is because, although alloys with a high initial permeability are useful for unpolarised cores, they are easily saturated, so that materials of lower initial permeability may give better results in the presence of a D.C. magnetising force. Since the eddy-current loss increases with frequency and with lamination thickness, the latter will be determined by the frequency range over which the transformer is to be used. The eddy-current loss at a given frequency is relatively higher for a high permeability alloy than for one of lower initial permeability using the same lamination thickness. In all cases, the lamination thickness chosen will be the largest standard thickness which can be tolerated from the point of view of eddy-current losses. At still higher frequencies where the optimum lamination thickness would be too small to be practicable, powder-core and ferrites are generally more suitable.

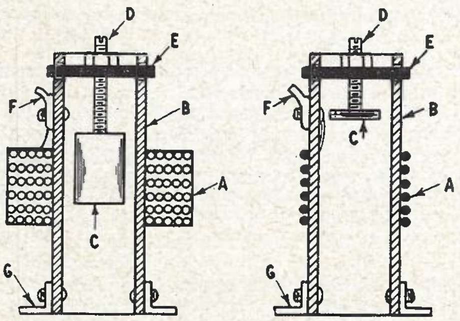
The stranding of the windings is carried out in order to minimise conductor eddy-current losses and the general principle is that the strand diameter is reduced until the eddy-current loss comes within the required limits. The number of strands is determined by the overall conductor diameter which, in turn, is fixed by the required number of turns and the cross-sectional area of the winding space. The available winding space is usually divided equally between the windings. An exception to this rule is a "voltage" transformer, such as that used at the input of an amplifier, in which the secondary carries virtually no current. The secondary resistance, in such cases, is relatively unimportant and the winding space allocated to the secondary would be less than half the total.

RADIO I, 1953

Q. 1. *Describe, with sketches, the constructional features of inductors suitable for the radio-frequency stages of (a) medium-wave and (b) short-wave receivers.*

If the total tuning capacitance of a resonant circuit is 300 μμF, what value of inductance is needed to tune to 1 Mc/s?

A. 1.(*a*) Sketch (*a*) is a cross-sectional diagram of an inductor suitable for the radio-frequency stages of a medium-wave receiver.



(a) (b)

It comprises a wave-wound coil A, mounted on a cylindrical paxolin former, B, with an iron-dust-core slug, C, which can be adjusted by the screw D working in a tapped hole in a short piece of brass strip, E. The brass strip fits into slots cut in the paxolin former. The coil connections are joined to soldering tags riveted to the paxolin former, one of which is shown at F, and the former is fixed to the receiver chassis by the lugs G.

(*b*) Sketch (*b*) shows a radio-frequency inductor for a short-wave receiver; the construction is basically similar to that of the medium-wave coil. The coil consists of a single-layer solenoid of bare wire wound directly on the former, and varnished to secure the turns in position. The inductance can be adjusted by the brass damping disk C fixed to the screw D. Screwing the disk into the coil decreases the inductance.

The formula connecting the resonance frequency f, in cycles/sec, inductance L, in henries, and capacitance C, in farads, of a resonant circuit is:

$$f = 1/(2\pi\sqrt{LC})$$
$$\text{so } f^2 = 1/(4\pi^2 LC)$$
$$\text{or } L = 1/(4\pi^2 f^2 C)$$

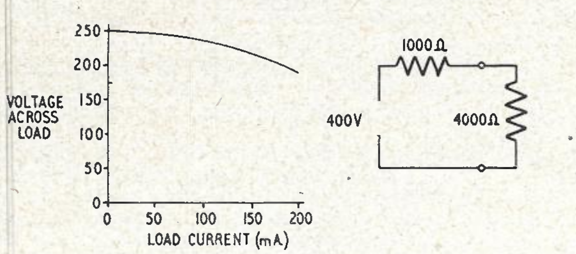
Substituting the given values:

$$L = 1/(4\pi^2 \times 10^6 \times 10^6 \times 300 \times 10^{-12})$$
$$= 1/(1{,}200\pi^2) \text{ henry}$$
$$= 10^6/(1{,}200\pi^2) = \underline{84{\cdot}5 \text{ microhenries.}}$$

Q. 2. *What is meant by the* voltage regulation characteristic *of a high-tension supply unit?*

The open-circuit E.M.F. of a high-tension supply unit is 400*V and the internal resistance is* 1,000 *ohms. Find the voltage developed across a load resistance of* 4,000 *ohms, and the current in the load.*

A. 2. The voltage regulation characteristic of a high-tension supply unit is the relation between the potential difference across the load and the current through the load for a range of load currents. It is usually displayed in graphical form as in sketch (*a*),



(*a*) (*b*)

which shows load voltage plotted against load current from zero to the maximum safe current for the unit. For zero load current the potential difference is equal to the open-circuit E.M.F. of the supply unit, but as the load current is increased the potential difference across the load decreases owing to the voltage dropped across the internal resistance of the unit. This internal resistance is due to the resistances of the smoothing chokes, the rectifier itself and of the high-tension transformer.

When a particularly stable H.T. supply voltage is needed some form of electronic voltage regulator is used, and the graphical voltage regulation characteristic of such a device is, of course, a nearly-horizontal line.

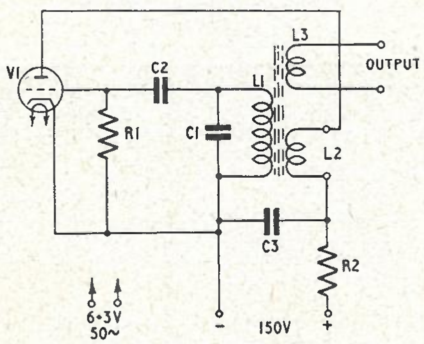
Sketch (*b*) shows the equivalent circuit of the given high-tension supply unit and its load. By Ohm's law,

the load current = 400/(1,000 + 4,000) = 0·08 amp.
and so the voltage across the load = 0·08 × 4,000 = 320 volts.

Q. 3. *Draw the circuit diagram of a simple audio-frequency LC valve oscillator with suitable output circuit arrangements.*

If the tuning inductor used has an inductance of 1 *henry, calculate the oscillation frequency when the value of the associated capacitor is* 0·025 *microfarad.*

A. 3. The sketch shows the circuit diagram of a simple audio-frequency LC valve oscillator, using an inductive feedback circuit. The resonant



circuit L1, C1 determines the oscillation frequency and is connected between the grid and cathode of the triode valve V1. The coil L1 is wound on a magnetic core, either of iron-dust or of laminated iron. A secondary winding L2, is wound on the same core as L1, and is connected in the anode circuit to feed energy back to maintain the oscillations. There is a third winding, L3, on the core, which provides a coupling to the output circuit. The amplitude of oscillation is controlled by the grid leak resistor, R1, and capacitor C2, which provide an increasing grid bias as the amplitude builds up. Resistor R2 and capacitor C3 decouple the high-tension supply lead. The load winding L3 should have very few turns, or changes in the impedance of the load connected to it will affect the frequency of oscillation. Often L3 is connected to the grid circuit of a buffer amplifier valve, to reduce the effect of load changes on frequency.

The formula connecting the oscillation frequency *f*, in cycles/sec., with the inductance *L*, in henries, and the capacitance *C*, in farads, of a resonant circuit is:

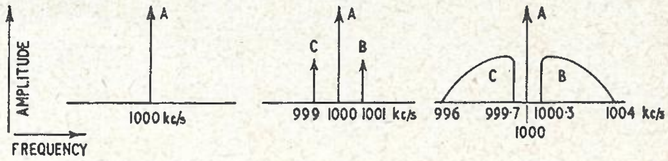
$$f = 1/(2\pi\sqrt{LC})$$

and substituting the given values

$$f = 1/(2\pi\sqrt{1 \times 0{\cdot}025 \times 10^{-6}}) \text{ cycles/sec.}$$
$$= 1/(2\pi \times 0{\cdot}154 \times 10^{-3}) \text{ cycles/sec.}$$
$$= \underline{1034 \text{ cycles/sec.}}$$

Q. 4. *Explain what you understand by the* sidebands *of an amplitude-modulated wave. Illustrate your answer with reference to a carrier modulated by* (*a*) *a single frequency tone and* (*b*) *speech. State the factors that determine the amplitudes of, and the frequency ranges occupied by, the sidebands.*

A. 4. 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. Thus, sketch (*a*) shows the spectrum of an unmodulated 1,000 kc/s carrier wave; it consists of a single



(*a*) (*b*) (*c*)

oscillation, A, of frequency 1,000 kc/s. Sketch (*b*) shows the spectrum of the same carrier when it is 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 and having the 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), and their presence can be demonstrated by tuning a very selective radio receiver slowly from just below 999 kc/s to just above 1,001 kc/s when three separate responses will be observed. Sketch (*c*) shows the spectrum of a 1,000 kc/s carrier wave amplitude-modulated by commercial-quality speech having components in the range 0·3 to 4 kc/s. Each single-frequency component in the complex speech wave generates an upper and a lower side-frequency and the bands of side frequencies corresponding to the whole speech wave are called the upper and lower sidebands. The upper sideband in sketch (*c*) extends from (1,000 + 0·3) to (1,000 + 4) kc/s, and the lower sideband from (1,000 — 0·3) to (1,000 — 4) kc/s.

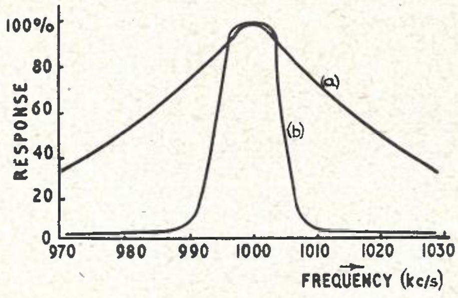
The amplitudes of the upper and lower side-frequency components produced by a single frequency tone are equal, and depend upon the amplitude of the carrier wave, *E*, and on the depth of modulation *m* per cent.; they are, in fact, each equal to $(\frac{1}{2} \times \frac{m}{100} \times E)$. The frequency ranges occupied by the sidebands depend on the carrier-frequency, *F* kc/s, and on the lowest, f_1 kc/s, and highest, f_2 kc/s, frequencies present in the *modulating* wave. The frequency ranges are then:

Lower sideband $(F-f_2)$ to $(F-f_1)$ kc/s.
Upper sideband $(F+f_1)$ to $(F+f_2)$ kc/s.

Q. 5. *Sketch the approximate selectivity characteristics of—*
(*a*) *a simple crystal-detector broadcast receiver,*
and (*b*) *a super-heterodyne broadcast receiver.*

Explain why with (*a*) *it is difficult to separate transmissions* 100 *kc/s apart whereas with* (*b*) *transmissions spaced only* 10 *kc/s apart are easily separated.*

A. 5. The approximate selectivity characteristic of a simple crystal-detector broadcast receiver is shown in the sketch, curve (*a*), and that of a superheterodyne broadcast receiver is shown as curve (*b*). Both receivers are assumed to be tuned to 1,000 kc/s.



The simple crystal-detector receiver has a single resonant circuit, which is damped by the load of the crystal and headphones, and its response is, therefore, fairly broad. Curve (*a*) corresponds to the response of a single resonant circuit with a Q-value of 50, and it will be seen that the response to a signal spaced 30 kc/s away from the carrier-frequency is only reduced to 30 per cent. of the response to the carrier-frequency. Even at 100 kc/s away from the carrier-frequency the response of such a circuit would only be reduced to 10 per cent. of that to the carrier.

The superheterodyne receiver on the other hand uses several double-tuned coupled circuits, and has a band-pass response with steep sides as shown in curve (*b*). The response to a frequency only 10 kc/s away from the carrier-frequency is only 3 per cent. of that to the carrier, and 30 kc/s away the response might be no more than 0·1 per cent. of maximum.

With the crystal receiver discussed above, a transmission separated from the wanted signal by 100 kc/s, and of equal signal strength, would only be suppressed to 10 per cent. of the amplitude of the wanted signal, and would therefore still be rather troublesome. With the superheterodyne receiver, however, an equally strong transmission spaced 10 kc/s away from the wanted signal would be suppressed to 3 per cent. of the wanted signal's amplitude which would be sufficient to avoid interference.

Q. 6. *Why is it necessary to include a "detector" stage in an amplitude-modulated radio receiver? Give the circuit diagram and describe the operation of a detector stage using a diode valve.*

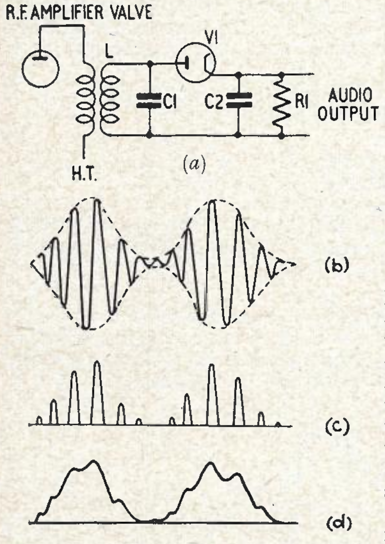
A. 6. An amplitude-modulated radio wave after amplification by the radio-frequency stages of a radio receiver consists of a high-frequency oscillatory current with an amplitude varying in sympathy with the audio-frequency modulation imposed upon it. If this current were applied directly to the headphones or loudspeaker, no audible sounds would result because:

(*a*) 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;

(*b*) even if sufficient high-frequency current could be made to flow through the voice coil the inertia of the coil and cone would prevent the loudspeaker from responding; and

(*c*) 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 high-frequency oscillatory current but only to changes in its amplitude. Such a device is called a detector, because it detects the presence of the high-frequency current.



Sketch (*a*) shows a circuit diagram of a diode detector stage which comprises a tuned circuit, L, C1, a diode valve, V1, a load resistor, R1, and a decoupling capacitor, C2. Sketch (*b*) shows the waveform of the voltage developed across the tuned-circuit capacitor, C1, and applied to the diode. The diode valve conducts only when its anode potential is positive with respect to its cathode, which happens at each positive peak of the signal wave. The diode valve passes a pulse of anode current at each positive peak, as shown in sketch (*c*), and this anode current charges the capacitor, C2, to a potential only slightly less than the peak voltage of the signal. Between peaks the diode's anode potential is negative with respect to its cathode and no anode current flows. During this interval some of the charge on capacitor C2 leaks away through the load resistor R1. The voltage across C2, R1 then follows the peak voltage of the signal as shown in sketch (*d*), and so reproduces the waveform of the applied modulation. The resistance of R1 should be sufficiently low to enable the charge on capacitor C2 to follow the highest modulating frequency, but it must not be too low or the diode valve will not be able to charge the capacitor adequately.

Q. 7. *A super-heterodyne receiver is to tune from 200 to 500 metres wavelength and the intermediate frequency is to be 110 kc/s. Calculate the highest and lowest frequencies of—*

(a) the R.F. input circuit,

and (b) the local oscillator,

corresponding to the specified wavelength range.

A. 7. The relation between the frequency, f c/s, and wavelength, λ metres, of a radio wave is:

$$f\lambda = 300{,}000{,}000 \text{ metres/sec.}$$

Substituting the values given for the required wavelength range, the maximum and minimum signal frequencies are:

$$f_1 = 300{,}000{,}000/200 = 1{,}500{,}000 \text{ c/s} = \underline{1{,}500 \text{ kc/s}}$$

$$f_2 = 300{,}000{,}000/500 = 600{,}000 \text{ c/s} = \underline{600 \text{ kc/s}}$$

and these are the highest and lowest tune frequencies for the R.F. input circuit.

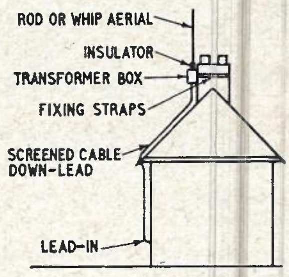
If the intermediate frequency is to be 110 kc/s the local oscillator can be set 110 kc/s higher or lower than the signal frequency. When the local oscillator frequency is set higher than the signal frequency, the ratio of the highest and lowest oscillator frequencies required is smaller than when the oscillator frequency is set lower than the signal frequency, which makes tuning easier, so this setting is preferred. The highest and lowest local oscillator frequencies are therefore:

$$1{,}500 + 110 = \underline{1{,}610 \text{ kc/s}}$$

$$\text{and} \quad 600 + 110 = \underline{710 \text{ kc/s}}$$

Q. 8. *Describe, with a sketch, an outdoor receiving aerial suitable for long and medium wavelengths. Explain why such an aerial usually picks up less locally generated interference than an indoor aerial.*

A. 8. The sketch illustrates an outdoor receiving aerial suitable for long and medium wavelengths. The aerial consists of a self-supporting metal rod or whip about 6 ft. long, which is mounted on a suitably high point such as a chimney stack. The aerial is fixed to a metal screening box from which it is insulated. Inside the box is a radio-frequency transformer which matches the aerial to the screened low-impedance cable used for the lead-in to the house. An aerial of this type is especially good at rejecting locally-generated interference for the reasons listed below:



(*a*) The aerial itself is mounted high and well away from the house's electric wiring, which radiates interference caused by mains-operated domestic electric equipment. It is also relatively far away from motor-car sources of ignition interference.

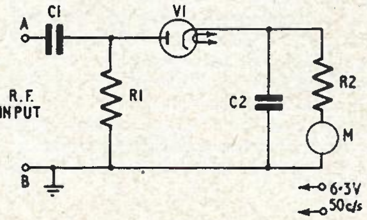
(*b*) The down lead being screened and of low impedance, its coupling to sources of interference in the house is weak.

(*e*) The aerial being high and not shielded by neighbouring structures picks up a strong signal from the desired transmission.

An indoor aerial, however, is poor in almost all the respects listed above. Thus it is often closely coupled to the house wiring, in many cases running parallel with it. Again, the indoor aerial is shielded by being within the house so that it picks up a poor signal from the wanted station, and the shielding is often increased by running the aerial wire very close to the walls.

Q. 9. *How would you construct a simple valve voltmeter suitable for voltages up to 5 volts at frequencies up to 10 Mc/s? Explain how such an instrument could be calibrated.*

A. 9. As the voltmeter is required to measure voltages up to 5V, a simple diode half-wave rectifier circuit can be used, as shown in the sketch. The R.F. input is applied between terminals A and B, B being joined to earth; and a D.C. blocking capacitor, C1, prevents the diode valve, V1, from responding to direct potentials, on which



the radio-frequency voltages may be superposed. Resistor R1 provides a D.C. path for the rectified current. The radio-frequency potential difference across R1 is applied to the diode, V1, and the rectified current flows through the diode load resistor R2 and its associated smoothing capacitor C2. A microammeter, M, measures the load current, which is proportional to the applied radio-frequency voltage. Resistors R1 and R2 should have resistances as high as possible, compatible with the sensitivity of M and the required voltage range, in order to increase the impedance of the voltmeter. Capacitors C1 and C2 are chosen to suit the lowest frequency which is to be measured; their reactances must be low compared with the resistances of R1 and R2. Suitable values for the range 1 kc/s to 10 Mc/s, 0·5 to 5·0V, would be R1 = R2 = 100,000 ohms, C1 = C2 = 0·01 μF, M = 50 microamps. F.S.D. Care should be taken in the construction to avoid introducing stray capacitances to earth from the terminal A or the capacitor C1 or the lead joining it to the diode anode.

There are two alternative methods of calibration. In the first the valve voltmeter is calibrated by applying to it a series of alternating potentials from the 50 c/s A.C. mains, which are simultaneously measured by a standard A.C. voltmeter; this method assumes that capacitors C1 and C2 are of sufficient capacitance to avoid errors at 50 c/s. In the second method the valve voltmeter is set to measure the potential developed across a low resistance of known value, when it is carrying a radio-frequency current measured by a thermocouple. This method can be applied at any frequency, but relies on a knowledge of the radio-frequency resistance of the resistor. Both methods may be in error if the waveform of the calibrating current is non-sinusoidal, since the diode voltmeter measures peak voltage, whereas the thermocouple and 50 c/s standard voltmeter measure R.M.S. values.

Q. 10. *Compare the advantages and disadvantages of absorption and heterodyne wavemeters for the frequency range 1 to 10 Mc/s, and give examples of the use of each type.*

A. 10. *Accuracy.* Absorption wavemeters for the range 1 to 10 Mc/s have measurement errors of from ±0·1 per cent. to ±2 per cent. The measurement errors of portable heterodyne wavemeters may be as low as ±0·005 per cent., and the errors of elaborate, non-portable, heterodyne wavemeters may be as low as ±0·00001 per cent.

Sensitivity. Absorption wavemeters are relatively insensitive and need to be coupled quite closely to a fairly high-powered part of the circuit. The close coupling will alter the reactances in both the wavemeter and the circuit being measured, which may lead to appreciable frequency errors. Heterodyne wavemeters usually require a signal of only a small fraction of a volt, and have high input impedances which have little effect on the circuits to which they are coupled.

Simplicity, Robustness and Portability. Absorption wavemeters are very simple instruments and may contain no thermionic valves and require no power supplies. They are usually of robust construction and come to little harm when accidentally overloaded. Heterodyne wavemeters are fairly complex devices using one or more valves and needing H.T. and L.T. power supplies. They are thus larger and heavier than absorption wavemeters. Their input circuits may be damaged if they are accidentally coupled to a high-power circuit.

Stability of Calibration. The long-term accuracy of an absorption wavemeter depends on the stability of its inductors and capacitor, and can be affected by mechanical damage caused by rough handling. The accuracy of a heterodyne wavemeter usually depends on a quartz crystal standard and is less susceptible to degradation in use.

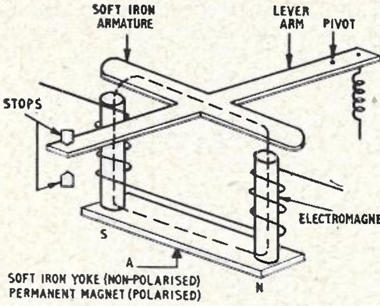
Effect of Harmonics. Absorption wavemeters respond to harmonic frequencies when tuned to them, but the resonance indication is usually much feebler than for the fundamental frequency. Heterodyne wavemeters may give beats on harmonic and sub-harmonic frequencies which are difficult to distinguish from that with the fundamental frequency.

Use of Absorption and Heterodyne Wavemeters. Absorption wavemeters are most useful for relatively rough measurements on powerful sources such as radio transmitters, e.g. an absorption wavemeter may be used to check the tune of the harmonic generator stages of a transmitter. Equally, they may be used to line up the local oscillators in a superheterodyne radio receiver. Heterodyne wavemeters are used when more accurate measurements of frequency are required, e.g. for checking the frequency of a crystal-controlled transmitter, or for measurements of the frequency of a received radio signal.

ELEMENTARY TELECOMMUNICATIONS PRACTICE, 1953

Q. 1. *Describe, with the aid of simple sketches, the principle of operation of a telegraph sounder when it is (a) non-polarised, and (b) polarised by means of a permanent magnet. What is the purpose of polarising the sounder?*

A. 1. The sketch shows the magnetic circuit of a telegraph sounder.



(*a*) *Non-polarised.* The magnetic circuit consists of a soft iron yoke, A, joined to two soft iron cores round each of which is wound a coil of wire to form electromagnets. The circuit is completed by a soft iron armature carried on a lever arm pivoted at its end. The two coils are connected in series. In the idle condition the spring attached to the lever arm holds the armature away from the cores. When a current flows through the coils the two soft iron cores become temporary magnets and have fields much the same as that of a bar magnet. Opposite magnetic poles are formed at the cores at the respective air gaps and the magnetic flux passes round the cores, across the air gaps and through the armature and yoke as shown by the broken line path in the sketch. The armature, moving on its pivot, is thus attracted towards the cores against the action of the spring. The armature releases when the magnetic field decays on cessation of the current.

The sound emitted when the armature extension strikes the lower stop indicates the commencement of a signal, and that emitted when the armature returns to its normal position, the extension striking the top stop, indicates the end of the signal. A small air gap gives greater sensitivity, but reduced intensity of sound. The tension of the spring is adjusted so that the armature operate and release times are substantially the same, and so that the clicks emitted on operate and release are of much the same loudness.

(*b*) *Polarised.* The magnetic circuit of the polarised sounder is much the same as the non-polarised type except that the member A is a steel permanent magnet instead of a soft iron yoke. This permanent magnet polarises the soft iron cores with opposite polarities at the respective air gaps and the soft iron armature tends to be attracted. This pull is balanced by adjusting the tension of the spring. If a current through the coils produces an operating magnetic field in the cores in a direction so as to aid the polarising field, the pull on the armature overcomes the tension of the spring and the armature is attracted to give a click. If the direction of the operating current is reversed, then the operating field set up opposes the standing polarising field, which is thus reduced and the armature returns to the normal position under the action of the spring to give a second click. If the armature was not operated, then this reversed current merely results in the armature remaining in the unoperated position. Due to the action of the spring, the sounder would respond to single current signals in the aiding direction as well as to double current.

In the most sensitive, or "neutral" adjustment, the tension of the spring is adjusted so that the armature will remain in either the up or down position. In the up position the pull of the spring prevails, whilst in the down position the magnetic attraction of the polarising field is greater than the pull of the spring. These positions of balance are upset by a very small current impulse which therefore produces movement of the armature.

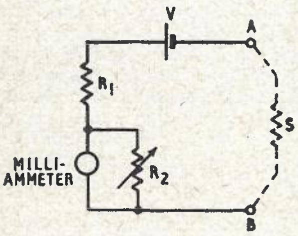
The polarisation of the sounder increases the sensitivity of the instrument due to the presence of the large standing magnetic field. The polarised sounder can therefore be used on longer, higher resistance lines than would be permitted by the non-polarised type. The polarisation also allows directional operation, the armature moving in one direction, against the spring, when the operating current is in the aiding direction, and in the other direction, the pull of the spring prevailing, when the current is reversed to oppose the polarising field.

In both the polarised and non-polarised versions, arrangements are incorporated to ensure a residual gap when the armature is operated, so preventing a closed magnetic circuit, as otherwise the release would be erratic.

The sounder gives audible indication of received Morse signals, these being interpreted by noting the duration of the silence between the two clicks, a short interval denoting a dot, and a longer interval a dash.

Q. 2. *Describe, with the aid of a simple diagram, how a milliammeter, in conjunction with a primary cell battery, may be calibrated to measure resistance by direct reading. State any limitation in this method of measuring resistance and any precautions which may be adopted to obtain a good result.*

A. 2. The sketch shows how a milliammeter and a primary cell may be connected to form a simple ohm-meter. Resistor R_1, of value about equal to the mid-scale reading of the instrument, is connected in series with the milliammeter. R_2, connected in shunt with the milliammeter, is variable. The instrument is calibrated as follows. Terminals A and B are short-circuited, and R_2 is adjusted until a full scale deflection is obtained. The short-circuit is then removed, being replaced by a resistor of known value. A deflection is then obtained which is less than full scale. This deflection, which corresponds to the resistance value, is noted on the scale. Other values of resistance are then connected across A and B and the different deflections again noted. The instrument is thus calibrated to read directly in ohms, and if S, a resistance to be measured, is connected across A and B, its value can be read directly from the scale according to the deflection of the needle.



Re-setting for zero resistance position (i.e. full scale deflection) can be effected by adjusting R_2, as may be reasoned as follows.

With A and B short-circuited, as the resistance of the parallel arrangement of the meter and R_2 is low, the current I flowing is substantially proportional to V/R_1 where V is the battery voltage (1)

When the short-circuit is removed and resistance S connected, the current I_1 flowing is proportional to $V/(R_1 + S)$ .. .. (2)

From (1) $V = kIR_1$

and from (2) $V = kI_1 (R_1 + S)$ where k is a constant.

Assuming that the battery volts, V, have remained constant, then

$$I_1 (R_1 + S) = IR_1$$

$$\text{and } S = \frac{IR_1}{I_1} - R_1 = R_1\left(\frac{I}{I_1} - 1\right)$$

from which it is seen that the result depends upon R_1 (which is fixed) and the ratio of the two currents.

As the ratio only of the currents is concerned, the actual current values are therefore immaterial, and it is permissible to use the variable shunt R_2 for bringing the needle initially to full scale deflection (zero on the resistance scale) whatever the battery voltage may be, and thus correct for any variation in battery voltage. The second deflection, with the resistance to be measured in circuit, is therefore a measure of the resistance.

This method of measuring resistance has the following limitations:—

(*a*) Variation in battery voltage and internal resistance of the battery would give an incorrect result unless precautions were taken.

(*b*) Unless a high voltage and a highly sensitive milliammeter be used, the range of the instrument, and thus the accuracy, is limited.

(*c*) As the method does not depend upon a balance (or a "null") condition, there is the human limitation of accurately reading the scale. With a balance method (as in the Wheatstone bridge) there is no deflection of the needle at balance and this condition can be read with certainty.

Limitation (*a*) requires the precaution of re-adjusting R_2 to give the required full scale deflection on short-circuit before making a resistance measurement. This re-adjustment is necessary as the accuracy depends on a short-circuit producing a full scale deflection.

Due to (*b*), it is obviously desirable to use high volts and a sensitive instrument when measuring fairly high resistance values.

Due to (*b*) and (*c*), the application of the instrument is limited. It cannot be used where a high degree of accuracy is required, and is rarely used for measuring high resistance (i.e. above, say, 1 megohm).

Q. 3. *State, briefly, the way in which heat is transferred by (a) conduction, and (b) convection.*

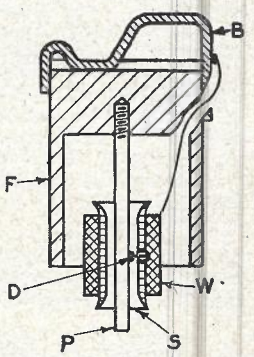
Sketch and describe the construction of a heat coil and explain how the operation of this device depends upon the processes of heat conduction and convection.

A. 3. (*a*) *Conduction.* If heat is imparted to one part of a body, the other parts in its neighbourhood undergo a rise in temperature, because heat is transferred to them. The heat is transferred from layer to layer through the body, whilst no change occurs in the relative positions of the parts of the body. This is known as conduction.

The rate at which heat passes through a substance depends on the thermal conductivity, which has different values for different substances.

(*b*) *Convection.* Convection is said to occur when heat is actually conveyed from one point to another by the movement of particles of matter. Generally, convection takes place automatically, as in the case of gases and liquids, which rise when heated due to expansion and thus becoming less dense.

The sketch shows a section of a heat coil of the earthing type. The body consists of a thimble of fibre or ebonite, F, into which is fixed a brass pin, P. A sleeve of copper, S, having an internal diameter slightly greater than the diameter of the pin, is prevented from sliding along the latter by a spot of solder, D, which has a low melting point. The sleeve is wound with double silk covered nickel or German silver wire, W, the coil having a resistance of about 4 ohms. One end of the coil is electrically connected to the sleeve, being soldered at D, and the other end is soldered to a brass cap, B, which is secured to the top of the thimble. This cap is specially shaped to fit rigidly within the slot of the outer mounting spring, so preventing rotation of the heat coil, and thus maintaining the position of contact between the two elements and obviating possible high resistance at this point. The sleeve, which projects beyond the end of the thimble, is belled out so that it provides a sharp circular contact of low resistance upon the inner mounting spring.



The operation of the heat coil is dependent upon the generation of sufficient heat to melt the solder. The sleeve then slides up the pin into the thimble under the pressure of the mounting spring, which then makes contact with an earthed spring so that the line is earthed and the fault current shunted away from the exchange apparatus. The heat coil is designed to carry a current of 350 mA continuously, but to operate within 210 seconds with a current of 500 mA.

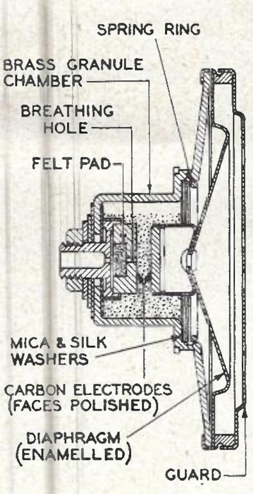
When a current flows through a resistance, power in watts, given by I^2R, is expended and dissipated in heat. Thus when a current flows through the winding of the heat coil, heat is generated and the temperature of the winding rises. There is a thermal conducting path from the winding to the solder spot which is thus heated by conduction. There is also a solid substance thermal conducting path, either direct or indirect, from the winding to all the component parts of the heat coil and the mounting, and heat is transferred from the winding, by conduction, at a rate depending on the thermal conductivities of the various component parts. The temperature of the whole coil, and the mounting, thus rises, but the highest temperature will be at the winding and its immediate neighbourhood which includes the solder spot.

The heat coil is mounted in free air, and thus the heat will be transferred away from the various surfaces of the coil and the mounting, by convection air currents.

The design of the coil is such that with currents not exceeding 350 mA, the temperature at the winding, and thus the solder spot, stabilises at a value below the melting point of the solder. In this condition, heat is transferred away from the winding by conduction, and from the heat coil as a whole by convection, at a rate equal to the rate at which heat is generated by the current, and the temperature does not rise above a certain value. At currents greater than 350 mA, heat is generated at a rate greater than it can be transferred away from the winding and the solder spot by conduction and convection, and the temperature at the solder spot rises. The solder melts after a time lag depending on the magnitude of the current, and the heat coil operates; the greater the current the less the time lag.

Q. 4. *Describe, with a sketch, the construction of a carbon granule microphone. Describe the principle of its operation and state why carbon is a suitable material for the granules.*

A. 4. The sketch shows a sectional view of an inset type carbon granule telephone microphone. It has a conical aluminium diaphragm carrying a hollow aluminium cylinder fixed to its centre. A plate of polished carbon, the moving electrode, projects from the cylinder through mica and silk washers into the granule chamber. The whole of the moving assembly is made as light as possible. The fixed carbon electrode is attached to, but insulated from, the rear of the casing of the instrument so that the faces of the two electrodes are parallel and about 75 mils. apart. This space is filled with carbon granules.



All inner surfaces of the casing are coated with insulating material, so that the only current path between the electrodes is through the granules. A small hole at the rear wall of the casing ensures equalisation of air pressure without and within the instrument. The front of the diaphragm is protected by a metal grid, and all metal surfaces are rust proof. This form of microphone will work in any position, which makes it very suitable for the telephone hand-set.

The electrical resistance between the two carbon electrodes is governed by the nature of the contact between the granules. A number of theories have been advanced to explain the exact manner in which the carbon granules act in varying the resistance of the current path. It is generally accepted however, that probably the chief cause of the microphone action is the variation of contact area of the granules with deformation of the carbon material; the deformation being temporary as the carbon is not usually stressed beyond its elastic limit. When the granules are compressed the resistance between neighbouring granules is decreased, thereby lowering the resistance between the electrodes. Conversely, when the pressure is released, the granule contact area decreases and the resistance increases. Hence, when sound waves impinge on the diaphragm and cause it to vibrate, the changes in pressure applied to the granules cause corresponding changes in resistance between the electrodes. If the microphone is connected in series with a battery, the variation in resistance will modulate the battery current. The current output of the microphone can therefore be resolved into two components:—

(1) The steady battery current which flows when the diaphragm is not experiencing any change in pressure,

and

(2) An alternating component caused by the change in pressure applied to the diaphragm, the frequency and magnitude of this alternating component varying in sympathy with the original sound waves.

It can be shown that the alternating component, and thus the output of the microphone, is proportional to:—

(*a*) The magnitude of the steady current.

and

(*b*) The percentage change in resistance of the microphone circuit caused by the acoustic pressure on the diaphragm.

The properties possessed by carbon which make granules of this substance suitable for use in microphones are:—

(1) It is infusible.

(2) It does not oxidise.

(3) Poor electrical conductivity.

(4) Resistance decreases with increased contact area.

It is desirable that the performance of the microphone should be constant throughout its life, and it is clear that properties (1) and (2) are important for this reason alone.

Due to (1), the granules are unaffected by the heating effect of the current and will remain as constant separate bodies, while (2) ensures that their surface condition is impervious to the surrounding air and does not alter. Otherwise there would be the possibility of dirty contact resulting in noise and poor performance.

Advantage is taken of (3) and (4) for the actual operation of the microphone. If the conductivity was good, then there would be little or no difference in the resistance between any two granules no matter whether the contact surface be large or small.

Q. 5. *Describe, briefly, how a secondary cell battery may be maintained in good working order. Why is it necessary to measure the specific gravity of the electrolyte? How is it measured?*

A. 5. A secondary cell battery may be maintained in good working order by observing the following precautions:—

(*a*) The specific gravity of the electrolyte, after the initial charge, should be checked to ensure it is of correct value. If it is too strong this tends to produce sulphation during discharge, and if it is too weak, the capacity of the cell will be reduced.

(*b*) A certain amount of water is lost due to evaporation and gassing, leading to over-concentration of the acid. The electrolyte should, therefore, be topped up when necessary with water of a suitable purity and should cover the plates completely.

(*c*) A careful check should be kept on the specific gravity of each cell of the battery. If one cell is found to have a much lower specific gravity than the rest it will indicate a fault within that particular cell.

(*d*) The battery should not be overcharged, as the gassing which results is liable to loosen the active material of the plates which will reduce the capacity and life of the plates and may cause short-circuits between the plates.

(*e*) If the battery is over-discharged, or infrequently or insufficiently charged, sulphation will take place. This reduces the capacity of the battery.

(*f*) The battery should not be charged or discharged at too high a rate. This tends to cause buckling and also to loosen the active material of the plates.

(*g*) After the battery has been in use for a considerable time, any active material which has fallen to the bottom of the cells should be removed, as this is liable to cause short-circuits and also reduces the specific gravity of the electrolyte.

The percentage of acid in the electrolyte is greatest when the cell is fully charged and least when completely discharged. Thus the strength of the electrolyte is a condition by which the state of a secondary cell can be ascertained. The specific gravity of the electrolyte, which is also a measure of the strength of the solution, is thus an indication of the charge or quantity of energy in the cell.

It is important, therefore, that the specific gravity be measured in the maintenance of secondary cells as this is considered to be the only reliable method of ascertaining the electrical state and behaviour of the cell. The readings serve as a guide to the following:—

(1) On discharge—the remaining charge in the cell and when the cell is fully discharged.

(2) On charge—the charge in the cell and when the cell is fully charged.

(3) Faults such as short-circuited or otherwise faulty plates or contaminated electrolyte will be shown by the irregular nature of the specific gravity readings.

(4) Too much or too little acid content in the electrolyte.

The specific gravity is measured by means of an instrument called an hydrometer, which floats partially submerged in the electrolyte. The depth of immersion is such that the weight of the liquid displaced is equal to the weight of the instrument. The depth of immersion therefore increases as the specific gravity of the electrolyte decreases. The specific gravity is read by noting the level of the surface of the electrolyte on a graduated scale on the hydrometer, which reading is a measure of the depth of immersion of the instrument.

Q. 6. *Give in general terms, an outline description of a public telephone system. State, briefly, how both the exchange switching and external line plants may be provided to meet the present requirements and also to allow for future growth.*

A. 6. In order that every subscriber may have means of telephone communication with every other subscriber, a system of telephone exchanges is necessary, since it is obviously impossible to provide wires connecting the premises of every subscriber directly with those of every other. Under the exchange system a pair of wires is run from each subscriber's premises to a common point, the exchange, and these pairs are interconnected at the exchange to allow subscribers to speak to each other as required.

There are, then, three main essentials for a telephone service, (*a*) the telephone instrument at the subscriber's premises, (*b*) the line to the exchange, and (*c*) the exchange switching plant. There is not of course, one central exchange for the whole country, there are many, and circuits between them are necessary as connecting links. These circuits or lines, when connecting neighbouring exchanges are called junction circuits, and when connecting towns some distance apart, are called trunk circuits.

The external line plant may be overhead or underground; new plant laid is more usually underground.

There are two types of exchange switching plant, manual and automatic. The manual type requires an operator to interconnect the circuits by means of plugs and cords at a switchboard, the requirement being passed verbally to the operator by the calling subscriber. The call may be extended from an operator on one manual exchange to an operator on another manual exchange as required. All new exchanges are of the automatic type. Here the circuits are interconnected by means of machines (switches) actuated by electrical impulses transmitted from the calling subscriber's instrument when the subscriber operates an impulse sender device (the dial) which is incorporated in the telephone set. The number of digits and impulses transmitted corresponds to the required subscriber's number. When the call is required to be routed via intermediate (tandem) automatic exchanges, routing digits, dialled in addition to the subscriber's numerical number, route the call to the exchange on which the required subscriber is connected. The routing digits actuate the switches at the intermediate exchanges which interconnect the junctions incoming to, and outgoing from, the tandem exchange, to switch the call through.

Calls are charged against the caller by the operation of a meter individual to each subscriber. In the manual system, the meter is operated by the operator (by key operation) on effective calls, and in the automatic system the meter is operated automatically when the called subscriber answers.

Subscribers lines are required per subscriber on the exchange. The exchange switching plant and the junction circuits are provided based on the volume of traffic expected to be originated by the subscribers.

It is clearly undesirable to install only sufficient equipment to meet the requirements at the opening date of a new automatic exchange. Some provision must be made in the initial installation for growth during the first few years, both in the number of subscribers' lines and in the traffic. The provision of a large quantity of spare equipment is wasteful. Some types of equipment can be installed quickly and without the expenditure of much labour. The margin of spares on such equipment can therefore be kept at a low level, thereby reducing the quantity of ineffective plant. On the other hand certain parts of the equipment require a considerable amount of engineering work during the manufacture and installation and it is uneconomical to add small portions of such equipment at frequent intervals. In every case there is an optimum planning period for each part of the exchange design in order to give the most economical arrangement over a number of years.

In general the periods adopted are:—

(*a*) The exchange numbering scheme is designed to meet the anticipated growth for 30 years beyond the opening date of the exchange.

(*b*) The exchange building is designed to meet the anticipated development for a period of 20 years from the opening date.

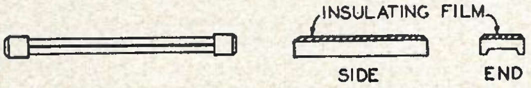
(*c*) Line plant is usually installed to meet present requirements plus an anticipated 10 years growth. This may be varied depending on local circumstances.

(*d*) Apparatus racks, selector banks and main internal cabling are installed to meet present requirements plus a 5 years growth.

(*e*) Switches and relay sets are provided to meet present requirements plus a 3 years growth.

Q. 7. *Describe, with the aid of simple sketches, the construction of (a) a fuse, and (b) a lightning protector. Where and why would these two devices be fitted to an external telephone line which enters a building?*

A. 7. (*a*) Sketch (*a*) shows the construction of a fuse. It consists of about 2 in. of fine-gauge phosphor bronze wire contained in a glass tube. Each end of the wire is soldered to a metal end cap which is cemented to the end of the tube. The fuse is rated at 1·5 amps. and blows at 3·0 amps.



(*a*) (*b*)

(*b*) Sketch (*b*) shows the construction of the protector used in most exchanges. It comprises two carbon blocks shaped as shown, each provided with a coat of insulating varnish approximately 1·5 mils thick. The edges of the blocks are bevelled to prevent leakage across the edges. Two blocks are held, with their varnished faces in contact, by springs, one of which is connected to line and the other to earth. The breakdown voltage of a pair of carbon blocks mounted in this way is between 600 and 900V.

A new type of protector is coming into use, more particularly in locations which may be damp, such as unattended exchanges. It consists of two channel section brass electrodes separated by a thin perforated sheet of insulating material, the whole being enclosed in a moulding of synthetic resin of high insulation resistance and low nflammability such as polythene. The breakdown voltage is 600 to 900V, and the reliability of this protector, especially in damp or dusty situations, is superior to that of the carbon type.

The protective devices would be fitted to the telephone line immediately it enters the building and before the point where it is connected to any apparatus. In practice external lines are terminated on a main distribution frame in telephone exchanges and are connected to the internal wiring of the exchange at this frame. The protective devices described are therefore conveniently mounted on the main distribution frame.

The fuses protect the apparatus in the building by disconnecting the line when contact occurs with a power supply or under any other condition where currents greater than 3 amps. are experienced. The fuse wire melts when the current exceeds this value and isolates the exchange apparatus.

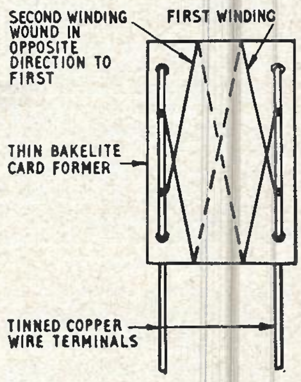
The protectors protect the apparatus in the building against line contact with a high voltage source, or against lightning strikes. A potential in excess of some 600V will puncture the varnish and cause an arc to earth. A surge which comprises a high voltage for a short duration will take this low impedance path in preference to the higher impedance path via the exchange equipment. If the discharge is very heavy, or of long duration, the fuse will also blow to disconnect the line.

Q. 8. *A wire-wound resistor is to be used at high frequencies and is required to be as little inductive and capacitive as possible. Sketch and describe the construction of a suitable type. Why is a carbon type resistor normally satisfactory from these two aspects?*

A. 8. When a length of wire is wound in turns as a solenoid, a magnetic field, similar to that of a bar magnet, is set up when a current flows, and when the current changes, the field changes and the coil exhibits inductive reactance. Also, adjacent sections of the turns may be regarded as the electrodes of a capacitor, the dielectric being formed by the space between the sections, and the coil exhibits capacitive reactance when the current changes. The coil is said to possess self-inductance and self-capacitance and the impedance of the coil is not constant with frequency. A wire-wound resistor may be regarded as a coil of wire, and as the ideal resistor for high frequency application should be completely non-reactive to present the same resistance at all frequencies, special arrangements must be made to eliminate, or reduce, the self-inductance and capacitance.

The self-inductance is reduced by reducing the magnetic field, and this may be achieved by arranging for the field set up by one conductor to be neutralised by a field set up in the opposite direction by an adjacent conductor. The self-capacitance can be reduced by arranging that the turns are widely spaced and that the potential difference between adjacent turns is as small as possible.

The sketch shows the construction of a typical resistor with an Ayrton-Perry type winding, giving a very 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, leaving space between turns equal to the diameter of the wire. A second wire is then wound in the space between the first turns and in parallel with the first, but in the opposite direction, 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 wires are at nearly the same potential. The single layer type winding also keeps the capacitance low. The two windings are soldered to the wire terminals as shown, the windings being in parallel from the electrical point of view.

Thus in general, the windings of a non-inductive wire-wound resistor are arranged in at least 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, which is difficult to achieve in practice. The turns of each section are placed as close as possible to minimise this effect, but this in turn increases the self-capacitance. To reduce this to a minimum, not only must the potential difference between turns be as low as possible, the turns should also be widely spaced which conflicts with the non-inductive requirement. It follows therefore, that a satisfactory resistor is a compromise between the effects of inductance and capacitance.

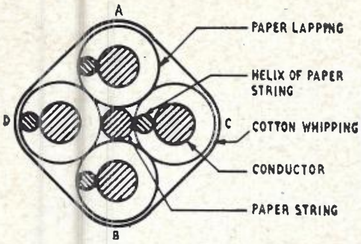
The carbon rod composition type resistor is not of solenoid construction and is thus non-inductive for all practical purposes. There is a small capacitance between the two end metal caps carrying the wire terminals, but as these caps are of small area and, relatively, very widely spaced, the effect is so small as to be negligible.

A carbon film resistor with a spiralled groove cut through the film simulates a single layer coil and a slight inductance and capacitance is introduced. The effect is very small however, as the simulated coil is of single layer, the "turns" are few and relatively widely separated. The effect is only of significance when the frequency is very high, say above 10 Mc/s. This type of resistor also has the small self-capacitance between the two end caps, but as before, the effect is negligible.

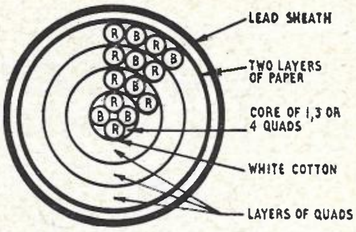
Q. 9. *Describe, with the aid of a simple sketch, the construction of an underground cable of the star-quad type. What is meant by the term* lay *as applied to the construction of such a cable?*

A. 9. In the star-quad cable each conductor, of annealed copper, is lapped with a helix of paper string over which is a helical lapping of insulating paper, sketch (*a*). This arrangement ensures that the

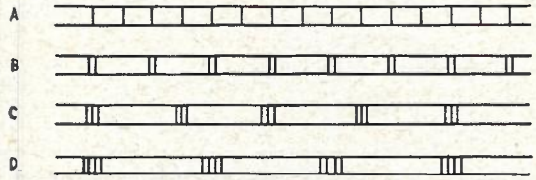
(*a*)



(*b*)



(*c*)



(*d*)

paper forms a regular cylindrical covering with dry air between the paper and conductor. On star-quad cables for subscribers' lines the paper string is omitted and the conductor kept approximately central in the cylindrical covering by creases in the paper lapping. Four such conductors are twisted together on a central core of paper string to form one quad, sketch (*b*). Each quad is lapped with a cotton whipping for identification. The quads so obtained are stranded into a symmetrical cable commencing with a core of 1, 3 or 4 quads and continued in quads arranged in layers. The number of quads in each layer is six more than in the preceding layer until the required number of circuits is obtained. The cable so obtained is covered with two lappings of paper and a lead sheath, sketch (*c*).

To identify the conductors the insulating paper round each wire is marked with red or blue lines as shown in sketch (*d*). It will be seen that the amount of ink on each paper is arranged to be the same to equalise the effect on the capacitance and leakance. Alternate quads in each layer are marked with red or blue ink. The cotton whippings round the quads are black and white in alternate layers with a marker and reference quad in each layer which has an additional orange whipping.

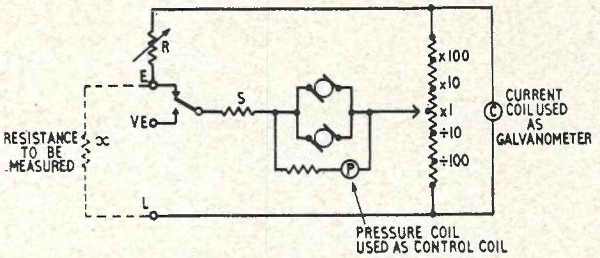
Inductive interference can occur between adjacent pairs of wires running together for a considerable distance, and crosstalk results. This arises as the inductive effect on one wire of the pair is not equal to that on the other. The sphere of disturbance due to each twisted pair is usually limited to about three pairs next to it on either side. To overcome this it is arranged that the two wires of a pair uniformly change their position with respect to each other and with such frequency that the inductive effects on each wire are equal and balance. In star-quad cables the four wires of the quad are twisted together about the common axis, and the lay, or pitch, is the axial length in inches in which the four conductors in one quad unit make one complete twist. Adjacent quads in a layer, and the various layers of quads, have a different lay, e.g. in a 20-lb. conductor star-quad cable, the successive quads in the outer layer have lays, or pitches, of 3, 4, 5 and 6 in. respectively, repeated round the layer.

Adjacent layers in the cable are also stranded in opposite directions to reduce capacitive disturbances and thus crosstalk.

Q. 10. *Describe, with the aid of simple diagrams, how you would connect up and use the bridge megger (a) for bridge tests, and (b) for megger tests. State typical circumstances under which each test could be used.*

A. 10. The bridge-megger is a dual purpose instrument which can be used for Wheatstone bridge type tests or megger tests by the operation of a changeover switch. It incorporates a hand-driven generator, the armature of which has two windings, a pressure and a current coil fixed approximately at right angles to each other on a spindle carrying a pointer which moves over a scale. Four terminals are provided—Earth, Line, Guard and Varley Earth; also two rotary switches, one marked "Bridge-Meg-Varley" for use in accordance with the type of test to be made, and the other marked "÷100, ÷10, ×1, ×10, ×100" for use as a ratio switch in the bridge tests.

(*a*) *Bridge Test.* The rotary switch is turned to "Bridge" and in this condition the internal connections of the instrument are as shown in sketch (*a*). The external resistance, *x*, to be measured is



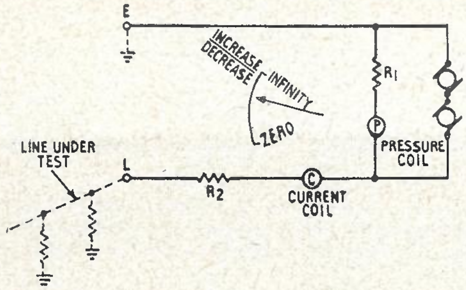
(*a*)

connected between terminals E and L. The rotary switch places the two windings of the generator armature in parallel to reduce the voltage by half but increasing the maximum current the generator can deliver.

The pressure coil supplies a controlling force which tends to keep the needle on the infinity mark and actually achieves this when there is no current in the current (or "galvanometer") coil, i.e., at balance of the bridge. The tapped resistance ratio arms are incorporated in the instrument. In later types, the variable arm *R* is also incorporated in the instrument. The ratio arm has five taps so arranged that the resistance measured is equal to 1/100, 1/10, 1, 10 or 100 times the resistance inserted into the variable arm *R*, which resistance can be read on a scale. *R* can be varied from 1 to 9,999 ohms and as the ratio arm can be varied to give from 1/100th to 100 times this value, the bridge will thus measure accurately resistances between 0·01 and 999,900 ohms.

A resistance *S* is connected in series with the generator and bridge to prevent excessive currents when measuring low resistance. Terminal VE is provided in the later instruments for making Varley tests, this additional terminal being necessary as the variable arm *R* is included in the instrument. The instrument generates 250V when used at Bridge. The method of operation is as follows. *R* is set at zero. The generator is then turned causing the pointer to move to a position on the scale on the side of the infinity line marked "Increase." *R* is then increased until the pointer rests exactly on the infinity line. The generator is then turned at full speed until the clutch is felt to slip, in order that the maximum effect may be obtained, and, if necessary, further adjustment made to the setting of *R* to obtain balance, i.e., when the pointer rests at infinity. The value of the resistance *x* under test is then read directly from the setting of *R* if the ratio arm is set at "×1." If *x* is small, say less than 100 ohms, the ratio switch is then moved to ÷10 or ÷100 when the value of *x* is equal to the reading shown by *R* divided by 10 or 100 respectively. Conversely, if *x* is large, the ratio switch is set at ×10 or ×100, when *x* will be equal to the reading of *R* multiplied by 10 or 100.

(*b*) *Megger Test.* The rotary switch is turned to "Megger" and in this condition the internal connections of the instrument are as shown in sketch (*b*), which shows the typical case of the megger being used to measure a wire to earth insulation resistance. The



(*b*)

rotary switch places the two windings of the generator in series to increase the voltage to 500V, but reduce the current.

A current through the current coil tends to turn the pointer in one direction, and a current through the pressure coil in the other. If no connection exists between E and L, then all the current from the generator passes through the pressure coil and the pointer moves to infinity. If E and L are short-circuited, then all the current flows through the current coil and the pointer moves to zero. The current through the current coil is inversely proportional to the resistance connected between E and L. Thus, due to the movement of the two coils, the pointer takes up a position relative to the currents flowing in the current and pressure coils, and as the current through the current coil depends upon the resistance under test between E and L, the value of this resistance is read by the pointer on the calibrated scale.

The resistances R_1 and R_2 protect the moving coils from damage by heavy currents and their presence is allowed for in the calibration of the instrument.

Having connected E to earth and L to the external line under test, the distant end of which is disconnected, the generator handle is turned until it is felt to slip. The insulation resistance between the line and earth is then read directly by the pointer on the scale.

If the insulation resistance between two lines is required, one line is connected to E and the other to L, both lines being disconnected at their distant ends. The operation as described above is then carried out.

Typical circumstances under which each test could be used are:—

(*a*) *Bridge.*
- (1) Measuring resistance, which may be the resistance of a component, or a line, either loop or single wire.
- (2) Localisation of faults on lines.

(*b*) *Megger.*
- (1) Measuring insulation resistance of lines (wire-to-earth or wire-to-wire), apparatus and wiring.

Thus the bridge test is used when accuracy is required and when the resistances concerned may be small. The megger test is used when a high degree of accuracy is not essential and when the resistances concerned may be very high.

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Q. 1. *Write down the formula from which the resistance of X can be calculated in the Wheatstone Bridge circuit shown in Fig. 1.*

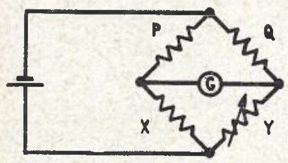


FIG. 1.

P and Q, the ratio arms of a Wheatstone Bridge, are intended to have values of 100 *and* 1,000 *ohms respectively. Q is known to be accurate, but P has an error of unknown value. To overcome this in determining the value of X, two measurements are taken. In the first, with the connections as in the Figure, a balance is obtained when Y* = 5,000 *ohms.*

In the second, with the resistors P and Q interchanged, but without any other alteration to the circuit, a balance is obtained when Y = 60·5 *ohms.*

Calculate the value of X and the actual value of P.

A. 1. A Wheatstone Bridge is balanced when there is no potential difference between the two galvanometer connections. The condition is given by

$$\frac{P}{X} = \frac{Q}{Y}$$

Let the true value of the inaccurate arm be $(100 + p)$ ohms. Then with first arrangement, for balance we have

$$\frac{100 + p}{X} = \frac{1{,}000}{5{,}000}$$

i.e. $$X = 5(100 + p) \quad \ldots\ldots (1)$$

With the second arrangement when P and Q are interchanged

$$\frac{1{,}000}{X} = \frac{100 + p}{60{\cdot}5}$$

i.e. $$X = \frac{60{,}500}{100 + p} \quad \ldots\ldots (2)$$

Multiplying (1) by (2) gives

$$X^2 = 302{,}500$$

i.e $$X = \sqrt{302{,}500} = \underline{550 \text{ ohms}}$$

Substituting in (1) gives

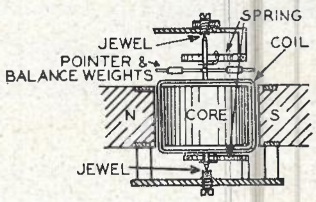
$$p = 10 \text{ ohms}$$

The true value of P is therefore <u>110 ohms.</u>

Q. 2. *Describe the construction and method of action of a moving coil meter. Include in your answer a sketch showing how the direction of deflection of the coil is related to the direction of the current in the coil and of the field of the permanent magnet.*

What are the advantages of this type of ammeter compared with a moving-iron instrument?

A. 2. The chief constructional features of a moving-coil milliammeter are shown in part-section in sketch (*a*). A permanent magnet of horseshoe form creates a strong radial magnetic field in the small air gaps between each of its curved pole pieces NS and a fixed soft iron cylindrical core concentric with the pole faces. A coil of fine insulated wire supported on an aluminium former is pivoted on jewelled bearings so that it can rotate freely in the gaps through about 90°, the coil cutting the magnetic field in the air gaps at right angles. The ends of the coil are connected to fine phosphor-bronze coil springs, which are insulated both from the coil former and the frame of the instrument. They serve, not only as flexible connectors, but also as control springs to provide a restoring torque that is exactly proportional to the angular deflection of the coil. A light aluminium pointer attached to the coil system indicates the deflection of the coil on a suitable scale. Stops of springy wire limit the travel of the pointer; an adjustment in one of the coil springs permits the pointer to be set to zero on the scale when the restoring torque is zero.



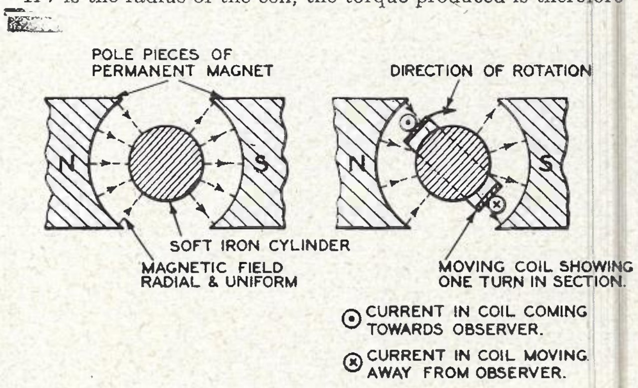
(*a*)

The instrument operates on the "motor principle." When the direct current, i, to be measured passes through the turns of the coil, the magnetic field created interacts with the permanent field (Flux Density B) in the air gap to produce a force Q at right angles to the coil as in sketch (*b*).

$$Q \propto B\,i\,N\,l$$

where N is the number of turns on the coil, and l is the length of one side of the coil.

If r is the radius of the coil, the torque produced is therefore



(*b*)

$$T \propto B\,i\,N\,l\,2\,r$$
$$\text{or } T \propto B\,N\,A\,i$$

where $2lr = A$, the area of the coil.

The deflection ϕ is proportional to the torque T, and the coil will rotate until the restoring torque of the coil springs is exactly equal to the deflecting torque on the coil. Hence $\phi \propto BNAi$.

The deflection is proportional to the current passing through the coil.

The sensitivity of the instrument to deflecting current is proportional to the number of turns on the coil, to the magnetic field strength in the air gap and to the area of the coil.

The relative directions of the field, the current in the coil and the deflecting torque can be determined by Fleming's Left Hand Rule. (See sketch (*b*).)

Oscillations due to the inertia of the moving-coil system are damped by eddy currents set up in the aluminium former when it moves in the magnetic field of the air gap. These eddy currents set up a field tending to oppose the oscillation, and also dissipate the kinetic energy of the moving system as heat resulting from the $i^2 R$ losses in the aluminium former. The damping does not affect the final position of rest of the pointer.

The moving-coil milliammeter is more sensitive than the moving iron. It is unaffected by external magnetic fields, and as its control is provided by the coil springs its movement can be balanced to work in any position.

One disadvantage is that it cannot indicate on A.C. unless a rectifier is used.

Q. 3. *State Ohm's Law.*

Two resistors A and B are connected as in Fig. 2 to a 10-volt battery and the current taken from the supply is found to be 1·5 amperes. If the resistance of A is twice that of B, find the value of B and the current taken when they are connected to the supply as in Fig. 3.

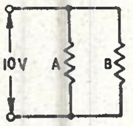


FIG. 2.

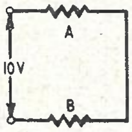


FIG. 3.

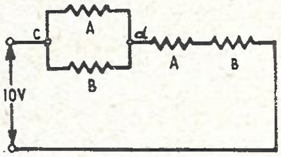


FIG. 4.

Four resistors, two each being equal to A and two equal to B, are now connected across the 10-volt supply as in Fig. 4. Find the voltage between the points c and d, and the power dissipated in the resistor A connected between these two points.

A. 3. Ohm's Law states that the current in any conductor is directly proportional to the potential difference between its ends. It is assumed that the conductor is not affected by the passage of the current and that its temperature remains constant.

Let x ohms be the resistance of B. Then A is $2x$ ohms. With the connections of Fig. 2 and a 10-volt supply, the currents in A and B are $\frac{10}{2x}$ and $\frac{10}{x}$ amps. respectively.

$$\therefore\ 1{\cdot}5 = \frac{10}{2x} + \frac{10}{x}$$

$$\text{and } x = \frac{1{\cdot}5}{15} = 10 \text{ ohms.}$$

$$\therefore\ \underline{\text{B} = 10 \text{ ohms and A} = 20 \text{ ohms.}}$$

In Fig. 3, the total resistance across the battery = 30 ohms.

$$\therefore\ \text{Battery current} = \frac{10}{30} = \underline{\tfrac{1}{3}\text{ amp.}}$$

In Fig. 4, the resistance of A in parallel with B

$$= \frac{10 \times 20}{10 + 20} = \frac{20}{3} \text{ ohms} = 6{\cdot}67 \text{ ohms.}$$

$$\text{The voltage between points c d} = \frac{6{\cdot}67}{36{\cdot}67} \times 10 = \underline{1{\cdot}82 \text{ volts.}}$$

The power dissipated in A between points c d

$$= \frac{E^2}{R} = \frac{(1{\cdot}82)^2}{20} \text{ watts.}$$

$$= \underline{0{\cdot}166 \text{ watt.}}$$

Q. 4. *State the difference between the terms Power and Energy and name the units in which they are commonly given in telecommunications practice.*

A battery of constant voltage V is discharging into two resistors each of R ohms connected in series. What is the power being supplied by the battery?

In what form does the energy finally appear?

A small electrically-heated drying oven has two independent heating elements each of 1,000 *ohms in its heating unit. Switching is provided so that the oven temperature can be altered by rearranging the resistor connections. How many different heating positions can be obtained and what is the electrical power drawn in each arrangement from a* 200-*volt battery of negligible internal resistance?*

A. 4. "Power" is the rate of expenditure of energy. The electrical unit of power is the watt, defined as the expenditure of one Joule per second; this corresponds to a 1-volt source supplying a load with a steady current of 1 ampere.

"Energy" is a general term referring to the amount of work performed. Electrical energy is measured in joules. Power supply installations use as a unit the kilowatt-hour, which is equivalent to $3{\cdot}6 \times 10^6$ joules.

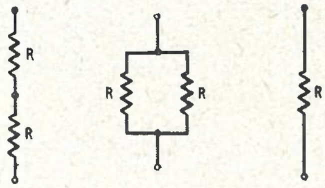
The power supplied from a source of voltage V when a current of I amps. is flowing $= VI$ watts.

If the load is a resistance $2R$ ohms, then from Ohm's law, $I = \frac{V}{2R}$

$$\therefore\ \text{Power supplied per second} = \underline{\frac{V^2}{2R} \text{ watts.}}$$

This electrical energy appears as heat in the resistor.

Three different resistor arrangements can be provided, and in each case the terminals will be connected to the 200-volt supply.



(*a*) (*b*) (*c*)

For two resistors in series, as in sketch (*a*),

$$\text{Power} = \frac{V^2}{2R} = \frac{(200)^2}{2 \times 1{,}000} = \underline{20 \text{ watts.}}$$

For two resistors in parallel, as in sketch (*b*),

$$\text{Power} = \frac{V^2}{R/2} = \frac{2(200)^2}{1{,}000} = \underline{80 \text{ watts.}}$$

For one resistor only, as in sketch (*c*),

$$\text{Power} = \frac{V^2}{R} = \frac{(200)^2}{1{,}000} = \underline{40 \text{ watts.}}$$

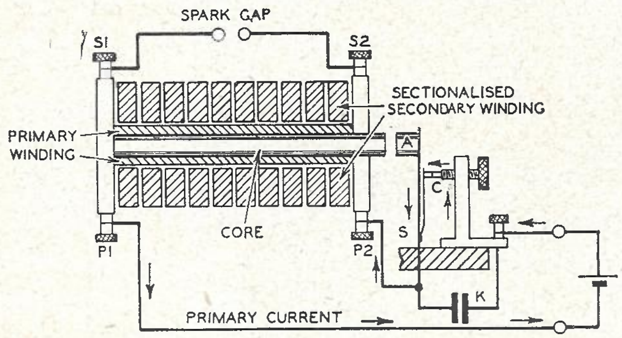
Q. 5. *Describe the construction and method of operation of an induction coil (spark coil) for producing high voltages.*

What factors determine the magnitude of the voltage produced by such a coil?

A. 5. The spark coil is a device for generating very high voltages from a low-voltage source, such as a 6-volt secondary cell.

An iron core carries a primary coil consisting of a few hundred turns of heavy-gauge insulated copper wire. Over this and very carefully insulated from it by an ebonite former is wound a large, sectionalised, secondary coil containing many thousands of turns of fine insulated wire. The sections are themselves insulated from each other to distribute the potential drop along the coil as smoothly as possible.

The soft-iron armature, A, of a magnetically operated make-and-break switch capable of rapid operation is mounted so that, when the



iron core of the coil is magnetised, magnetic attraction opens the switch. When the magnetic attraction ceases, the switch closes again.

The action of the coil can be seen from the sketch.

The battery supplies direct current through the make-and-break switch contact to the low-resistance primary coil. A large magnetic field is created very rapidly as the current builds up after the switch closes. As these lines of force cut the turns of the secondary coil, an e.m.f. is induced therein proportional to the number of turns on this coil. As it has very many turns, a high e.m.f. is induced. The magnetic field also actuates the magnetic switch, so breaking the primary current and causing the field to collapse. An e.m.f. in the reverse direction is then induced in the secondary coil.

Very large forms of the spark coil may have motor-driven mercury switch make-and-breaks instead of the simple magnetic vibrator.

It will be evident that the magnitude of the secondary voltage depends upon the rapidity with which the primary current can be broken. As the primary coil has a considerable inductance it can store an appreciable amount of energy in its magnetic field, and all this must be removed quickly to obtain a high rate of fall of flux. A capacitor, K, is therefore connected across the contacts in order that the energy, which would otherwise dissipate slowly by means of an arc at the opening contacts, may be absorbed quickly as a charge in the capacitor. This leads to a much more rapid fall in the core flux, and hence a higher induced voltage in the secondary. By reducing sparking at the contacts the capacitor reduces contact wear. When the contacts close at the commencement of a cycle, the capacitor tends to delay the build-up of the current. The secondary e.m.f. induced at the "make," which is opposite in direction to that at "break," is therefore reduced by the capacitor. The net result is that the e.m.f. at the secondary terminals is almost entirely due to the "break" condition and is therefore almost uni-directional.

Q. 6. *Two parallel-plate capacitors are designed for the same working voltage and the same capacitance, but one has air-dielectric and the other mica. Which will have the smaller dimensions and why?*

A mica-dielectric capacitor consists of two parallel plates each of effective area 100 sq. cms., spaced 1 mm. apart. The plates are connected to a circuit which provides a constant current of 2 microamps.

In how many microseconds will the potential difference of the plates change by 100 volts? Take the permittivity (dielectric constant) of mica as 7·0. The capacitance of an air-dielectric capacitor having plates 1 sq. cm. in area and spaced 1 cm. apart may be taken as 0·0885 $\mu\mu F$.

A. 6. The capacitance of a parallel plate capacitor is given by

$$C = \frac{k \times A}{4\pi d} \times \frac{10^{-11}}{9} \text{ farads.}$$

where A is the effective area of the dielectric in sq. cms.
d is the distance between the inner conducting surfaces.
k is the permittivity (dielectric constant) of the insulating material totally filling the space between the plates.

Now the permittivity, k, of air may be taken as unity and for mica it is 7·0.

The capacitance will be increased by seven times if mica replaces air as the dielectric. The area of both the plates can therefore be reduced to one-seventh of their previous size to give the same value of capacitance with mica as previously with air.

Since the capacitance when $A = 1$, $d = 1$, $k = 1$ is given as 0·0885 $\mu\mu F$ we can say that, if $A = 100$, $d = 0{\cdot}1$, $k = 7$, then,

$$\text{Capacitance} = 0{\cdot}0885 \times \frac{7 \times 100}{0{\cdot}1}$$

$$= 620 \text{ micromicrofarads.}$$

The charge Q in coulombs given to the capacitor in time t seconds when the charging current i is constant is the product $Q = it$.
But, also, $Q = CV$
where V is the voltage difference in the plates produced by the charge Q coulombs.

$$t = \frac{CV}{i} = \frac{620 \times 10^{-12} \times 100}{2 \times 10^{-6}} \times 10^{6} = \underline{31{,}000 \text{ microseconds.}}$$

Q. 7. *State Faraday's Laws of Electrolysis.*

The weight of a small copper plate is to be increased by depositing exactly 1 gram of copper on it electrolytically. Describe briefly a simple method of doing this.

If the plating operation is to take exactly one hour using a constant current, to what value should the current be adjusted?

Assume that the electro-chemical equivalent of copper is 0·0007 grams per coulomb.

A. 7. Faraday's first law of electrolysis states that the weight of ions liberated by a current flowing in an electrolytic cell is proportional to the quantity of electricity that has passed.

If a steady current is flowing, the quantity of electricity in coulombs is the product of the current in amps. and its duration in seconds.

Faraday's second law states that the weights of ions liberated in various electrolytes by a given quantity of electricity are proportional to the chemical equivalents of the ions.

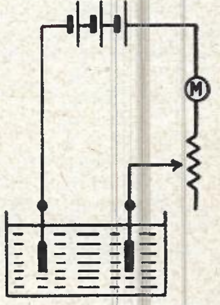
In the electro-deposition of metal, the mass in grams deposited in time t secs. by a constant current of I amps. is given by

$$m = kIt$$

where k is the electro-chemical equivalent of the metal. If $t = 3600$ seconds, $k = 0{\cdot}0007$ and $m = 1$ gram,

$$I = \frac{1}{3{,}600 \times 0{\cdot}0007} = 0{\cdot}397 \text{ amp., or } \underline{0{\cdot}4 \text{ amp.}} \text{ (approximately).}$$

The deposition of 1 gram of copper on to the copper plate can be carried out electrolytically. The copper plate is suspended by a connecting wire so that it can act as the cathode in an electrolytic bath containing an aqueous solution of copper sulphate. A second copper plate suspended a centimetre or so away from the first acts as the anode. The source of direct current can conveniently be a battery of large 2-volt cells, the negative terminal of the battery being connected to the cathode plate, and the positive to the anode. An adjustable rheostat, a switch, and an ammeter must be included in the battery circuit as shown in the sketch. The battery voltage must be chosen to give a current of approximately 0·4 amp.; the precise adjustment to this value can then be readily made by means of the rheostat.



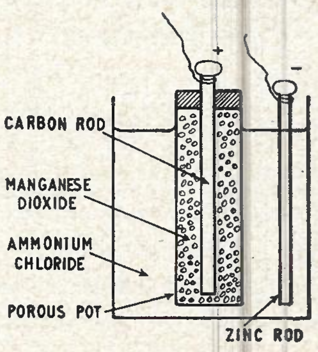
The circuit should be set up on trial and preliminary adjustments made with a spare copper plate as cathode. The specimen plate is then substituted as cathode. The current is switched on and a current of 0·4 amp. is allowed to pass for exactly one hour. During this time, one gram of copper will be deposited, as can readily be checked by weighing the plate dry, before and after the experiment.

Q. 8. *Why is a depolariser employed in a Leclanché Cell?*

Sketch and describe any form of Leclanché Cell with which you are familiar and mention the class of duty for which it is particularly suitable.

A. 8. A depolariser, manganese dioxide, is necessary in a Leclanché cell to remove the hydrogen that would otherwise adhere to the surface of the positive, carbon, electrode as a result of the chemical changes occurring when the cell delivers current.

A simple form of Leclanché cell is shown in the sketch. A glass vessel contains, as an electrolyte, a solution of ammonium chloride in water. A zinc rod, in which is dissolved a small amount of mercury to prevent local action and wasteful eating away of the zinc, forms the negative electrode. The positive electrode is a carbon rod supported for convenience in a porous earthenware pot into which is also packed the depolariser, powdered manganese dioxide mixed with powdered carbon to decrease its electrical resistance. The electrolyte can enter the pot and make contact with the carbon rod.



The e.m.f. of a new Leclanché cell is about 1·5 volts, and its internal resistance is of the order of 0·5 ohm. It is most suitable for light-current intermittent duties, such as local-battery telephone work of electric bell operation. The Leclanché cell tends to polarise, i.e. increase its internal resistance, if too heavy a current is drawn from it; but it rapidly recovers when allowed to rest. The cell does not produce noxious fumes and contains no highly corrosive substances.

The only maintenance required is the replacing of water lost by evaporation from the electrolyte and, at longer intervals, the renewal of the zinc rod which is slowly dissolved as a result of the cell's supplying current.

The chemical action of the cell may briefly be described as follows.

The electrolyte, NH_4Cl, consists of positively charged ammonium ions (NH_4+) and negatively charged chlorine ions ($Cl -$).

At the zinc, negative, plate, the chlorine ions give up negative charges, forming zinc chloride ($ZnCl_2$) which dissolves in the electrolyte.

$$Zn + 2\,Cl \rightarrow ZnCl_2.$$

At the carbon, positive, plate, the ammonium ions give up positive charges, and, without reacting with the carbon, split up to ammonia gas and hydrogen.

$$2\,NH_4 \rightarrow 2NH_3 + H_2.$$

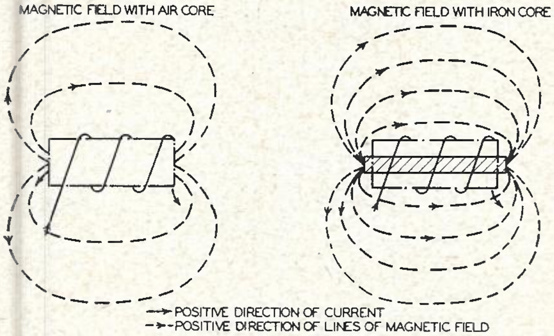
The hydrogen ions pair up into molecules (H_2) and if allowed to remain would cause polarisation by adhering to the surface of the carbon. The duty of the depolariser, manganese dioxide (MnO_2), is to give up oxygen to combine with the hydrogen and form water, forming a lower oxide of manganese (Mn_2O_3) in the process.

$$2MnO_2 + H_2 \rightarrow Mn_2O_3 + H_2O$$

Q. 9. *What determines the magnitude of the self-induced e.m.f. in a coil of wire that is carrying a changing current?*

What will be the difference between the results obtained when the coil has an air core and when a soft iron core is inserted? Give reasons for your answer and include sketches of the magnetic field surrounding the coil in both cases.

A. 9. The electric current flowing in the coil of wire will set up a magnetic field linking with the turns of the coil, as shown in section in sketch (*a*), the strength of the field being proportional to the current



(*a*) (*b*)

flowing. If the current changes, the strength of the magnetic field must also change and as a result the number of magnetic lines linking the coil must change.

Now Faraday's Law of Magnetic Induction states that whenever the magnetic flux linking with the turns of a coil changes, an e.m.f. must be induced in the coil. The direction of the e.m.f. will be such as to tend to oppose the change of current in the coil.

The magnitude of the induced e.m.f. is proportional to (the rate of change of the magnetic flux effectively linking with the coil) × (the number of turns in the coil).

The rate of change of the flux is determined by the rate of change of the current flowing in the coil and by the magnetic reluctance of the path of this flux. A low reluctance path will enable a given current to produce a higher magnetic flux than will a high reluctance path.

If an iron core is inserted in the coil, the magnetic flux will be increased as shown in sketch (*b*) because the reluctance of its total path is reduced by the iron. A greater change of flux compared with that for an air core will therefore result from a given change of current in the coil. Hence, the presence of the iron will increase the self-induced e.m.f. compared with the value obtainable from the same rate of change of current when the core is entirely air.

Q. 10. *A D.C. voltmeter whose scale is engraved for the range* 0 *to* 10 *volts is found to consist of a D.C. milliammeter connected to a bobbin of fine resistance wire. The milliammeter alone has a resistance of* 100 *ohms and gives a full-scale deflection when a current of* 2 *milliamps passes through it.*

Calculate the resistance of the bobbin of wire and show how it is connected to the milliammeter.

If the milliammeter is to be converted to a D.C. ammeter with a range of 0 *to* 1 *amp., what changes would be required?*

Calculate the value of any resistor you may need to use.

A. 10. In order to convert the milliammeter into a voltmeter, resistance must be connected in series with it to limit the total current to 2 milliamps when 10 volts are applied across the whole circuit.

Then total resistance of voltmeter $= \dfrac{10}{2 \times 10^{-3}} = 5{,}000$ ohms.

As the milliammeter coil has a resistance of 100 ohms, the external resistance must be <u>4,900 ohms.</u>

The milliammeter can be converted into an ammeter by means of a shunt resistance of low value.

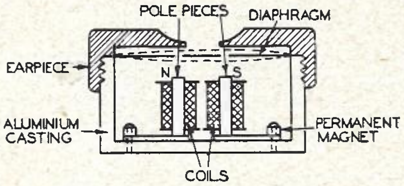
The milliammeter will require 0·002 amp. in its 100-ohm coil for full scale deflection. The voltage across the 100-ohm milliammeter will then be 0·2 volt. If this condition is to be produced when 1 amp. flows, the shunt resistor (R ohms) must pass ($1 - 0{\cdot}002$) amp. when a p.d. of 0·2 volt is applied.

Then, by Ohm's Law, $R = \dfrac{0{\cdot}2}{0{\cdot}998}$ ohm.

$= \underline{0{\cdot}2004 \text{ ohm.}}$

Q. 11 *The magnet system in a telephone receiver often consists of a permanent magnet with separate pole pieces added. Explain why this construction is adopted and describe the properties desirable in the magnetic materials employed. What material is commonly used for the magnetic diaphragm on this type of telephone receiver? Give reasons for your answer.*

A. 11. The permanent magnet and pole pieces of a typical telephone receiver (shown in the sketch) are made separately because the magnetic properties required for the two parts cannot readily be obtained in any single type of material.



The operation of the receiver demands a very strong magnetic flux across the small air gap between pole faces and vibrating diaphragm. This is generated by a powerful permanent magnet that must be light in weight and as small as possible. Permanent magnet steel, having the properties of high magnetic retentivity and coercivity is therefore used; but such steel cannot economically be machined accurately or finished to a precise tolerance: it is also low in permeability. Pole pieces of soft iron having high permeability and good machining properties are therefore attached to the magnet poles, and the coils of fine wire that carry the speech currents are wound on the soft iron portion of the magnetic circuit. The high permeability of this soft iron ensures the greatest possible change in the magnetic flux for a given alternating current in the speech coils. The pole faces can be readily ground to give an accurately shaped air gap. The material used in these pole pieces should preferably have a high electrical resistance and a low hysteresis coefficient to minimise iron losses due to the pulsating field.

The diaphragm has to vibrate to pass on the speech frequencies to the surrounding air and must also be responsive to flux changes arising from its speech currents in the coils. It is commonly made of thin stalloy sheet, a springy ferrous alloy having a high permeability so that it offers a low reluctance path to the magnetic flux between the pole faces. Its electrical resistance is also high to minimise eddy currents, and its hysteresis coefficient low. The diaphragm is given a rustproof surface because stalloy rusts readily if not protected.

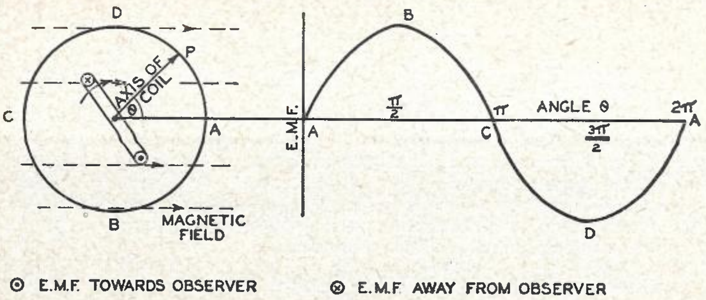
Q. 12. *A circular coil of wire rotates about a diameter at a constant speed in a uniform magnetic field, the axis of rotation being perpendicular to the direction of the field.*

Draw a sketch showing the relative directions of the field, the motion of the coil and the e.m.f. induced.

The average e.m.f. measured over a half-cycle is found to be 100 *volts, when the coil, which has* 5,000 *turns, is rotating at* 20 *revolutions per second. Calculate the magnetic field strength, if the effective area of the coil is* 100 *sq. cms.*

A. 12. The relative directions of the magnetic field, the motion of the coil and the induced e.m.f. are shown in the sketch. The e.m.f. reverses its direction each half-revolution, resulting in the sinusoidal voltage shown.

For one half-revolution, the flux linkage will rise from zero to a maximum and back to zero again. The average e.m.f. induced equals the average rate of change of flux linking with the coil.



$$\therefore \text{Average e.m.f. induced in half revolution} = \frac{\text{Flux cut by coil} \times \text{No. of turns on coil}}{\text{Time for half-revolution}}$$

$$\therefore \quad 100 = \frac{100 \times 5{,}000 \times 2\phi}{\frac{1}{2} \times \frac{1}{20}} \times 10^{-8} \text{ volts.}$$

where ϕ is the magnetic field strength.

$$\text{Whence, } \phi = \frac{1 \times 10^8}{80 \times 5{,}000}$$

$$= \frac{10^3}{4} = \underline{250 \text{ lines per sq. cm.}}$$

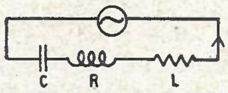
TELECOMMUNICATIONS (PRINCIPLES) II, 1953

Q. 1. *Explain the meaning of the term "resonance" in a circuit consisting of an inductor and capacitor connected in series and energised by a source of alternating E.M.F. of adjustable frequency.*

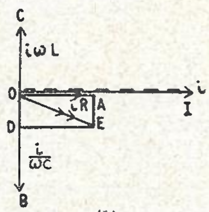
An alternator supplies a sinusoidal current to a load consisting of an adjustable capacitor in series with a 0·1 henry inductor having a resistance of 5 ohms. To what value should the capacitor be set to give resonance when the alternator has a frequency of 200 c/s?

If the voltage at the alternator terminals is then 10V r.m.s., what is the current flowing in the circuit and the power dissipated?

A. 1. The R.M.S. current in all the components in a series connected inductor-capacitor circuit, which must, as shown in sketch (*a*), include a resistance term R to denote the equivalent resistance of the inductor and the capacitor losses, will always be the same at any given instant. If OI is the current vector, sketch (*b*),



(*a*)



(*b*)

the voltage across the capacitor C will be OB $= \frac{i}{\omega C}$, lagging 90° on OI, and across the inductance it will be OC $= i\omega L$ leading the current by 90°.

ω is the angular frequency, where $\omega = 2\pi \times$ frequency.

The voltage drop across R will be OA $= iR$ in phase with the current.

In general, when OB is unequal to OC, there will be a resultant quadrature voltage component (OB — OC) = OD. The voltage across the whole circuit will then be OE, the vector addition of OD and OA.

If now the frequency is such that OC = OB, then OD = zero, and the voltage drop across the circuit is OA in phase with the current i. This minimum condition is known as Series Resonance of the circuit. The frequency at which it occurs is independent of the resistance R.

For series resonance,

$$i\omega L = \frac{i}{\omega C}$$

$$\text{or } \omega = \frac{1}{\sqrt{LC}}$$

In the example $\omega = 2\pi \times 200$. Taking $\pi^2 = 10$, we have

$$C = \frac{1}{\omega^2 L} = \frac{10^6}{4\pi^2 \times (200)^2 \times 0{\cdot}1} = \frac{10}{1{\cdot}58}$$

$$= \underline{6{\cdot}34 \text{ microfarads.}}$$

At resonance, the current is determined only by the resistance.

$$\therefore \quad i = \frac{10}{5} = \underline{2 \text{ amps.}}$$

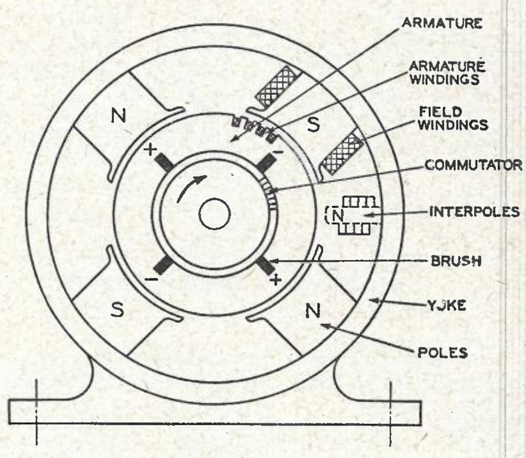
Power is lost only in the resistor.

Power loss $= i^2R = 2^2 \times 5 = \underline{20 \text{ watts.}}$

Q. 2. *Describe the principle of operation of a direct current generator. Sketch and explain the output voltage/output current characteristics that you would expect from such a generator running at a constant speed when its field coils are—*

(*a*) *shunt excited,*
(*b*) *series excited,*
(*c*) *supplied from a constant voltage battery.*

A. 2. Sketch (*a*) indicates the principal features of a medium



(*a*)

size, 4-pole, D.C. generator. The stator consists of the yoke, usually of cast steel, to which are bolted the four field magnets. The field windings are wound around the field magnets and are connected in series in such a direction that adjacent poles have opposite polarity as shown. On medium and large size machines additional smaller poles, called commutating or interpoles, are placed between the main poles and have a winding around them of heavy copper conductor connected in series with the armature winding. These poles are to compensate armature reaction and assist the reversal of current in the armature coils during the time of commutation.

The armature consists of a large number of circular laminations which are slotted around the circumference to form the slots for the armature winding. The armature winding may be either of the lap or wave type and is of heavy copper conductors. The commutator is at one end of the armature and consists of a number of copper segments, each insulated with mica strip, clamped together to form a ring, the outside circumference of which is turned to form a smooth running surface for the brushes. The coils of the armature winding are each connected to a segment of the commutator by radial connectors, called risers. The external electrical connection to the commutator is made by the brushes, which are usually of carbon, and are fixed in suitable holders so that they ride freely over the commutator when the machine is running. Brushes of the same polarity are connected in parallel.

An E.M.F. is generated in the armature winding when it is rotated in the magnetic field of the field magnets. This E.M.F. is proportional to the rate at which the magnetic lines are cut and to the number of armature conductors in series between the brushes.

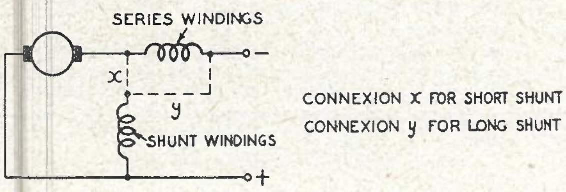
Then, for a machine with P poles, the total flux cut by each armature conductor during one revolution is $P \times \phi$ where ϕ is the magnetic flux in the air gap at each pole face.

If N is the number of armature conductors in series between brushes and R is the armature speed in R.P.M.

$$\text{E.M.F. generated} = \frac{P \times \phi \times N \times R}{60 \times 10^8} \text{ volts}$$

Small D.C. generators are not usually fitted with interpoles to assist commutation.

Series windings consisting of a few turns of heavy gauge copper conductor are sometimes added on the main poles of the field. The machine then becomes a compound-wound D.C. generator as shown in sketch (*b*).

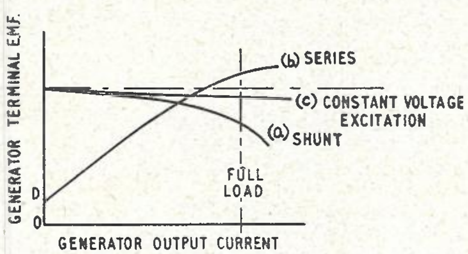


(*b*)

The shunt winding may be connected either as a "long shunt" or a "short shunt," the latter being the more usual arrangement. The series windings will give additional magnetic flux through the armature conductor in proportion to the current being drawn from the generator; this provides a boost to the output E.M.F. to compensate for the increased internal voltage drop which occurs with increased armature current.

The series winding therefore helps to hold the output voltage constant with increasing load.

The characteristic curves are as shown in sketch (*c*). In (*a*),



(*c*)

shunt-connected, the voltage across the field winding will decrease slightly by the extent of the voltage drop across the armature resistance. There will therefore be a slight decrease in field current as the armature output current rises. The curve droops as a result, and curves more sharply when magnetic saturation is approached. At zero output current, the terminal e.m.f. is a maximum.

In (*b*) the armature current generates the field flux. At zero current output, only the residual flux can generate an e.m.f., OD. The field flux rises smoothly with increasing armature current.

In (*c*) the field flux is kept constant throughout. The e.m.f. generated is therefore constant, but the armature resistance gives a small voltage loss proportional to output current. The characteristic is a straight line, with a small downward slope.

Q. 3. *A 400W electric lamp operating from a 200V 50-c/s supply is to be provided with a dimming device which, when connected in series, reduces the voltage across the lamp to 100V. There are available either—*

(*a*) *a resistor,*

or

(*b*) *an inductor having a resistance of 20 ohms.*

Determine the value of the resistance necessary if method (a) is used, and calculate the inductance in method (b), using vector diagrams or otherwise.

Determine the power wasted in the dimming device in each case and explain why one is more economical than the other.

Assume that the change of resistance of the lamp over the voltage range is negligible.

A. 3. The lamp is equivalent to a constant resistance R ohms. Since the power (P) dissipated in R ohms by a supply of voltage V is

$$P = \frac{V^2}{R}$$

we have $R = \frac{V^2}{P} = \frac{(200)^2}{400} = 100$ ohms.

(*a*) If a resistor r ohms is connected in series, the circuit is purely resistive throughout. The voltage across the lamp and across the series resistor will be in phase with the current, as in sketch (*a*).

(*a*)

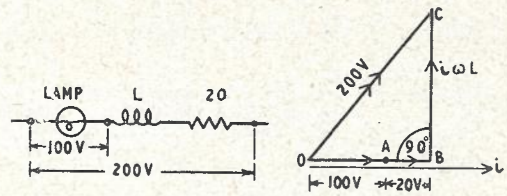
Hence, a resistor of 100 ohms is needed.

(*b*) Let L be the series inductance. The same current will flow in the lamp and the inductor.

By Ohm's Law, since 100V drop must occur across the lamp of 100 ohms, the current

$$i = \frac{100}{100} = 1 \text{ amp.}$$

Let O i be the current vector, in sketch (*b*).



(*b*)

The voltage drop in the lamp is then OA, 100V, in phase with i.

The voltage drop in the resistive component of the inductor is AB, 20V, also in phase.

BC, at right angles to the current vector, is the direction of the voltage across the inductance L.

The point C is determined by striking an arc OC of length equivalent to 200V, the supply voltage.

$$\begin{aligned} OB &= 120 \text{ volts} \\ BC &= (2\pi 50\, L \times 1) \\ &= 100\pi L, \text{ the voltage across the inductance } L. \\ OC &= \text{supply voltage} = 200 \text{ volts} \\ \text{then } OC^2 &= OB^2 + BC^2 \\ BC &= \sqrt{OC^2 - OB^2} = \sqrt{200^2 - 120^2} = \sqrt{80 \times 320} = 160 \\ \therefore \quad L &= \frac{160}{100\pi} = 0{\cdot}51 \text{ henry.} \end{aligned}$$

Power lost in the dimming device in (*a*) $= i^2R = 1^2 \times 100 = 100$ watts.

Power lost in the dimming device in (*b*) $= i^2r = 20$ watts.

The method (*b*) is the more economical because the impedance of the inductance provides a voltage drop in quadrature with the current, i.e. without loss of power. Only the unavoidable resistance component of the inductance wastes power.

Q. 4. *A parallel plate capacitor, consisting of three metal plates A, B, C, each of effective area 50 sq. cm. with 2 millimetres gap between adjacent plates, is constructed so that all the plates are insulated from each other. The dielectric between the plates can be either air, mica or wax as required.*

Calculate the maximum and minimum capacitances that can be obtained from the capacitor and name the dielectrics you would select in each case.

The plates A and C are now connected together. The space between A and B is filled with mica, and that between B and C with wax. Determine the capacitance between B and the other two plates, and the energy stored in the capacitor when it is charged to a p.d. of 100 volts.

The capacitance of an air-dielectric capacitor having plates 1 sq. cm. in area and spaced 1 cm. apart may be taken as 0·0885 μμF.

Assume that the permittivities (dielectric constants) of air, mica and wax are 1·0, 7·0 and 2·2 respectively.

A. 4. The capacitance of a parallel plate capacitor is given by

$$C = \frac{k \times a}{4\pi d} \times \frac{10^{-11}}{9} \text{ microfarads}$$

where a is the effective area of the dielectric, d is the distance between the plates and k is permittivity.

The maximum capacitance will be given by the arrangement of sketch (*a*). The outer plates are connected together to give one electrode. The inner plate, effective on both sides, is the other

(a) (b) (c)

electrode. Mica, having the highest permittivity of the three dielectrics, would be used between both pairs of plates.

$$C_{max} = \frac{7 \times (2 \times 50)}{0 \cdot 2} \times 0 \cdot 0885 = \underline{310\ \mu\mu\text{F}}$$

The minimum capacitance will require the greatest value of d and minimum values of k and area of plate. The electrodes A and C will be used, B being ignored and disconnected as in sketch (*b*); air will be the dielectric.

$$C_{min} = \frac{1 \times 50}{2 \times 0 \cdot 2} \times 0 \cdot 0885 = \underline{11 \cdot 1\ \mu\mu\text{F}}$$

When A and C are connected together the arrangement is equivalent to two capacitors in parallel, both having the same physical dimensions but with different dielectrics, as shown in sketch (*c*)

$$\text{Capacitance} = \frac{50}{0 \cdot 2}(7 \cdot 0 + 2 \cdot 2) \times 0 \cdot 0885$$
$$= \underline{204\ \mu\mu\text{F}}$$

The energy stored in a capacitor of C farads charged to V volts $= \frac{1}{2}CV^2$. For the given example $C = 204\ \mu\mu$F and $V = 100$ volts. The energy stored $= \frac{1}{2}(204 \times 10^{-12}) \times (100)^2 = \underline{1 \cdot 02 \text{ microjoules}}$.

Q. 5. *Define the term resistivity (specific resistance) of a conductor.*

A composite conductor contains a single solid copper wire 0·1 *in. diameter over which is laid a number of steel wires that are equivalent in cross-sectional area to a steel tube of outer diameter* 0·25 *in. and inner diameter* 0·1 *in. Calculate the resistance of* 1,000 *yards of this composite conductor.*

What proportion of direct current carried by the conductor will flow in the copper?

Assume that the resistivities of copper and steel are 1·8 *and* 10 *microhms per cm.*^{3} *respectively.*

A. 5. The resistivity, or specific resistance, of a conductor is the resistance between opposite faces of a unit cube of the material at a given temperature.

If l is the length of a conductor having uniform cross-sectional area a, and resistivity k, then

$$\text{Resistance} = k\frac{l}{a}$$

In the example, the *copper* conductor has a specific resistance of $\frac{1 \cdot 8 \times 10^{-6}}{2 \cdot 54}$ ohms per inch cube.

$\therefore$ Resistance, R_1, of 1,000 yards length

$$= \frac{1 \cdot 8 \times 10^{-6}}{2 \cdot 54} \times \frac{(1{,}000 \times 36)}{\pi\left(\frac{0 \cdot 1}{2}\right)^2} \text{ ohms}$$
$$= 3 \cdot 25 \text{ ohms.}$$

The *steel* conductor has a specific resistance of

$$\frac{10 \times 10^{-6}}{2 \cdot 54} \text{ ohms per inch cube.}$$

$\therefore$ Resistance, R_2, of 1,000 yards

$$= \frac{10 \times 10^{-6}}{2 \cdot 54} \times \frac{1{,}000 \times 36}{\frac{\pi}{4}\left(0 \cdot 25\right)^2 - \frac{\pi}{4}\left(0 \cdot 1\right)^2}$$
$$= 3 \cdot 44 \text{ ohms.}$$

Since the two conductors are effectively connected in parallel their joint resistance, R, is given by

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$
$$R = \frac{R_1 R_2}{R_1 + R_2} = \frac{3 \cdot 44 \times 3 \cdot 25}{3 \cdot 44 + 3 \cdot 25}$$
$$= \underline{1 \cdot 68 \text{ ohms.}}$$

The direct current will divide in inverse ratio of the resistances.

$$\therefore \text{ Proportion of current flowing in the copper} = \frac{3 \cdot 44}{6 \cdot 69} = \underline{51 \cdot 5\%}$$

Q. 6. *How is the difference between the electrical conductivity of metals and insulators explained by the simple electron theory?*

What properties are desirable in the insulating material used for covering copper wire intended for coils of low voltage telecommunications equipment such as relays?

Name two different materials that are in common use for this purpose.

A. 6. The simple electron theory postulates that all matter is composed of a relatively small number of elements, each of which is an agglomeration of a particular type of atom. Atoms of any individual element are all similar in constitution, the internal geometry of the atom being typical of the particular element and a guide to its properties.

Every atom is constructed from three types of particles.

(*a*) Electrons, carrying a negative electrical charge of $1 \cdot 59 \times 10^{-19}$ coulombs and an equivalent mass of 9×10^{-28} grams;

(*b*) protons having a positive charge of $1 \cdot 59 \times 10^{-19}$ coulombs and a mass 1,840 times that of the electron;

(*c*) neutrons having no electrical charge, but a mass equal to that of the proton.

The simplest atom is that of hydrogen, consisting of one proton as nucleus around which one electron moves in a fixed orbit. Atoms of other elements are more complex, having a nucleus made up of protons and neutrons that together represent most of the mass of the atom and exhibit a positive charge, while round the nucleus move electrons that are negatively charged. The complete atom normally appears uncharged because the negative and positive charges are equal. The electrons are grouped in "shells," the number of these depending upon the nature and complexity of the atom.

In atoms of a metal, electrons in the outer orbit are relatively easily displaced by an external electric field. When, therefore, a P.D. is applied across a conductor, electrons are displaced from one atom to another by the potential gradient, the positive charge exhibited by an atom that has lost an electron serving to attract another electron from a neighbouring atom. The resulting "electron drift" constitutes an electric current. It can only occur in materials in which an outer electron is "free," i.e. readily detachable from its orbit.

Atoms of insulating materials do not in general possess this free electron; consequently they do not readily permit electronic drift, i.e., they have a high resistance, as only an occasional free electron is available.

Insulating material for covering copper wire must firstly have high resistivity at normal temperatures; it should be mechanically robust to withstand pressure; it must be flexible and resistant to deterioration and corrosion with age even when warm and in damp atmospheres. Low permittivity is also desirable to keep the self-capacitance of a coil to a minimum. The insulating material must safely withstand temperature rises to 60°C or more.

Synthetic enamel is one of the best modern insulating materials for copper wire. Two layers of cotton closely wound as a covering on the wire are also satisfactory. Where economy of space justifies the cost, silk may be used instead of cotton.

Q. 7. *A* 2·0 *microfarad capacitor is charged from a constant potential source of* 100 *volts through a series resistor of* 1 *megohm.*

What is the maximum value of the charging current and at what instant in the charging process does it occur?

Calculate the time required for the P.D. across the capacitor to become 63·2 *volts, and the energy then stored in the capacitor.*

Sketch, and comment upon, the shape of the voltage/time curve for the charging process.

A. 7. When a capacitance C farads is charged through a resistance R ohms from source of voltage V_0 the P.D. (V) across the capacitance after time t seconds is given by

$$V = V_0(1 - e^{-t/CR})$$

in which CR is known as the time-constant of the circuit.

The current flowing is determined by the P.D. across the resistor, which is given by

$$(V_0 - V) = V_0 e^{-t/CR}$$
$$\text{When } t = 0,\ e^{-t/CR} = e^0 = 1.$$

$\therefore$ P.D. across resistor $= V_0$, the highest possible value.

The current I is therefore a maximum at the instant of switch-on.

$$\text{and } I = \frac{100}{10^6} \times 1{,}000 \text{ milliamps.}$$
$$= \underline{0 \cdot 1 \text{ milliamp.}}$$

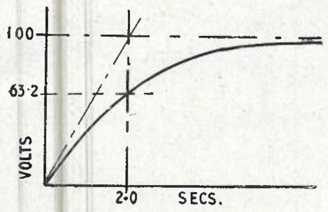
Since $(1 - e^{-1}) = 0 \cdot 632$, the time for the P.D. across the capacitor to rise to 63·2 per cent. of the source is given by

$$t/CR = 1 \text{ or } t = CR$$
$$\therefore \text{ time required} = 2 \cdot 0 \times 10^{-6} \times 1 \times 10^6$$
$$= \underline{2 \cdot 0 \text{ seconds.}}$$

The energy stored $= \frac{1}{2} CV^2$ joules

$$= \frac{2 \cdot 0 \times 10^{-6}}{2} \times (63 \cdot 2)^2 \text{ joules.}$$

$$= \underline{4 \cdot 0 \times 10^{-3} \text{ joules.}}$$



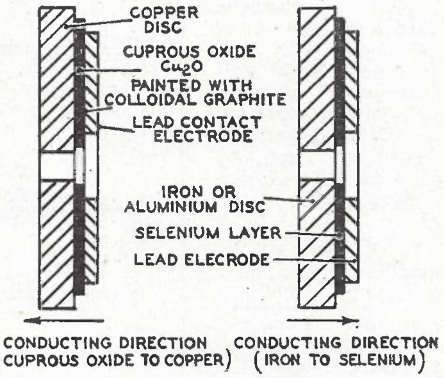
The voltage/time curve is an exponential, shown in the sketch. It rises from zero voltage at zero time, with the instantaneous starting current being of 0·1 milliamp. The curve rises to 63·2 volts after 2 seconds and is asymptotic to the steady value of 100 volts.

Q. 8. *Describe with the aid of sketches the construction and characteristics of any type of metal rectifier with which you are familiar and state the factors which determine its current and voltage rating.*

Sketch the circuit connections you would employ for (a) a full-wave rectifier, and (b) a half-wave rectifier, and compare for the two cases the current waveforms that would be obtained in a resistive load without smoothing in the circuit.

What factors determine the physical size of the rectifiers in the two cases?

A. 8. The resistance to the passage of electric current across the surface between certain pairs of electrical conductors pressed intimately in contact, for example, cuprous oxide with copper, or selenium with steel, is much higher in one direction than in the other. This property of high reverse, and low forward, resistance can be used to rectify an alternating current. The construction of a copper oxide rectifier is shown in sketch (*a*) and of a selenium rectifier in



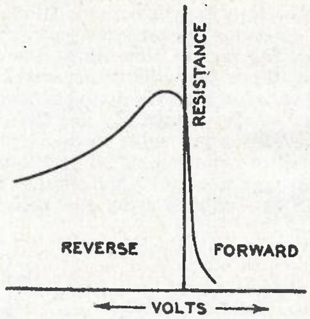
(*a*) (*b*)

sketch (*b*). In the former, the rectifying layer is made by forming cuprous oxide directly on one side of a copper disc, and the low, or forward, resistance direction is from the cuprous oxide to the copper. Electrical contact is made by clamping lead washers against the oxide and copper surfaces, and large cooling fins can be placed against the lead. Each disc is drilled beforehand and the assembly of the necessary number of disc elements is held together by a bolt within an insulating tube.

One such rectifier will withstand a peak voltage up to 8 volts in the high resistance direction, but it should operate well below this value for safety, e.g. 6 volts. For larger voltages, discs can be assembled in series, unlike poles abutting, until the required operating reverse voltage is built up. To increase the current-carrying capacity, several disc assemblies, each having the same number and type cf discs, can be connected in parallel.

Selenium rectifiers can stand a peak reverse voltage of about 20 volts, and can withstand slightly higher current rating with safety. The construction (see sketch (*b*)) is basically similar to that of the copper oxide rectifier.

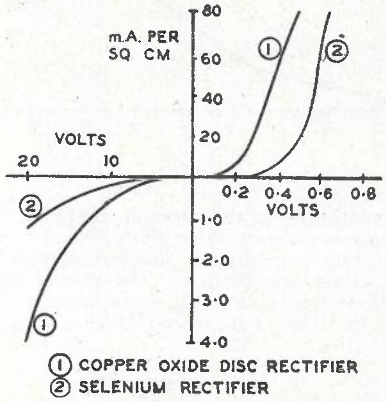
The voltage rating of a given metal rectifier depends upon the number of rectifying elements connected in series, the peak voltage across each element being limited to the maximum value stated above. The current rating is limited by the operating temperature reached by the rectifying element under load conditions. Improved cooling will increase the permissible current rating of a given area of rectifier element. The heating effect is due to i^2R loss from the unavoidable resistance of the rectifiers, which depends upon the materials used in them, and also, to some extent, upon the applied voltage. A typical voltage-resistance curve is shown in sketch (*c*).



(*c*)

A typical current-voltage curve is shown in sketch (*d*).

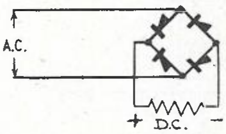
Metal rectifiers have a high self-capacitance, the selenium type



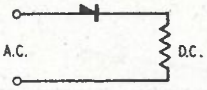
(*d*)

exceeding the copper oxide in this respect. They also have a tendency to age, in that their forward resistance increases slightly with the passage of time.

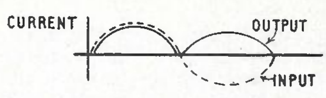
The full-wave rectifier circuit is shown in sketch (*e*). The load-current flowing in a purely resistive load will have the waveform



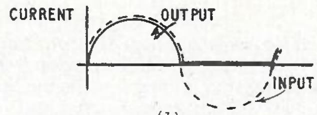
(*e*)



(*f*)



(*g*)



(*h*)

shown in sketch (*g*), each alternate half-cycle being inverted by the rectifier. If the A.C. supply is sinusoidal the half-cycle current waveforms in the resistive load will, in the absence of any smoothing, also be approximately sinusoidal.

The half-wave rectifier circuit in sketch (*f*) produces the current waveforms of sketch (*h*) in which alternate half-cycles are suppressed by the reverse resistance of the rectifier.

Q. 9. *What factors control the value of the anode current in a thermionic triode valve?*

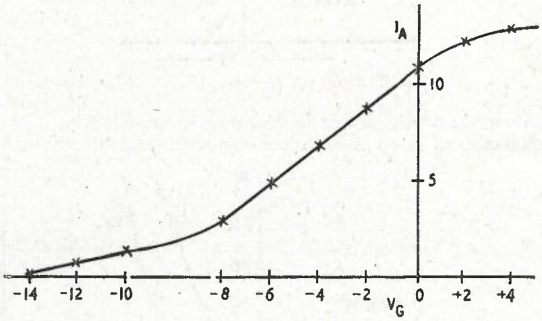
The following table gives values of anode current and grid voltage for a fixed value of anode voltage on a certain triode valve. Plot the V_g/I_a curve and from it, or otherwise, derive the curve relating the mutual conductance and the grid voltage for the same value of anode voltage:—

V_g *volts*	..	—14	—12	—10	—8	—6	—4	—2	0	+2	+4
I_a *mA*	..	0·3	0·8	1·5	3	5	7	9	11	12·5	13

What is the approximate value of the grid voltage swing permissible under this condition of anode voltage for distortionless amplification?

A. 9. The anode current in a thermionic triode valve is that part of the stream of electrons leaving the cathode that eventually reaches the anode. The factors that affect the magnitude of this stream are therefore those that affect the anode current.

For given conditions of cathode temperature, the control grid voltage V_G and the anode voltage V_A are the controlling factors. The former, V_G, usually a few volts negative, has the more pronounced effect of the two because of its proximity to the cathode. The larger the negative value of V_G the smaller the anode current, as shown in sketch (*a*), plotted from the table of values in the question.



(*a*)

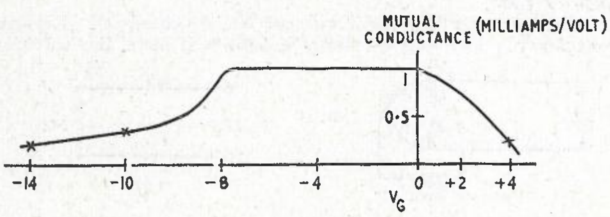
The flattening of the curve at the upper end occurs when all the electron stream emitted by the cathode reaches the anode. The anode current can only be increased beyond this value by raising the cathode temperature. The heater current therefore controls the saturation value of the anode current.

The mutual conductance of the valve with a fixed anode voltage is given by

$$g = \frac{\delta I_A}{\delta V_G}$$

The curve relating g and V_G can therefore be obtained by plotting the slope of the V_G/I_A curve against values of V_G.

This curve is shown in sketch (*b*).



(*b*)

Distortionless amplification can only occur when the anode current change is strictly proportional to the grid voltage change producing it, i.e. over the region where the g/V_G curve is level, and the I_A/V_G characteristic straight. The maximum permissible grid voltage swing is 0 to -8 volts.

***Q*. 10.** *Draw the vector diagrams relating voltages and currents in the circuit shown in Fig. 1, assuming that the alternator is supplying a sinusoidal output of* 10*V at an angular frequency of* 5,000 *radians per sec.* ($2\pi f = 5{,}000$).

Hence, or otherwise, determine the magnitude of the current in the 50-ohm resistor, and the power factor presented by the circuit to the alternator.

What additional component would restore the power factor to unity? Calculate its value and show where you would connect it.

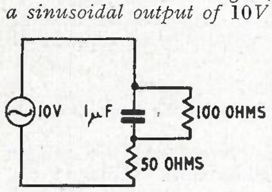
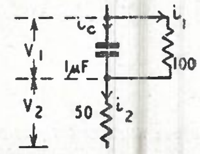


FIG. 1

A. 10. As shown in sketch (*a*), let V_1 be the voltage across the capacitor, V_2 that across the 50-ohm resistor; i_1 the current in the 100-ohm resistor, i_2 in the 50-ohm resistor and i_c that in the capacitor. The impedance of the capacitor when $2\pi f = 5000$ is



(*a*)

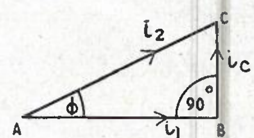
$$\frac{1}{2\pi fC} = \frac{1}{5000 \times 1 \times 10^{-6}} = \frac{1}{5 \times 10^{-3}} \text{ ohms}$$

$$\text{Then } i_c = \frac{V_1}{1/2\pi fC} = V_1 \times 5 \times 10^{-3} \text{ amps.} = 5\ V_1 \text{ mA.}$$

$$i_1 = \frac{V_1}{100} = 10\ V_1 \text{ mA.}$$

The current vector i_c will lead the voltage vector V_1 by 90° and i_1 will be in phase with V_1.

The vector currents are shown by the △ ABC in sketch (*b*). The vector sum of i_c and i_1 is i_2.



(b)

The angle ϕ

$$= \tan^{-1}\frac{5V_1}{10V_1} = \tan^{-1}\frac{1}{2} = 26°\ 34'$$

$$i_2 = \frac{10\,V_1}{\cos\phi} = \frac{10}{0{\cdot}8944} \cdot V_1$$

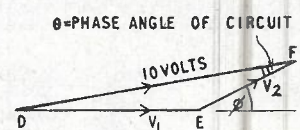
$$= 11{\cdot}18 V_1 \text{ mA.} \quad .. \quad (1)$$

Now the voltage across the 50-ohm resistor will be, by Ohm's Law,

$$V_2 = 50 i_2 = 50 \times 0{\cdot}0118 V_1$$
$$= 0{\cdot}58 V_1$$

i_2 will be in phase with V_2.

Since i_1 has been shown to be in phase with V_1, the phase angle between V_1 and V_2 is ϕ from △ CAB. Sketch (*c*) shows the voltage vector diagram.



(c)

If DE is drawn with unit length to represent V_1 and EF with length $0{\cdot}56V_1$ to represent V_2, and $\phi = 26°\ 34'$, then DF represents the supply voltage.

By measurement, DF = 1·53.

But DF is given as 10V.

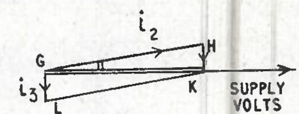
$$\therefore \text{ DE represents } \frac{10}{\text{DF}} = 6{\cdot}5\text{V.}$$

∴ from equation (1),

$$i_2 = 11{\cdot}2 \times 6{\cdot}5 = \underline{72{\cdot}8 \text{ mA.}}$$

The current taken from the supply leads the supply voltage by $\hat{\text{DFE}} = 17°$.

The Power Factor = cos 17°
= $\underline{0{\cdot}96}$



(d)

Power Factor correction requires that the current taken from the supply shall be in phase with the supply voltage, i.e. vector i_2 must be in phase with the 10V vector whereas in the condition of Fig. 1 it is leading by the angle $\hat{\text{DFE}}$.

Any component added to correct the power factor must therefore take a lagging current of value sufficient to bring the resultant current taken from the supply into phase with the supply voltage.

Sketch (*d*) shows the current i_2 leading the supply voltage, V, by 17°.

If the current GL, lagging on V by 90°, is added, the resultant current GK will be in phase with V.

Then $i_3 = i_2 \sin 17° = 72{\cdot}8 \times 0{\cdot}2924 = \underline{21{\cdot}3 \text{ mA.}}$

If L is the shunt inductance, across the 10-V supply,

$$i_3 = \frac{10}{\omega L} \text{ and } L = \frac{10}{\omega i_3} = \frac{10^4}{5000 \times 21{\cdot}3} = \underline{0{\cdot}094 \text{ henrys.}}$$

(*To be continued*)

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