SUPPLEMENT
TO
THE POST OFFICE ELECTRICAL ENGINEERS' JOURNAL

Vol. XXXI April, 1938 No. 1

CIVIL SERVICE COMMISSION EXAMINATIONS, 1936

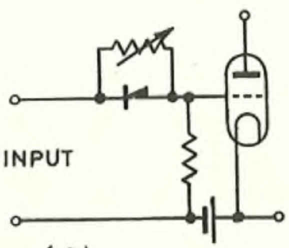
LIMITED COMPETITION FOR PROBATIONARY INSPECTORSHIPS.

Permission to reproduce the questions has been obtained from the Controller, H.M. Stationery Office, and is gratefully acknowledged.

RADIO COMMUNICATION

Q. 1. *Describe how valve amplitude distortion is reduced by* (a) *grid voltage compensation,* (b) *anode current compensation.*

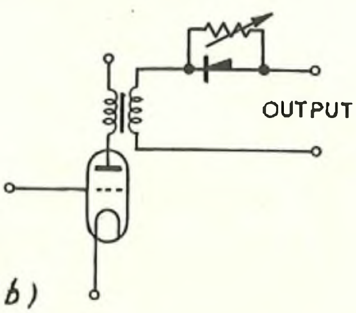
A. 1. The principle of both methods of compensation for valve amplitude distortion depends on the introduction into the circuit of an element having a non-linear characteristic in such a manner that the effect of its non-linearity is as far as possible equal and opposite to that of the valve. A convenient form of non-linear element is the dry-plate metal-oxide rectifier shunted by a variable resistor to enable the characteristic to be adjusted, within limits.



(a)

Sketch (a) shows the method of connecting the rectifier combination in the grid circuit of a valve amplifier. This method does not affect the power output from the valve, but it has the disadvantage that the amount of compensating non-linearity introduced is independent of the anode load of the valve, although the valve distortion is dependent on the anode load.

Sketch (b) shows the application to the anode circuit of an amplifier. In this case the output power of the valve is somewhat reduced, but the degree of compensation is dependent on the load impedance, so that the improvement obtained with the device may be to some extent independent of load changes.

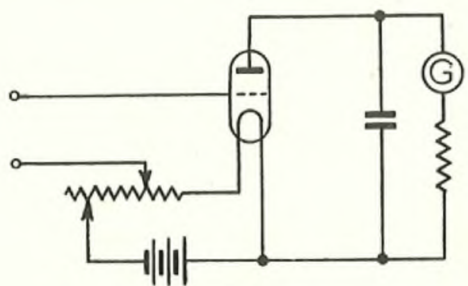


(b)

Q. 2. *Describe* (a) *any type of thermo-electric ammeter,* (b) *the Moullin apparatus for the measurement of high frequency voltages, and* (c) *a method of measuring peak voltages.*

A. 2. (*a*) A useful and common form of thermo-electric ammeter consists of an ordinary D.C. microammeter instrument combined with a thermo-couple. For measurement of currents of an ampere or more, the thermo-couple may be formed from a length of resistance wire to which is welded a couple of constantin and steel or manganin. For smaller currents a more delicate form of construction is required, and a small filament of resistance wire may be attached to a minute couple by a bead of vitreous insulating material, the whole being enclosed in a highly exhausted glass bulb.

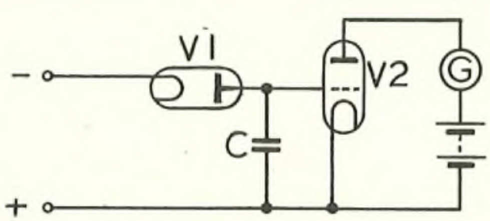
(*b*) Sketch (a) shows the connections of a simple form of Moullin voltmeter for high frequency measurements. The



(a)

voltage to be measured is applied to the grid circuit of a triode in series with a potential-dividing arrangement for obtaining a convenient value of grid bias. The anode circuit includes a galvanometer and swamping resistance but no high tension battery. The apparatus is calibrated by comparison with a standard instrument and a special note is made of the small galvanometer deflection which remains when the input terminals are short-circuited. When in use thereafter, the calibration of the apparatus may be compensated for variation of the filament battery merely by adjusting the filament rheostat until the special deflection is obtained with no input.

(*c*) Sketch (b) illustrates a rectifier-condenser type of peak voltmeter. The voltage to be measured is applied to a diode rectifying valve V1 and a condenser C in series. When the



(b)

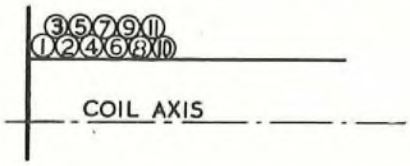
instantaneous voltage is of a sense such that the input terminals are positive and negative as indicated, the condenser tends to be charged through the valve. A short time after the application of a steady alternating voltage, therefore, the condenser becomes charged to the peak value of the voltage. This condenser voltage is measured by a simple valve voltmeter arrangement consisting of the valve V2 and galvanometer G, the whole apparatus being calibrated by comparison with a standard instrument.

Q. 3. *Enumerate the various methods of winding tuning coils so that their self-capacity is reduced to a minimum.*

A. 3. The following are the six principal methods :

(1) *Sectional Winding.* In this method the turns of a solenoid are grouped into sections, each consisting of several layers with a small number of turns per layer.

(2) *Bank Winding.* The sketch illustrates the application of the bank winding method to a solenoid. The object is to



ensure that the potential difference between adjacent turns is as small as possible.

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

(4) *Basket Winding.* This method gives a single-layer winding in which adjacent turns cross at an angle, the wire being wound in and out of a number of pins arranged in the form of a cylinder.

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

(6) *Honeycomb or Wave Winding.* In this method a multi-layer coil is obtained in which the turns of one layer are separated by air spaces and the turns of adjacent layers cross at an angle. This effect is produced by winding in a zigzag fashion from side to side of the winding surface.

Q. 4. *A condenser having a capacity of* 0·05 μF *is charged to a voltage V and then connected in series with an inductance of* 1,500 *microhenries having a resistance of* 22 *ohms.*

Calculate the time required for the oscillatory current to fall to one per cent. of its initial value.

A. 4. The oscillatory current decreases uniformly with time in a logarithmic manner according to the decay factor $\epsilon^{-Rt/2L}$, where R is the resistance in ohms, L the inductance in henries, t the time in seconds, and ϵ the base of natural logarithms.

The time required for the current to fall to one per cent. of its initial value is therefore given by the equation

$$\epsilon^{-\frac{22}{2\times1{,}500\times10^{-6}}t}=\frac{1}{100}$$

whence $$\frac{22}{2\times1{,}500\times10^{-6}}\,t=\log_{\epsilon}100$$

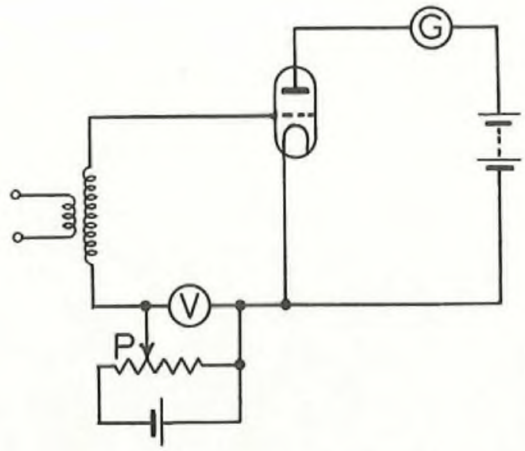
$$=2{\cdot}3026\times\log_{10}100$$
$$=2{\cdot}3026\times2$$

therefore $$t=\frac{2{\cdot}3026\times2\times2\times1{,}500\times10^{-6}}{22}\text{ secs.}$$

and the time of decay is 0·000628 seconds.

Q. 5. *What arrangement is used for measuring the depth of modulation and how is the percentage modulation arrived at ?*

A. 5. The sketch illustrates a simple form of slide-back voltmeter for measuring depth of modulation. The signal to be measured is applied through a transformer to the grid circuit of a triode in series with a potentiometer P for varying the bias. A voltmeter V is provided for accurately measuring this bias, and a galvanometer G is included in the anode circuit for indicating anode current.



The determination of percentage modulation requires three measurements. The first is taken with no signal entering the device, the potentiometer being adjusted so that the anode current is just reduced to zero or, better, to a definite but very small value. The reading of the voltmeter, say Vo, for this condition is noted.

Next the unmodulated carrier is applied and the bias is increased until the anode current is again reduced to zero or the chosen value. The voltmeter reading is now Vc.

Lastly, the modulated carrier is applied and the procedure repeated, the voltmeter reading now being Vm. It is clear that the changes of bias must correspond closely with the changes of the peak signal voltage from the secondary of the transformer, and the amplitude of the unmodulated carrier is therefore given by Vc – Vo, and the amplitude of the modulated carrier by Vm – Vo. The amplitude of the modulation is given by the difference (Vm – Vo) – Vc–Vo) = Vm – Vc.

The percentage modulation may therefore be found by evaluation of the following expression :—

$$\frac{Vm-Vc}{Vc-Vo}\times100$$

CITY AND GUILDS OF LONDON INSTITUTE EXAMINATIONS, 1937

RADIO COMMUNICATION. FINAL, 1937

Q. 1. *Derive expressions for the polar diagram in the horizontal plane for an antenna array consisting of N elements spaced half a wavelength apart in a straight line energised in phase.*

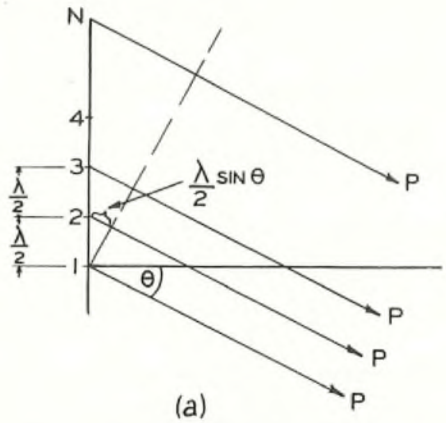
Derive a similar expression for the polar diagram of an array system having elements spaced half a wavelength and alternate elements phased 180 *degrees from the remainder, in order to secure maximum radiation in the line of elements.*

How does the sharpness of directivity compare in the two cases ?

A. 1. With reference to sketch (a), let P be a point at great distance from the array compared with its width, the direction of P making an angle θ with the normal to the line of the array.

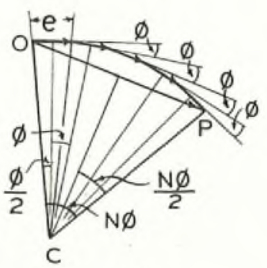
Then the field at P due to element 2 lags by an angle ϕ radians on the field at P due to element 1, and that due to 3 lags by the same angle on that due to 2 and so on, where

$$\phi=\frac{2\pi}{\lambda}\times\frac{\lambda}{2}\sin\theta=\pi\sin\theta.$$



(a)

The resultant field at P is the vector sum of the fields due to the N elements and is shown as OP in sketch (b). In this sketch, C is the centre of the circle of which the vectors are chords.



(b)

From sketch (b), if the radius of the circle CP = r, each vector $= e = 2r \sin \frac{\phi}{2}$, and $r = \dfrac{e}{2 \sin \frac{\phi}{2}}$

the resultant $= OP = 2r \sin \frac{N\phi}{2}$

When $\theta = 0$, all the vectors add in phase and OP has its maximum value. The above expression is then indeterminate since r is infinite, but obviously $OP_{max.} = Ne$.

The polar diagram is therefore given by the equation

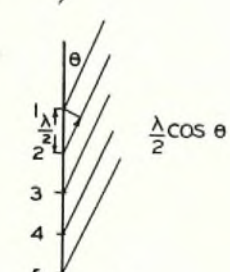
$$\frac{OP}{OP_{max.}} = \frac{2r \sin \frac{N\phi}{2}}{Ne} = \frac{\sin \frac{N\phi}{2}}{N \sin \frac{\phi}{2}}$$

$$\text{or } OP = OP_{max.} \frac{\sin \frac{N\phi}{2}}{N \sin \frac{\phi}{2}}$$

$$\text{i.e. } OP = OP_{max.} \frac{\sin \left(\frac{N\pi}{2} \sin \theta\right)}{N \sin\left(\frac{\pi}{2} \sin \theta\right)}$$

In the second case sketch (c), when $\theta = 0$ the signals from all the elements will arrive in phase and the total field at a distance will be Ne as before if we take θ in this case as the angle between the direction of transmission and the line of elements.

When θ has any value other than zero, the signals from element 2 will lead in phase relatively with the signal from element 1 as its travel has been reduced by an amount



(c)

$\frac{\lambda}{2} - \frac{\lambda}{2} \cos \theta$. The angle of lead therefore will be

$$\phi = 2\pi \times \frac{\frac{\lambda}{2}(1 - \cos \theta)}{\lambda} = \pi (1 - \cos \theta).$$

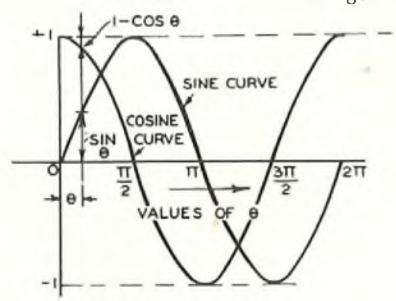
The same will apply to other elements, the signal from each leading by ϕ relative to the signal from the element in front.

The resulting signal will again be the vector sum of N signals, each differing in phase by ϕ as in the previous case, thus:

$$OP = OP_{max.} \frac{\sin \frac{N\phi}{2}}{N \sin \frac{\phi}{2}}$$

$$= OP_{max.} \frac{\sin \left\{\frac{N\pi}{2} (1 - \cos \theta)\right\}}{N \sin \left\{\frac{\pi}{2} (1 - \cos \theta)\right\}}$$

Regarding sharpness of directivity this will depend on the rapidity with which ϕ changes with changes of θ. In the broadside array ϕ is proportional to $\sin \theta$ whereas in the staggered array ϕ is proportional to $(1 - \cos \theta)$. Sketch (d) shows a sine and cosine curve on which $\sin \theta$ and $1 - \cos \theta$ are marked. It will be seen that $\sin \theta$ changes rapidly as θ



(d)

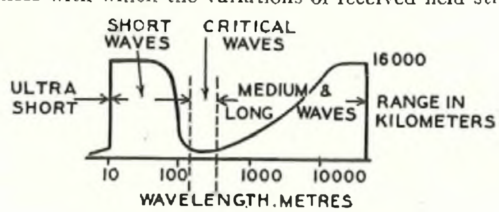
increases from 0, but that $1 - \cos \theta$ changes relatively slowly so that in consequence the broadside array will be much sharper in directivity than the staggered array.

Q. 2. What grounds are there for believing in the existence of ionised layers in the upper atmosphere? Describe the methods adopted to determine the heights of such layers.

A. 2. Evidence of the existence of ionised layers in the upper atmosphere is found in the behaviour of radio waves in transmission between emitter and receiver as observed in the conditions of reception experienced under varying circumstances. Some of the transmission phenomena which are consistent with the existence of such layers are referred to below.

Radio waves can be classified into four main groups within the spectrum employed for communication, according to their behaviour in transmission. The groups are: 1, ultra-short waves (below 10 metres); 2, short waves (10 to 150 metres); 3, critical waves (150 to about 400 metres); 4, medium and long waves (over 400 metres), the transition from one group to another being gradual and not well defined. Typical ranges of communication obtainable with these wavelengths are indicated in sketch (a).

The behaviour of medium and long waves in regard to the possible ranges obtainable with a given power, and the closeness with which the variations of received field strength

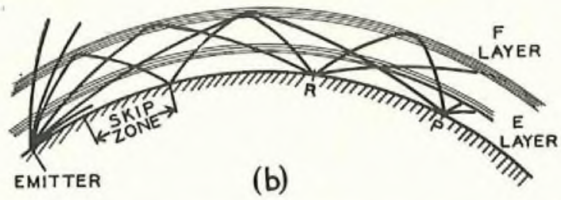


(a)

at a distance from the emitter follows daylight and darkness changes over the transmission path, are consistent with the existence of a layer of the atmosphere responding rapidly to the sun's rays in regard to its degree of ionisation. Such a layer must be comparatively dense and therefore comparatively low, and is known as the " E " layer. This layer functions as a good conductor at the lower frequencies and with the earth forms a spherical wave-guide, and long waves are found to maintain to great distances the state of vertical polarisation with which they are emitted. At the higher frequencies within the group there is some penetration of the layer accompanied by attenuation and shorter ranges.

The behaviour of the critical waves can be explained by the assumption that their frequencies are of the same order as the mean frequency of collision in the " E " layer of free electrons with gas molecules, with the result that such waves penetrate the layer and are rapidly attenuated. Thus during the day they are received only at short ranges when the direct ground ray provides a sufficient field strength ; at night they are found to be received generally with considerable fading, at greater distances, as if they were then able to penetrate the " E " layer to be reflected from or bent in a higher layer (the " F " layer) when the degree of ionisation is greater and owing to the lower gas pressure is maintained to a greater extent during darkness. Further evidence of passage through ionised layers is found in " night effect " in direction finding due to the inclination of the direction of propagation and to rotation of the plane of polarisation under the combined influence of the ionised medium and the earth's magnetic field.

The short waves similarly, but with rather less attenuation, penetrate the " E " layer, since their frequencies are higher than the mean collision frequency, and are returned by reflection at, or bending in the " F " layer. Evidence of this mechanism in transmission of short waves is found in the variation of received signal at varying distances from the emitter showing, beyond the range of the direct ray, a " skip "



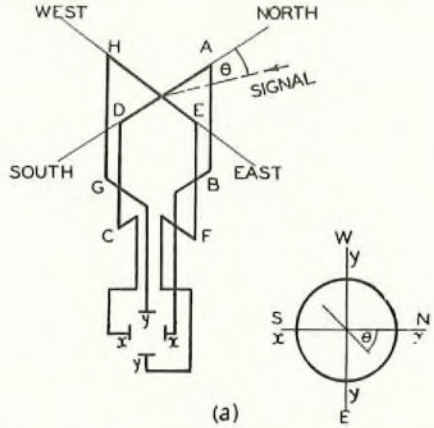
zone where little or nothing is received, followed by zones in which waves are receivable at different down-coming angles as indicated in sketch (b). At such points as R and P the different paths by which energy is received are evident in fading and in reception of repetitions of a signal in rapid succession. Short waves received beyond the range of the ground ray are also found to have undergone rotation of the plane of polarisation.

The heights of the various layers may be determined by sending a very short signal or " pulse " and observing the received signal at a short distance from the emitter by means of a cathode ray oscilloscope associated with the receiver. It is found that more than one pulse are received and that successive pulses have varying amplitudes. The first pulse is due to the direct ground ray and the others are due to one or more reflections from the several ionised layers. From the time intervals between received pulses, the difference in the path lengths and consequently the height of the layer, may be deduced.

Q. 3. Describe with sketches the principles of operation of any type of direct-reading direction finder for indicating the direction of arrival of an incoming wave.

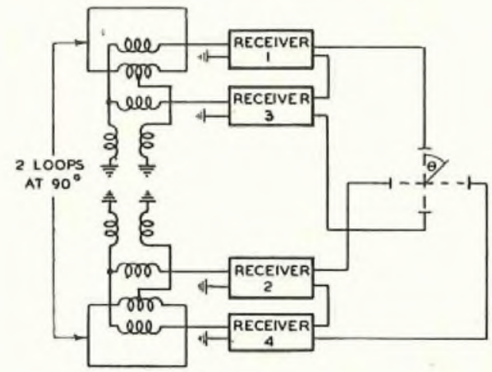
A. 3. A direct-reading direction finder may be arranged by applying to the deflecting plates of a cathode ray oscillograph, voltages induced in a pair of loops at right angles in the manner indicated in sketch (a).

A vertically polarised wave arriving along a direction at θ degrees to loop ABCD induces an E.M.F. across the xx plates proportional to $\cos\theta$ and across the yy plates proportional to $\sin\theta$. The resulting excursion of the spot on the screen of the oscillograph will therefore be composed of a movement along the xx axis proportional to $\cos\theta$, and a



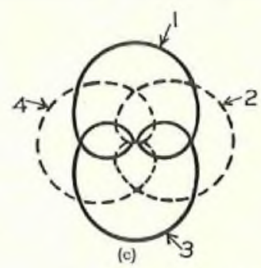
movement along the yy axis proportional to $\sin\theta$, the resultant locus being a straight line inclined θ degrees to the xx axis. The direction of the incoming signal can therefore be read off directly from a protractor scale marked on the screen.

The sensitivity of the apparatus may be increased by inserting amplifiers of equal sensitivity and giving equal phase shift to the received voltages, between each loop and the respective plates of the oscillograph. To ensure equal phase shifts, the amplifiers may take the form of superheterodyne receivers with a common beating oscillator.



(b)

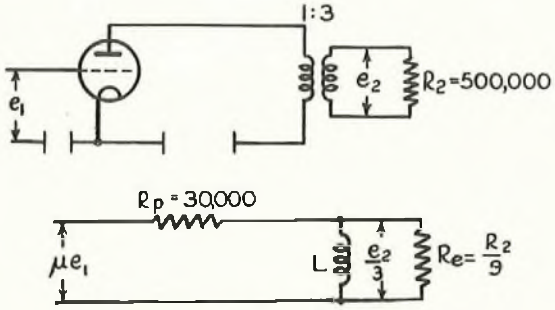
The method may be elaborated to avoid sense ambiguity by the arrangement shown in sketch (b). Each loop is coupled to a pair of receivers through a three-winding transformer, the primary of which is centre tapped and connected to earth through the primary of another transformer which enables the loops to function as omni-directional aerials, and so to add to the receiver inputs, E.M.F.s which are independent of the direction of the signal. Thus the polar diagram of response of each receiver is a cardioid. The receiver outputs are connected in pairs to the deflecting plates so that individual receivers of each pair deflect the spot in opposite directions along the respective axes as indicated in sketch (c). The movement at the spot due to a signal is then a straight line from the origin in a direction corresponding to the direction from which the signal arrived.



Q. 4. In an audio frequency amplifier the valve has an internal impedance of 30,000 ohms and an amplification factor of 40. It is coupled to the succeeding stage by a transformer having a ratio of 1 : 3 and a primary inductance of 30 henries. The secondary load is a resistance of 500,000 ohms.

Neglecting the internal capacitances of the valve and the self *capacitance, resistance and leakage of the transformer, what will be the amplification for frequencies of 100 and 10,000 cycles per second ?*

A. 4. The circuit and its equivalent circuit are shown in sketch (a).



(a)

Referring to the notation shown in the sketch $\mu = 40$, $Rp = 30{,}000$ ohms, $L = 30$ henries, $R_2 = 500{,}000$ ohms.

Also $Re = \frac{500{,}000}{9} = 55{,}555$.

The load impedance on the valve at 100 c.p.s. is given by

$$Z \underline{/\phi} = \frac{1}{A} \underline{/\phi}$$

where $$A \overline{\backslash\phi} = \sqrt{\frac{1}{\omega^2 L^2} + \frac{1}{R_e^2}} \;\overline{\backslash \tan^{-1} \frac{R_e}{\omega L}}$$

$$= \sqrt{\frac{1}{39 \cdot 4 \times 10^4 \times 900} + \frac{1}{30 \cdot 8 \times 10^8}} \;\overline{\backslash \tan^{-1} \frac{55{,}555}{628 \times 30}}$$

$$= \sqrt{\frac{1}{354 \cdot 6 \times 10^6} + \frac{1}{30 \cdot 8 \times 10^8}} \;\overline{\backslash \tan^{-1} 2 \cdot 95}$$

$$= \sqrt{2 \cdot 82 \times 10^{-9} + 3 \cdot 25 \times 10^{-10}} \;\overline{\backslash 71^\circ\, 17'}$$

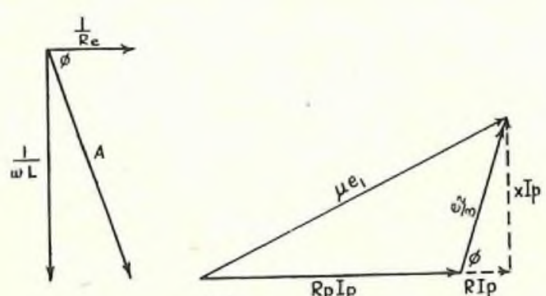
$$= \sqrt{31 \cdot 45 \times 10^{-10}} \;\overline{\backslash 71^\circ\, 17'}$$

$$= 5 \cdot 6 \times 10^{-5} \;\overline{\backslash 71^\circ\, 17'}$$

whence

$$Z \underline{/\phi} = 1 \cdot 785 \times 10^4 \;\underline{/ 71^\circ\, 17'}$$

If I_p is the magnitude of the plate current vector, from the voltage vector diagram for the equivalent circuit (sketch (b)),



(b)

$$\frac{e_2}{3} = ZI_p$$

$$\text{and } \mu e_1 = \sqrt{X^2 + (R_p + R)^2} \times I_p$$

$$\text{hence } \frac{e_2}{3} \times \frac{1}{\mu e_1} = \frac{Z\, I_p}{\sqrt{X^2 + (R_p + R)^2} \times I_p}$$

$$\text{and } \frac{e_2}{e_1} = 3\,\mu \times \frac{Z}{\sqrt{X^2 + (R^p + R)^2}}$$

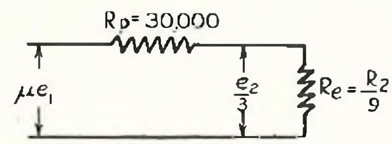
$$\text{and } X = 1 \cdot 785 \times 10^4 \sin 71^\circ\, 17'$$
$$= 1 \cdot 785 \times 10^4 \times \cdot 9471$$
$$= 1 \cdot 694 \times 10^4$$
$$X^2 = 2 \cdot 86 \times 10^8$$
$$R = 1 \cdot 785 \times 10^4 \cos 71^\circ\, 17'$$
$$= 1 \cdot 785 \times 10^4 \times \cdot 3209$$
$$= 0 \cdot 573 \times 10^4$$
$$R + R_p = 0 \cdot 573 \times 10^4 + 3 \times 10^4$$
$$= 3 \cdot 57 \times 10^4$$
$$\frac{e_2}{e_1} = \frac{3 \times 40 \times 1 \cdot 785 \times 10^4}{\sqrt{2 \cdot 86 \times 10^8 + 12 \cdot 75 \times 10^8}}$$
$$= \frac{120 \times 1 \cdot 785}{3 \cdot 96}$$
$$= 54 \cdot 1$$

which is the amplification for 100 cycles per second.

When $f = 10{,}000$ cycles per second

$$\omega = 6 \cdot 28 \times 10^4$$
$$\omega L = 6 \cdot 28 \times 10^4 \times 30$$
$$= 18.84 \times 10^5$$
$$\frac{1}{\omega L} = 5 \cdot 31 \times 10^{-7}$$
$$\left(\frac{1}{\omega L}\right)^2 = 28 \cdot 3 \times 10^{-14}$$
$$\frac{1}{R_e} = \frac{1}{55{,}555} = 1 \cdot 8 \times 10^{-5}$$
$$\left(\frac{1}{R_e}\right)^2 = 3 \cdot 24 \times 10^{-10}$$

Hence the shunt susceptance of the primary may be neglected in comparison with the equivalent load resistance and the equivalent circuit is that shown in sketch (c).



(c)

$$\text{and } \mu e_1 = (R_p + R_e) I_p$$
$$\frac{e_2}{3} = R_e I_p$$
$$\frac{e_2}{3} \times \frac{1}{\mu e_1} = \frac{R_e\, I_p}{(R_p + R_e)\, I_p}$$
$$\frac{e_2}{e_1} = \frac{3\mu \times R_e}{R_p + R_e}$$
$$= \frac{3 \times 40 \times 55{,}555}{30{,}000 + 55{,}555}$$
$$= 77 \cdot 8$$

which is the amplification at 10,000 cycles per second.

Q. 5. *A high frequency open wire transmission line has a distributed capacitance of $0 \cdot 02\, \mu F$ per mile and a distributed inductance of $7 \cdot 2\, mH$ per mile. What is the characteristic impedance of the line ?*

Find suitable dimensions of a quarter-wave matching line to match this transmission line to a load of 200 ohms.

A. 5. The characteristic impedance Z of a high frequency transmission line is given by

$$Z = \sqrt{\frac{L}{C}} = \sqrt{\frac{7 \cdot 2 \times 10^{-3}}{0 \cdot 02 \times 10^{-6}}}$$
$$= \sqrt{3 \cdot 6 \times 10^5} = 600 \text{ ohms.}$$

For a quarter-wave matching where Z_L is the impedance of the quarter-wave line, and Z_S and Z_R are the impedances connected at the ends of this line a perfect match will occur when $Z_L^2 = Z_S Z_R$

$$Z_L = \sqrt{Z_S Z_R}$$
$$= \sqrt{600 \times 200}$$
$$= 346 \cdot 4 \text{ ohms.}$$

The impedance of an open wire line is given by

$$Z_L = 276 \log_{10} \frac{2D}{d} \text{ ohms}$$

where D = conductor spacing
d = conductor diameter.

In this case

$$346 \cdot 4 = 276 \log_{10} \frac{2D}{d}$$

$$\frac{346 \cdot 4}{276} = 1 \cdot 256 = \log_{10} \frac{2D}{d}$$

hence $\frac{2D}{d}$ = antilog 1·256

$$= 18 \cdot 03$$

$$\frac{D}{d} = 9 \cdot 015$$

If the conductor is ½ inch copper tube

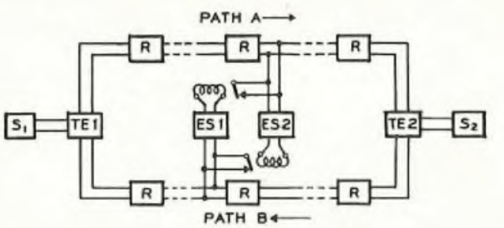
d = ·5
D = 9·015 × ·5
= 4·5075 inches.

Q. 6. *Explain briefly the functions and principles of operation of three of the following.*

(a) *Echo suppressor.*
(b) *Singing suppressor.*
(c) *Compandor.*
(d) *Volume indicator.*
(e) *Delay circuit.*

A. 6. (a) *Echo Suppressor.*

In a 4-wire telephone circuit such as that shown in sketch (a), owing to imperfections of the terminal balance and to reflections at S_1 and S_2, a proportion of speech energy passing



S1, S2 SUBSCRIBERS' APPARATUS.
TE1, TE2 TERMINAL HYBRIDS & BALANCE NETWORKS.
R REPEATER.
ES1, ES2 ECHO SUPPRESSORS.

(a)

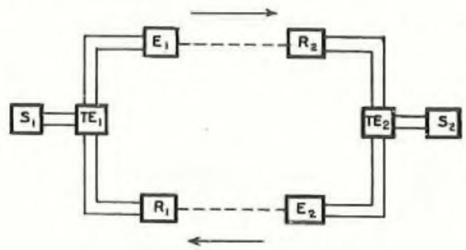
from S_2 to S_1 through the normal path B, is transmitted via TE1, path A, and TE2, to S_2, where it is heard as an echo, if the overall transmission time of the circuit is sufficiently long. Similarly a portion of the returned energy is passed via TE2 and path B to TE1 and S_1 where it is again heard as an echo but with a greater time lag, and so on. If the total loss round the circuit comprising TE1, path A, TE2 and path B, is less than the total gain, successive echos are produced with the echos of higher order progressively attenuated. In such a circuit echo suppressors are employed to prevent re-transmission along one path, of energy received along the other.

The suppressors may take the form shown in sketch (a), of amplifiers bridged across each line; the output of each amplifier is rectified to operate a relay which in turn short-circuits the opposite line. The operating time must be such that following commencement of speech the return path is blocked before arrival of the first echo, and after arrival of the first echo following cessation of speech, at the point where the return suppressor is connected.

As an alternative to relays which short-circuit the lines, blocking may be effected by using the output of the suppressor amplifier-detector fed from one line to bias the valves in an amplifier in the other line so that they present a large loss in series in the line.

(b) *Singing Suppressor.*

In a 4-wire telephone circuit equipped with echo-suppressors, such as that shown in sketch (a), if the net gain round the loop including A and B paths and the terminal equipments, is positive, then when neither subscriber is speaking, the circuit is liable to sing, the echo-suppressors opening and closing the circuit intermittently under the influence of the



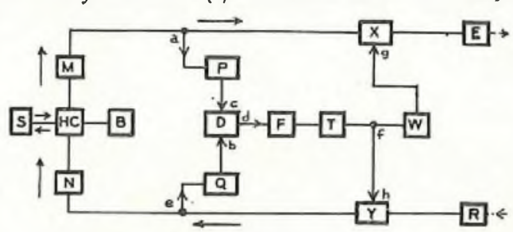
S1, S2 SUBSCRIBERS' CIRCUIT.
TE1, TE2 TERMINAL EQUIPMENT
E1, E2 RADIO EMITTERS
R1, R2 RADIO RECEIVERS

(b)

singing currents. A radio telephone circuit of similar form (sketch (b)) is operated with positive gain in the loop referred to; moreover, if the same frequency is employed for emission at each end, loop circuits of high gain exist from E1 to R1 and R1 to E1 via TE1 with a similar loop at the other end of the system.

Echos and singing are suppressed in such a circuit by the use of two interlocked suppressors at each end, one in each path.. In the normal condition both emitting paths are blocked and both receiving paths are clear; speech from one end clears the required emitting path and blocks the near receiving path.

One method of achieving the above result is shown schematically in sketch (c). With reference to the symbols



S SUBSCRIBERS' CIRCUIT
HC HYBRID COIL
B BALANCE NETWORK
M,N REPEATERS
P,Q AMPLIFIERS
D DIFFERENTIAL BALANCE
F AMPLIFIER
T RECTIFIER
W AUXILIARY SUPPRESSOR
X,Y SUPPRESSOR "AMPLIFIERS" HAVING ZERO GAIN IN CLEAR CONDITION & 100db LOSS IN BLOCKED CONDITION.
E EMITTER
R RECEIVER

(c)

shown in the sketch the operation is essentially as follows:

(1) With no speech from either end, the go path is blocked at X and the return path is clear.

(2) When the near subscriber (S) speaks a small portion of the speech energy is divided at (a) to the amplifier P, through D and F to the rectifier T. The output from T in a resistance-capacitance combination spplies a slowly rising negative voltage to bias the valves of Y and so to block the return path. Immediately after, a higher voltage is applied to W and results in the removal of the suppressing bias normally applied to the valves of X, and so clears the go path. On cessation of speech from S the fall of voltage at f first causes X to be blocked and then Y to be cleared.

(3) When the distant subscriber speaks an input is applied from e to Q and so to b where rectification takes place and

the rectified current is employed in D to prevent operation of the suppressor by current from " a " in the go path.

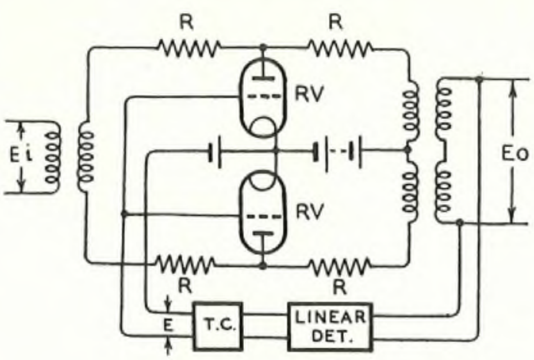
On cessation of speech from the distant subscriber a resistance-capacitance circuit associated with the rectifier at b causes the bias to fall sufficiently slowly to avoid false operation to the emitting condition due to echos from S. This delay is variable to suit varying conditions of the circuit to S. The gain of Q is also variable to suit varying levels of noise received from R; such noise must not be amplified by Q to such a degree as to prevent speech passing from " a " through D to set up the emitting condition, while Q must have sufficient gain to ensure that D is locked against input from " a " when speech is incoming from R.

(c) *The Compandor.*

The Compandor system is used in a radio telephone circuit to improve the signal to noise ratio during periods when the speech energy from the speaker is low.

The signal to noise ratio at the receiver under given conditions is dependent on the degree of modulation of the emitter, and is best when the emitter is fully modulated. By manual adjustment at the terminal position to allow for differing types of speaker and for differing line connections, it is practicable to reduce the amplitude range to that experienced between weak and strong syllables in normal speech, which range is of the order of 30 db.

The compandor is used to reduce still further the range of modulation depth. It consists of two parts, the compressor at the sending terminal and the expander at the receiving terminal. The compressor reduces the range of modulation at the emitter to about 15 db. so that the emitter is more deeply modulated by the weaker syllables than if no compressor were used. The circuit of a compressor is shown in sketch (d), and is a variable attenuating network arranged to



(d)

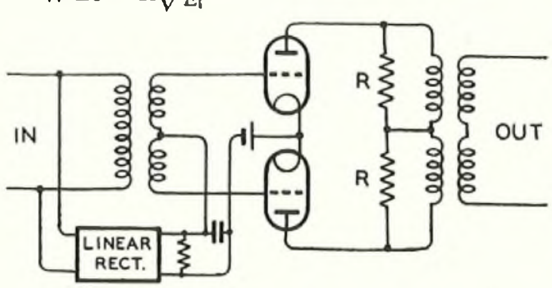
give an output voltage proportional to the square root of the input voltage. The network comprises series resistances R and two valves RV forming variable shunt resistors. The resistances of RV are inversely proportional to the voltage E fed back from the output through a linear rectifier and applied to the grid-filament circuit of RV. Using the notation of the sketch,

$$E_o = K_1 E_i R_v$$

$$R_v = \frac{1}{K_2 E} = \frac{1}{K_3 K_2 E_o}$$

$$\therefore E_o = \frac{K_1 E_i}{K_3 K_2 E_o}$$

$$\therefore E_o = K\sqrt{E_i}$$



(e)

K_1, K_2, K_3, K, are constants depending upon the details of the circuit design.

The time constant circuit TC is proportioned to allow the compressor to work at syllabic frequency.

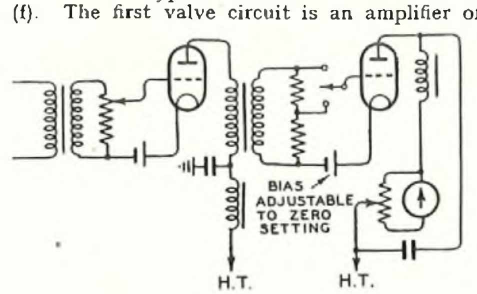
The expander used at the receiving end to restore the amplitude range to its original extent, is a variable gain amplifier. The gain is made proportional to the input amplitude by means of bias voltage taken from the output of a linear rectifier, the input of which is in parallel with the input to the expander. The circuit is shown in sketch (e). The resistors R assist in securing the correct relationship between input amplitude and gain throughout the speech frequency band; the use of a push-pull arrangement avoids the presence of even harmonics in the output.

(d) *Volume Indicator.*

The function of a volume indicator is to provide a check on the mean speech level at any part of a transmission system. It consists essentially of a voltmeter preceded by an amplifier and calibrated attenuator, bridged across the circuit where the level is to be checked.

The requirements to be fulfilled are as follows:—The input impedance must be high to avoid bridging losses and any appreciable variation of this loss over the range of level and frequency involved; the frequency response must be level over the speech frequency range; the design of the circuit and indicating meter including the inertia and damping of the latter must conform to arbitrary standards so that the meter response to speech currents is conveniently rapid.

The circuit of a typical volume indicator is shown in sketch (f). The first valve circuit is an amplifier of high



(f)

input impedance, and variable gain provided by the potentiometer across the secondary of the input transformer. The potentiometer is calibrated in steps of one or two db. as required. The resistance taps across the secondary of the intervalve transformer may be selected by a key to give further variation in gain in larger steps. The second valve is a detector, the anode current of which is indicated by the meter.

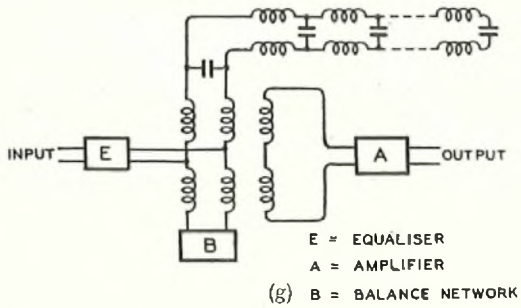
The instrument is calibrated at a suitable frequency within the speech range, the calibrating frequency level being set to the reference value (e.g. 1 milliwatt in the impedance of the circuit in which the indicator is to be used), and with gain controls set to show zero level the grid bias of the detector valve is adjusted to show zero on the meter (usually at approximately mid scale). By variation of the gain control above and below the zero setting the meter may be calibrated to read small variations of level (e.g. ± 2 db.) directly, and the sensitivity of the meter may be adjusted to maintain this calibration by means of the tapped shunt resistor. In use the gain is varied to maintain a zero level indication on the meter, when the input volume level above or below reference is given by the setting of the gain controls.

(e) *Delay Circuit.*

A delay circuit may be employed in radio telephone equipment interposed between the feed point to a voice-operated device and subsequent apparatus in the main circuit, to ensure completion of the voice-operated function before the speech currents reach the later parts of the main circuit. For example, one type of terminal equipment includes voice-operated anti-singing devices incorporating relays. In order to avoid the use of unduly sensitive relays susceptible to false operation by noise, these have an appreciable operating time. A delay network is inserted in the speech path and delays the transmission until the device has had time to operate, thus avoiding clipping of the outgoing speech.

A further example of the use of a delay network is in quiescent carrier systems where a delay network is interposed in the speech current path between the carrier "keying" circuit and the modulating equipment.

The delay circuit may be a low pass filter (or artificial loaded line) inserted in the line. In order to reduce the number of sections required, the delay circuit may be arranged as in sketch (g). In this arrangement the number of sections



(g)

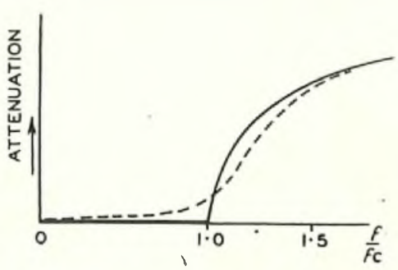
is halved by employing reflection from the open circuit termination of the delay network back into the hybrid; the hybrid is arranged to balance out current from the input end but to pass on the reflected current to the output circuit. The equaliser is to compensate for the frequency-attenuation characteristics of the delay network and the amplifier to compensate for losses in the network and due to the hybrid arrangement.

Q. 7. *What is the effect of resistance in modifying the performance of wave filters?*

What are the conditions determining the transmitting ranges and attenuating ranges of a wave filter?

A single T network having $Z_1/2$ as the value of the shunt impedance, is terminated with an impedance Z_K. It is required that the input impedance must also be Z_K. Find Z_K in terms of Z_1 and Z_2.

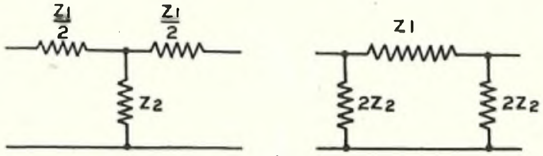
A. 7. The effect of resistance in modifying the performance of wave filters may be illustrated by the example of a low pass filter for which typical attenuation-frequency curves are given in sketch (a). The full line curve is for an ideal filter in which



(a)

there is no loss in the elements and the broken line curve is for the practical case in which resistance losses occur. It is seen that the sharpness of cut-off is reduced by resistance; the filter introduces some attenuation in the pass band and the attenuation is modified beyond the frequency of cut-off.

In a wave filter, if P is the propagation constant, A the attenuation constant and B the phase constant, $P=A+jB$, and within the transmitting range A is zero. Hence for a given transmitting range the elements must be arranged and proportioned so that the real part of the propagation constant is zero over this range. For example, in a T or π network



(b)

sketch (b), $\sinh P/2 = \sinh (A+jB)/2 = \sqrt{Z_1/4Z_2}$ Within the transmitting range $A = 0$.

$$\therefore \sinh \frac{jB}{2} = \sqrt{\frac{Z_1}{4Z_2}}$$

$$j \sin \frac{B}{2} = \sqrt{\frac{Z_1}{4Z_2}}$$

$$-\sin^2 \frac{B}{2} = \frac{Z_1}{4Z_2}$$

Therefore, within the transmitting range $Z_1/4Z_2$ lies between 0 and -1, and from the equations $Z_1/4Z_2=0$ and $Z_1/4Z_2 = -1$ the limits of the transmitting range may be found in terms of Z_1 and Z_2.

Applying this, for example, to a low pass filter sketch (c), we have

$$Z_1 = j\omega L_1$$

$$Z_2 = \frac{1}{j\omega C_2}$$

$$\frac{Z_1}{4Z_2} = \frac{\frac{j\omega L_1}{4}}{\frac{1}{j\omega C_2}} = \frac{-\omega^2 L_1 C_2}{4}$$

the limits of the transmitting range f_1 and f_2 are given by

$$\frac{-\omega_1^2 L_1 C_2}{4} = 0$$

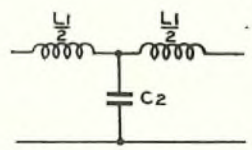
$$\text{whence } f_1 = 0$$

$$\frac{-\omega_2^2 L_1 C_2}{4} = -1$$

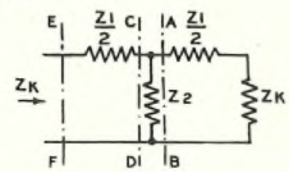
$$(2\pi f_2)^2 = \frac{4}{L_1 C_2}$$

$$2\pi f_2 = \frac{2}{\sqrt{L_1 C_2}}$$

$$f_2 = \frac{1}{\pi \sqrt{L_1 C_2}}$$



(c)



(d)

Using the notation of sketch (d),

$$Z_{AB} = \frac{Z_1}{2} + Z_K$$

$$Z_{CD} = \frac{Z_2\left(\frac{Z_1}{2} + Z_K\right)}{Z_2 + \frac{Z_1}{2} + Z_K}$$

$$\text{and } Z_{EF} = Z_K = \frac{Z_1}{2} + Z_{CD}$$

$$= \frac{Z_1}{2} + \frac{Z_2\left(\frac{Z_1}{2} + Z_K\right)}{Z_2 + \frac{Z_1}{2} + Z_K}$$

$$= \frac{\frac{Z_2 Z_1}{2} + Z_2 Z_K + \frac{Z_1}{2}\left(Z_2 + \frac{Z_1}{2} + Z_K\right)}{Z_2 + \frac{Z_1}{2} + Z_K}$$

$$Z_K Z_2 + \frac{Z_K Z_1}{2} + Z_K^2 = \frac{Z_2 Z_1}{2} + Z_2 Z_K + \frac{Z_1 Z_2}{2} + \frac{Z_1^2}{4} + \frac{Z_1 Z_K}{2}$$

$$Z_K^2 = \frac{Z_2 Z_1}{2} + \frac{Z_1^2}{4} + \frac{Z_1 Z_2}{2}$$

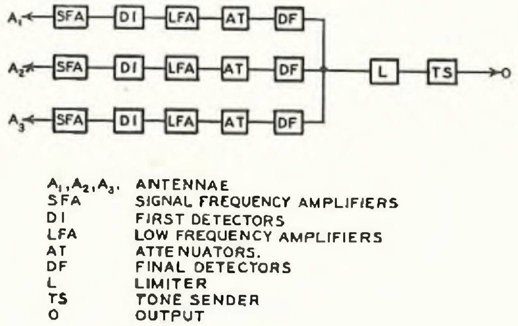
$$= \frac{Z_1^2}{4} + Z_1 Z_2$$

$$Z_K = \sqrt{\frac{Z_1^2}{4} + Z_1 Z_2}$$

Q. 8. Describe two methods of diversity reception suitable for short-wave telegraphy. Indicate the merits and demerits of each method.

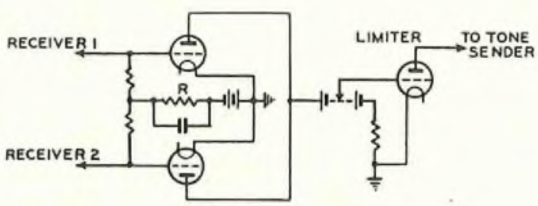
A. 8. Rapid fading of short-wave signals is found to be localised to the extent that when a deep fade is experienced at one point, at another a few wavelengths away the field may be maintained at a high value. By combining the outputs from two or more antennæ situated several wavelengths apart, the effect of fading in the final output of a receiver may be minimised.

One method by which the signals received on the several antennæ may be combined is shown in the block diagram of sketch (a). Complete receivers are associated with each



(a)

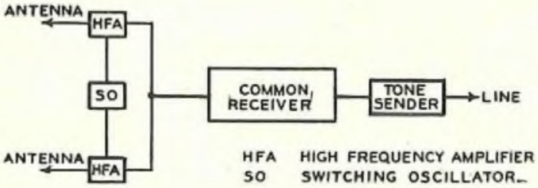
antenna and their final detector outputs all combine to produce a voltage across a common output resistance. This voltage is employed to key a tone generator which, provided the combined outputs give a voltage in excess of a limiting minimum, sends tone to the output line at constant level. This method is expensive since more than one complete receiver is required. It suffers also from the disadvantage that at any instant one or more of the receivers may be experiencing a deep fade and so contributes nothing to the signal output, but it still contributes noise. Also, if one receiver is experiencing selective fading with consequent distortion, this distortion appears in the output. A refinement which minimises the ill effect of the receiver experiencing weak fields is shown in sketch (b). A grid



(b)

resistor R, common to the final detector grid circuits, carries a current depending upon the sum of the signals received on the several antennæ if these are sufficient to produce grid current in the respective detectors. Thus the effect of R is to limit the final detector output current of receivers experiencing strong fields and to bias towards or beyond cut off, the final detectors of receivers experiencing weak fields.

A cheaper method of combining the signals from two antennæ is shown in sketch (c). The signals are fed to



(c)

separate high frequency amplifiers and arrangements are made to suppress each amplifier alternately so that their outputs are in effect switched alternately to the high frequency amplifier of a common receiver. The "switching" is effected by varying the grid bias of the first high frequency amplifiers by means of tone currents from an oscillator of frequency high enough to make each antenna effective once during each dot of signal. The consequent modulation of the signal necessitates a greater band width and hence a higher noise level in the receiver, or if the modulation frequency is kept very low, the speed at which signals may be received is limited. A switching frequency of the order of 300 cycles per second is used in practice.

This system is generally applied to two antennæ only and is less effective than methods using complete receivers with arrangements to select the output due to the strongest field, particularly under conditions of generally low field strength.

Q. 9. The aerial at a transmitting station has an effective height of 150 metres and the current at the base is 700 amperes at 16,000 cycles per second. What is the power radiated?

If the capacitance of the antenna is 0·04 microfarad, what is the voltage across the lead-out insulator?

Give a sketch and brief description of a suitable lead-out insulator for such a station.

A. 9. For an antenna with a large flat top operated at a wavelength long compared with the antenna height, if P is the power radiated in watts and h/λ is the ratio effective height/wavelength and I amperes the R.M.S. current at the base of the antenna we have,

$$P = 1{,}584 \frac{h^2}{\lambda^2} I^2$$

in the case given

$$= 1{,}584 \left(\frac{150}{18{,}750}\right)^2 700^2$$

$$= 1{,}584 \times (8 \times 10^{-3})^2 \times 49 \times 10^4$$

$$= 1{,}584 \times 64 \times 10^{-6} \times 49 \times 10^4$$

$$= 49{\cdot}7 \times 10^3$$

$$= 49{\cdot}7 \text{ kilowatts}$$

Assuming the aerial to be a concentrated capacitance in series with the loss and radiation resistances and all inductance (L) concentrated in the loading below the lead-out insulator, we have

$$V = \omega LI = \frac{I}{\omega C}$$

$$= \frac{700}{2\pi \times 16 \times 10^3 \times {\cdot}04 \times 10^{-6}}$$

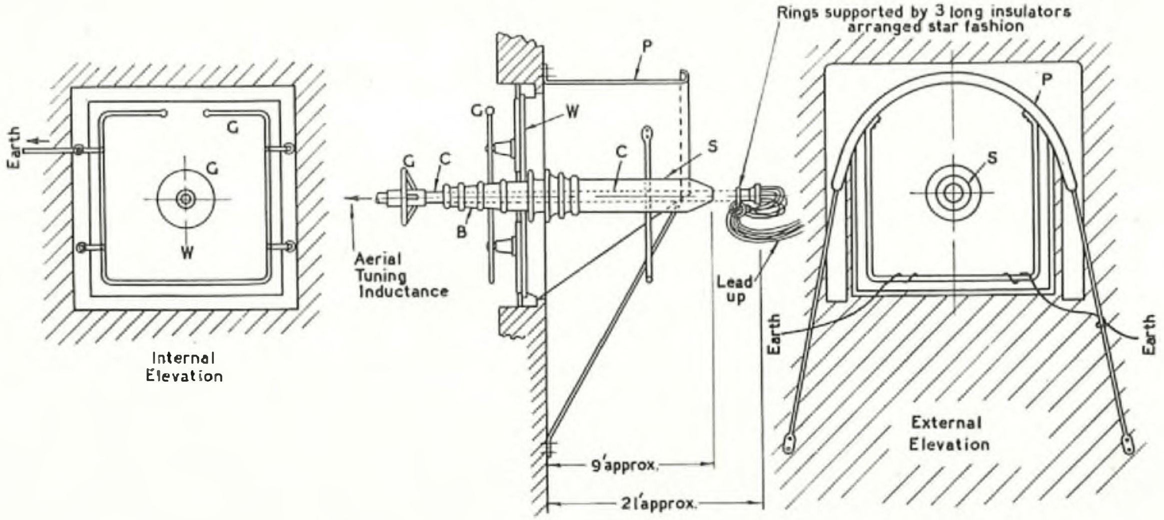
$$= \frac{7 \times 10^7}{2\pi \times 16 \times 4}$$

$$= \frac{7 \times 10^7}{128\pi}$$

$$= 174{,}200 \text{ volts.}$$

Actually the voltage will be less than this since owing to the inductance Lo of the aerial, ωL will be less than $1/\omega C$.

The sketch shows three views of a lead-out insulator suitable for such a station. It is seen to consist of a plate-glass window W, to which is bolted a porcelain bush B, which projects inside and outside and carries the lead-out conductor of copper tube C. Guard rings G,G, are fitted inside the window frame (this one is split to avoid induced circulating current) and round the conductor tube C. A sheet-metal cowling P protects the glass from rain and sleet or snow, and to minimise corona discharge between the tube C and the cowling; the effective diameter of the former is increased by a cylindrical sheath of sheet-metal S. An external guard ring is provided for the window frame, the upper half merging with the cowling. The stranded wires of the aerial lead are bunched into a flange at the end of the tube and sweated to it. These wires are allowed to hang loosely between the lead-out insulators and a support several feet away from the window.



This support is formed by three porcelain insulators arranged in star formation on a steel framework. In this manner the main lead-out insulator and the window on which it is mounted are relieved of mechanical stress due to the tension in the lead-out wires.

Q. 10. *Describe with diagrams how a single side band radio telephone transmission is produced.*

State how improvements in transmission due to single side-band working are distributed :

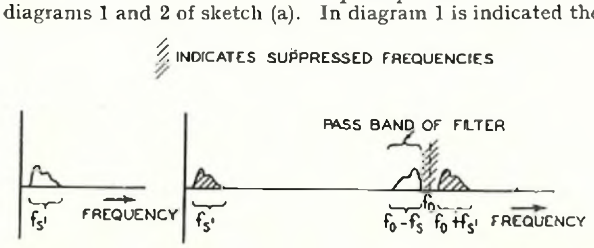
(a) *At the transmitter.*

(b) *At the receiver.*

What is the theoretical improvement in each case in decibels ?

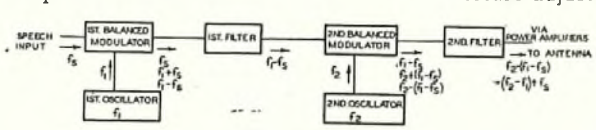
What difficulties arise in applying single side-band working to short-wave services, and how can they be overcome ?

A. 10. A single side-band transmission is produced by modulating a carrier by speech and suppressing the carrier and one side-band. The basic principle is illustrated in diagrams 1 and 2 of sketch (a). In diagram 1 is indicated the



(1) (a) (2)

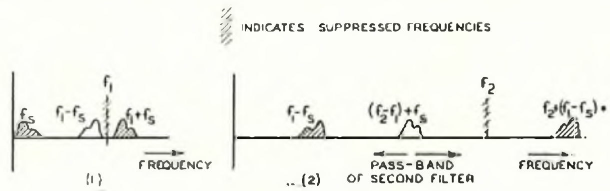
speech band of frequencies fs, and in diagram 2 the modulation products comprising upper and lower side-bands, $fo+fs$ and $fo-fs$, the carrier frequency fo, and the speech frequencies fs (higher order products are present but are not shown), all of which with the exception of one side-band (in this case $fo+fs$) are suppressed by filtering. The carrier fo and certain other unwanted products may be suppressed also by the use of a balanced modulator. In order to obtain easily adequate discrimination in the filters and to secure adjust-



(b)

ment of the radiated frequencies, a double modulation process is used. The apparatus required is shown in the block diagram of sketch (b), and the frequency changes involved are shown in diagrams 1 and 2 of sketch (c). The second filter now has to discriminate between frequency bands which are widely separated and can therefore be wide enough to accommodate some adjustment of the position of the transmitted band in the spectrum. The final frequencies are given by $(f_2-f_1)+fs$, and by adjustment of f_2 this transmitted band can be shifted.

The improvement in transmission due to single side-band working may be obtained by considering the application of



(c)

firstly double side-band, and secondly single side-band to the final stage of a transmitter in which the output is limited by the maximum permissible peak anode voltage.

(1) *Double Side-band.* Assuming 100 per cent. modulation, let V be the peak carrier voltage. Then the peak voltage when modulated is 2 V, and the amplitude of the side-bands in the received wave will be proportional to V/2 since the equation to the modulated wave can be written

$$V = V \sin pt + V/2 \cos (p-\omega)\, t - V/2 \cos (p+\omega)\, t$$

If there is no distortion in the transmission path the side-bands will add in phase with the result that the receiver output is proportional to $V/2+V/2$ or V.

(2) *Single Side-band.* If the same limit of peak voltage applies, the amplitude of the received single side-band is proportional to 2 V.

The relationship between the respective signal outputs is therefore 2 V/V or 2, or in decibel notation $20 \log_{10}2 = 20 \times \cdot 301$ or 6 decibels approximately. That is, due to transmitter conditions single side-band working effects an improvement of 6 decibels.

At the receiver the band width with the double side-band must be approximately twice as wide as with the single side-band, hence the output of noise energy with the former will be twice that with the latter, giving a further improvement in signal to noise ratio of 3 db.

In transmission conditions in which with double side-bands, the side-bands are received in random phase, the improvement may be augmented by a further 3 db.

In a given circuit the advantage may be employed to improve the signal-to-noise ratio, or to give approximately the same signal-to-noise ratio over the same working period with considerable saving of power and valve costs at the transmitter. A further saving of power is effected (and may be considerable when full power is used) since no power is emitted using the single side-bands (if complete carrier suppression is employed) between periods of speech emission. Further advantages at the receiver include reduction of the effect of certain types of fading since the constancy of the re-supplied carrier gives improved signal-to-noise ratio during deep fading.

The main difficulties associated with the application of single side-band working to short-wave services may be enumerated as follows :

(1) The constancy of the re-supplied carrier measured in cycles per second requires to be the same for both short- and long-wave transmission, about ± 15 cycles per second difference from the original suppressed carrier being the limits for tolerable speech. The percentage variation permissible with short waves is therefore much smaller than with the long waves.

(2) With short-wave transmission fading of the pilot frequency may be experienced and control of the re-supplied carrier frequency must be maintained during such periods of fading.

(3) It is more difficult with short waves to filter out the unwanted frequencies.

(4) Complete carrier suppression with short waves leaves no means of automatic gain control of the receiver. If the carrier is partially suppressed or a special pilot frequency is used for auto gain control and synchronisation of carrier, the auto-gain function may be lost by selective fading of the control frequency.

The methods of overcoming the above difficulties are as follows :

(1) The carrier is not completely suppressed or a separate pilot frequency near to the speech band is transmitted and used at the receiver to synchronise the oscillator which provides the re-supplied carrier. The carrier frequency, if used, may be partially suppressed to give peak voltages in the emitter about 20 db. below the peak voltage in the side-band.

(2) The controlling circuit is arranged to have a large time constant.

(3) Modulation may be effected in three stages and crystal filters employed.

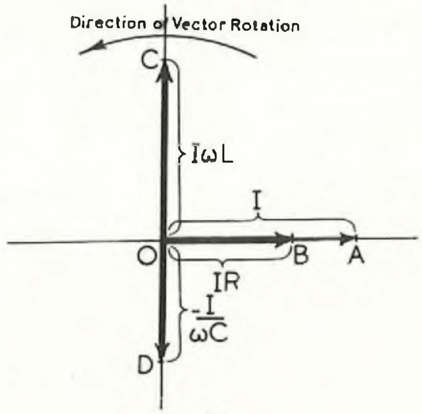
(4) The pilot frequency is used to provide automatic gain control in addition to synchronising the re-supplied carrier.

TELEGRAPHY—FINAL, 1937.

Q. 1. *A circuit containing capacitance C, inductance L and resistance R, all in series, is connected to an alternating supply of E.M.F. E. Derive an expression for the current in the circuit and give its value when C = 100 microfarads, L = 2 henries, R = 100 ohms, E = 1,400 volts and the supply frequency is $100/2\pi$ cycles per second.*

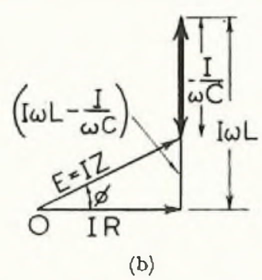
A. 1. Suppose the current in the circuit is I amperes. Then considering the voltage drops across the resistance, inductance and the capacitance, these when added vectorially must equal the E.M.F. applied to the circuit in magnitude and phase.

It may be proved that an alternating current I of frequency ω radians/sec. when flowing through a pure resistance R, produces a voltage drop equal to IR in phase with the current. For an inductance L the voltage drop is equal to $I\omega L$ at an angle 90° ahead in phase of the current ; whereas for a capacitance C the voltage drop is $I/\omega C$ at an angle 90° lagging in phase with respect to the current.



(a)

Sketch (a) indicates the current and voltage vectors in magnitude and phase relationship and from this may be derived the vector diagram of sketch (b), in which the voltage



(b)

vectors IR, $I\omega L$ and $I/\omega C$ have been added, to obtain the resultant voltage IZ where Z is equal to the impedance of the resistance, inductance and capacitance in series.

IZ must equal the applied voltage E.

$$\text{Thus } E = IZ$$
$$= \sqrt{(IR)^2 + (I\omega L - I/\omega C)^2}$$
$$= I\sqrt{R^2 + (\omega L - 1/\omega C)^2}$$
$$\therefore \quad I = \frac{E}{\sqrt{R^2 + (\omega L - 1/\omega C)^2}}$$

Furthermore the voltage E leads the current by an angle ϕ,

$$\text{where } \phi = \tan^{-1}\left(\frac{I\omega L - I/\omega C}{IR}\right)$$
$$\text{i.e. } \phi = \tan^{-1}\left(\frac{\omega L - 1/\omega C}{R}\right)$$

When C = 100 microfarads
L = 2 henries
R = 100 ohms
E = 1,400 volts

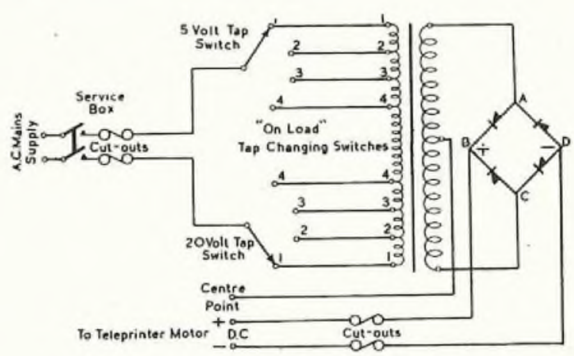
$$\text{and} \quad \omega = 2\pi \times \frac{100}{2\pi} = 100$$

$$\text{Then Current } I = \frac{1,400}{\sqrt{100^2 + \left(100.2 - \frac{10^6}{100.100}\right)^2}}$$
$$= \frac{1,400}{100\sqrt{2}} = \underline{9{\cdot}898 \text{ amperes}}$$

$$\text{Angle of lag of current} = \tan^{-1}\frac{1}{1} = \underline{45^\circ}$$

Q. 2. *Explain with the aid of a diagram how the power supply for a direct current teleprinter motor can be obtained from an alternating current supply.*

A. 2. The sketch indicates the arrangement employed for deriving a direct current power supply from A.C. mains for the operation of a teleprinter motor. The arrangement consists essentially of a full wave copper oxide metal rectifier having two " on-load " tap changing switches to permit adjustment of the D.C. output voltage to 110 volts to suit a range of A.C. mains supply voltages.



The A.C. supply is fed through a service box fitted with cut-outs, to two 4-position switches which are connected to tappings on the primary winding of a mains transformer. One switch permits adjustment of the A.C. input voltage in 20 volt steps, and the second switch permits adjustment in three steps of 5 volts each.

The secondary winding of the mains transformer is connected to points A and C of the copper oxide rectifier bridge ABCD as indicated in the sketch. The properties of a copper oxide metal rectifier are such that it offers a low resistance to current flowing in the direction of oxide to metal but a high backward resistance to current flowing in the direction from metal to oxide.

The nomenclature employed in the sketch for representing rectifier elements is such that AB is of low resistance to positive current in the direction A to B, from which it may be seen that the bridge ABCD operates as follows:

During positive half-waves of A.C., arms AB and DC are of low resistance and AD and BC high.

During negative half-waves of A.C., arms CB and DA are of low resistance but CD and BA are high.

Hence points B and D of the rectifier bridge are respectively + ve and − ve during the complete wave of A.C. and the D.C. power supply for the teleprinter motor is derived from these points via cut-outs.

In the sketch it will be seen that the centre point of the secondary winding of the transformer is brought out to form a neutral point. Normally this point is not required but is provided to enable a double current ± 55 volts supply to be available for signalling purposes for use in special circumstances.

Q. 3. *Describe the steps which are taken to reduce inductive disturbance or crosstalk in* (a) *cables*, (b) *aerial lines.*

A. 3. (*a*) Inductive disturbance or crosstalk in cables is minimised in the first instance by ensuring a high degree of uniformity in construction of the factory lengths of cable. Very close specification limits are set for (*a*) materials used and (*b*) electrical characteristics in respect of conductor resistance, leakance, inductance and capacitance.

The conductor resistance and the capacitance are the most important factors and inequalities must be kept to a minimum. This is done during manufacture by twinning, quadding and stranding, and during laying of the cable capacitance unbalance between circuits is minimised by a process of systematic jointing and/or test selection.

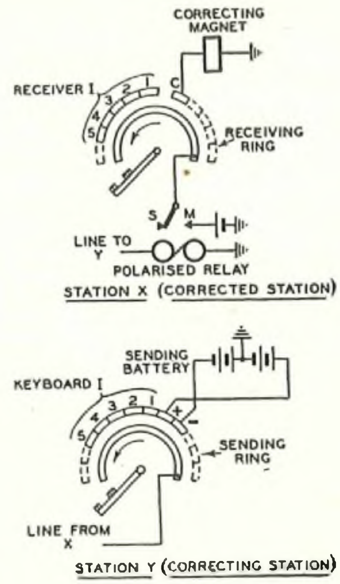
The "twinning" and "quadding" lays used in the manufacture of a cable cause conductors to be continuously transposed in their position relative to other conductors in the cable, and by suitable selection of the "lay" differences in wire-to-wire capacitance may be reduced to small proportions.

When phantom and double phantom circuits are derived from telephone side circuits the transformers used must be accurately differential.

(*b*) On aerial lines, crosstalk is minimised by means of a system of symmetrical twist or a transposition system of crosses. Where a phantom circuit is derived from two side circuits these circuits must be on the same pair of arms and on the same side of the pole. The four wires must also be of the same gauge and material; furthermore, where a transposition is used crosses between the side circuits are necessary. Inductive disturbance from aerial power lines often presents difficulty and in such instances, wherever possible, the relative routings of the power and telephone lines should be such that a minimum length and degree of parallelism exists; also the distance separating the two routes should be as large as possible. Where there is direct current telegraph transmission over either cable or aerial conductors, low pass filters having a cut-off of approximately 120 c.p.s. should be fitted on the line side of all transmitters. Telegraph signalling currents and voltages should also be kept as low as possible particularly where phantom and double phantom circuits are employed.

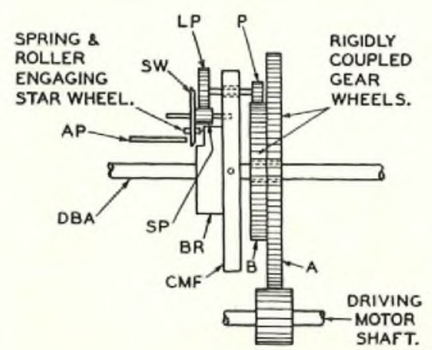
Q. 4. *Explain in some detail the operation of distributor correction in Baudot multiplex working.*

A. 4. Sketch (a) indicates the electrical principles employed for distributor correction in Baudot Multiplex working. Y is the "correcting station" and the speed of its distributor brushes (namely, 180 r.p.m.) is regarded as standard, while the distributor brushes of the "corrected station" X run at approximately 180¼ r.p.m. The distributors at both stations are driven from fractional h.p. electric motors fitted with Mendonca governors. A correcting current is transmitted from two adjacent segments of the sending ring at Y once per revolution of the distributor brush arms and this current is received at X via a special movable segment provided on the receiving ring. The relative positions of the − and + correcting segments at Y and the correcting segment C at X are such that if the brush at Y is on the positive segment and that at X is on C, the two sets of distributor brushes are in phase. If, however, the brush at Y is on the − segment when that at X is on C, then the brush arm at X is ahead in phase of that at Y.



(a)

At station X segment C is connected to earth via a distributor correcting magnet. Hence if the distributor brush arms of the stations X and Y arrive simultaneously at + and C, the correcting magnet at X will not operate because the polarised line relay at X is operated to the space contact which is disconnected. When, however, X is ahead in phase and such that its brush is on C when that at Y is on − segment, then the polarised line relay at X operates to mark and its tongue extends −ve battery to the correcting electromagnet and causes it to operate. The operation of this magnet is caused to produce the desired retardation in phase at station X in the following manner.



B − 96 TEETH.
P − SMALL PINION WHEEL 12 TEETH.
LP − LARGE " " 24 "
SP − STAR WHEEL PINION 12 "
SW − STAR WHEEL 15 "

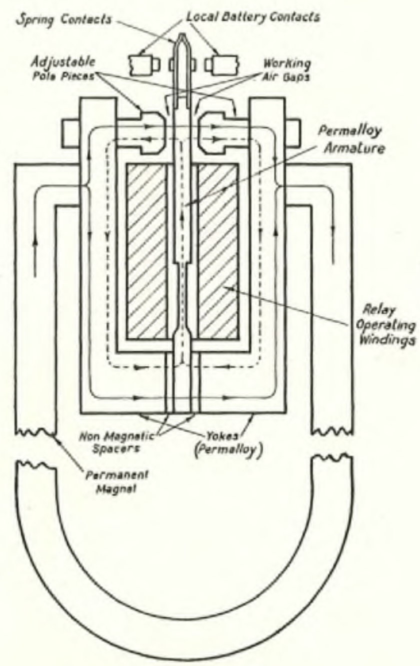
(b)

Sketch (b) indicates the method of driving the distributor brushes at station X. The distributor motor is geared to a main gear wheel A which is rigidly coupled to a second gear wheel B having 96 teeth. A and B are free to rotate on a sleeve fitted on the distributor brush axle (DBA). The correcting mechanism frame (CMF) is screwed to DBA and carries a satellite gear train comprising an axle fitted at one end with a small pinion wheel which engages B and at its other end a large pinion wheel which engages a star wheel pinion which carries a star wheel on its axle. The correcting mechanism frame carries a bridge piece BR to which is screwed a steel blade terminating in a small steel roller which normally rests between two adjacent teeth in the star wheel and exerts sufficient pressure to prevent the star wheel turning. Hence the satellite train is normally locked via the pinion wheels with the gear wheels B and A, and as a result the whole combination rotates at the driving speed of A. When, however, a tooth of the star wheel meets an obstruction its movement is temporarily arrested, the spring blade roller rises and allows the star wheel to turn until the obstruction is cleared. This movement results in a slight phase shift ($1\frac{1}{2}°$) between the correcting mechanism frame and the driving gear wheels B and A. The distributor brushes are thus retarded $1\frac{1}{2}°$ as often as the star wheel turns one tooth.

The obstruction offered to the star wheel teeth is presented by a steel pin AP controlled by the correcting electromagnet. Normally the pin does not engage the star wheel teeth, but when a correcting current flows through the electromagnet its armature forces the pin into the path of the star wheel teeth, causing the star wheel to rotate one tooth. After the star wheel has passed, a cam on the correcting mechanism frame restores the pin to its normal position.

Q. 5. *Describe, with the help of a sketch, the construction of a typical telegraph relay and explain its action, particular attention being paid to the magnetic circuit.*

A. 5. The sketch and the following descriptions refer to the type of telegraph relay employed as a receiving relay in a channel of the standard P.O. multi-channel V.F. system. The function of the relay is to receive rectified V.F. signals from the rectifier valve associated with the V.F. channel and repeat these signals on a double current basis to the receiving telegraph apparatus—usually a teleprinter. The magnetic circuit of the relay consists of a horseshoe-shaped tungsten steel permanent magnet having a L-shaped yoke of permalloy attached to each pole. The bottom of the L yokes serve to clamp one end of a permalloy armature. The armature and yokes are, however, magnetically separated from each other by non-magnetic spacers. The free end of the armature carries two nickel-silver springs and contacts and is free to play between the Mark and Space contacts of the relay which are fixed to a rigid support which also carries the permanent magnet. The armature contact springs are bent at their free ends and tensioned so that they touch and rest upon each other with a fixed pressure. By this construction the mass of the moving end of the armature is kept as small as possible and thus reduces the tendency for contact bounce during operation. The length of the armature is such that it is just long enough to operate between adjustable permalloy pole pieces which are screwed into the tops of the L yokes. A mechanical clamping device is provided for each pole piece.



Enclosing the armature and coaxial with it is a spool on which are wound the operating windings. The spool is rigidly located and such that it just allows free movement of the armature between the pole pieces.

The internal electrical connections to the relay terminate upon a jack-in type relay base to facilitate maintenance.

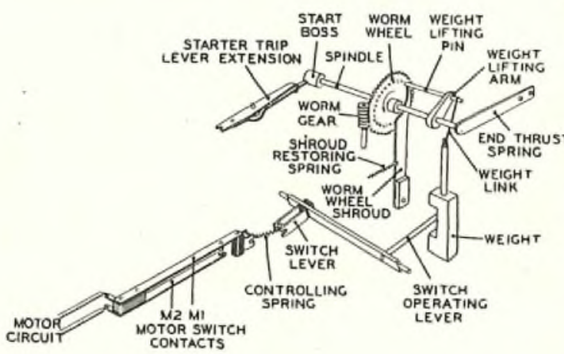
The operation of the relay is as follows :

When no current is flowing in the relay windings and the armature is symmetrically between the pole pieces, then the reluctance of the air gap between the N pole and the armature is the same as that between the S pole and the armature. Hence a balanced flux distribution exists as indicated by the full lines in the sketch, and equal and opposite forces are exerted by the N and S pole pieces on the free end of the armature. The armature therefore remains in equilibrium. If the armature is displaced slightly, say in the direction of the S pole, then the reluctance of the S pole air gap will decrease while that of the N pole air gap increases. A flux is set up through the length of the armature in a direction tending to produce a north polarity at the free end of the armature. The magnetic force exerted on the free end of the armature by the S pole is therefore greater than that exerted by the N pole. The armature therefore tends to operate to the S pole; furthermore, the force increases with the extent of the displacement of the armature from its mean position. This operating force is known as the polarising force.

When a current flows in the operating windings it produces an electromagnetic flux via the armature and the two parallel magnetic circuits formed by the pole pieces and the L-shaped yokes. The direction and distribution of this flux is indicated in the sketch by the dotted lines for a " spacing " operating current. The effect of this flux augments the flux in the S pole air gap and decreases that in the N pole air gap. This produces a magnetic unbalance and the armature operates in the direction of the greater pole gap flux, that is to "space." This action is assisted by the polarising force. Conversely it may be shown that a marking current will cause the armature to operate to the marking contact—again assisted by the polarising force.

Q. 6. *Explain the action of the automatic start-stop switch as fitted to certain teleprinters for controlling the starting and stopping of the motor.*

A. 6. The principle of the automatic start-stop switch of a Teleprinter No. 7 is indicated in the sketch. It depends for its action primarily upon the operation of the armature of the receiving electromagnet of the teleprinter. When a



spacing element of signal is received the movement of the armature of the receiving electromagnet causes a weight to drop and operate the switch controlling the power supply to the teleprinter motor. After a period of approximately 90 seconds during which no spacing elements of signal are received, the weight is lifted and disconnects the power supply from the teleprinter motor. The auto-start device thus enables a teleprinter to receive transmissions without necessitating the attendance of an operator, and furthermore, by disconnecting the motor during idle periods it reduces power consumption and instrument room noise.

The starter spindle is free to move longitudinally through a worm wheel, one end of the spindle carries the starter boss—mounted near the flexible extension of the starter trip lever—which is coupled to the electromagnet armature. The weight-lifting arm is fixed on the spindle at the other end and is coupled by a link to the weight. Fixed at the end of the weight-lifting arm is the weight-lifting pin, which is normally held in engagement in one of a series of holes in the worm wheel by the inward pressure of the end-thrust spring which acts on the spindle.

When the " start " signal, which is in a " spacing " direction, is received, the armature of the electromagnet is moved, causing the spindle of the automatic start-stop device to be thrust against the tension of the thrust spring. By this means the weight-lifting pin is withdrawn from the worm wheel and the weight is allowed to drop forcibly on the switch operating lever. This lever operates the automatic starting switch.

The function of the worm wheel shroud spring is to prevent the weight-lifting pin re-engaging with the worm wheel during the time in which the weight is falling to its lowest position, that is to the left of the bottom of the worm wheel shroud.

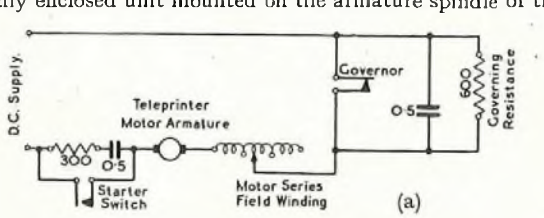
The worm wheel has a gear cut round its edge which engages a worm gear driven by the teleprinter motor. If during a period of 90 seconds no further signals are received—the electromagnet armature remaining on the " marking " stop—then the weight is drawn up by the weight-lifting arm to the position shown in the sketch. By this means the switch operating lever is raised causing the automatic start-stop switch to become disconnected. The worm wheel shroud spring is displaced by the weight-lifting pin as the weight is lifted, but is restored to its normal position by the shroud-restoring spring just before the switch is disconnected and the motor stopped.

Immediately the switch is tripped, the starter trip lever extension is so placed in the notch on the starter boss that the spindle must rotate appreciably before the starter-trip lever extension can again exert an end thrust on the spindle. This arrangement ensures that the mechanical load imposed on the electromagnet by the automatic start-stop switch is only intermittent and the switch does not require to be tripped at the commencement of each signal combination.

Q. 7. *Explain in detail, with the help of sketches, the action of the governor attached to the teleprinter motor.*

A. 7. Teleprinter motors are subjected in operation to conditions of varying mechanical load and fluctuations in mains supply voltage, hence unless some special provision is made the motor speed will vary in sympathy with these variations. For the condition of maximum operating margin it is necessary that the motor speed should be constant and the function of the teleprinter motor governor is to control any speed variations within very fine limits, namely $\pm$ 0·5 per cent.

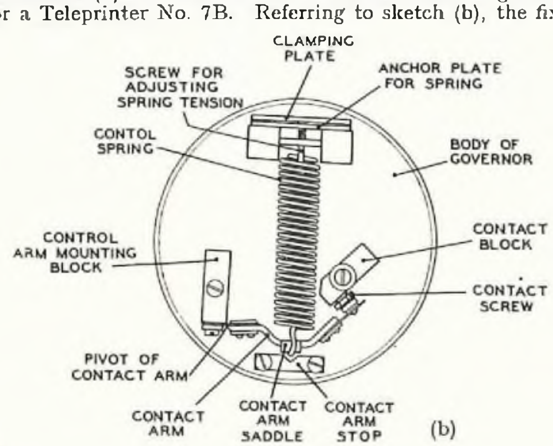
The governor employed is of the centrifugal type and is a totally enclosed unit mounted on the armature spindle of the



(a)

motor. Electrical connections between the governor and motor supply circuit are provided by means of two brushes which make contact with two concentric metallic rings mounted on the back of the governor.

The schematic circuit arrangement is shown in sketch (a) and sketch (b) indicates the mechanical details of the governor for a Teleprinter No. 7B. Referring to sketch (b), the fixed



(b)

contact is carried on a screw by means of which its position may be adjusted and locked as required. The contact arm is pivoted on the edge of a fixed block and is retained in position by a flexible spring; the free end of the contact arm carries a stiff flat spring riveted to it at an angle to the direction of movement of the arm. The flat spring carries the moving contact of the governor. When the governor contacts come together the flat spring bends slightly, and in so doing causes the moving contact to slide over the face of the fixed contact so that any surface irregularities of the contact faces become rubbed down, thus ensuring good contact. This action is known as a " wiping action " and tends to prevent pitting and/or building up of the contacts from the effects of arcing.

When the governor is rotating the contact arm tends to fly out under the action of centrifugal force, but this movement is opposed by the action of the spiral control spring acting upon the contact arm saddle. The speed at which the governor functions is dependent upon the tension in the control spring, and this may be adjusted as required by a screw in the anchor plate.

The action of the governor is as follows :—

When the motor is stationary or below standard speed the governor contacts are closed, thus short-circuiting the governor resistance. When, however, the governor speed increases above the standard speed then the centrifugal force on the contact arm exceeds the tension in the control spring, thus causing the contact arm to move outwards and remove the short-circuit from the governor resistance which is then introduced in series with the armature and field windings of the motor. The motor speed therefore decreases until the governor contacts again close. This action occurs continuously, the governor contacts alternately closing and opening. The speed of the motor, therefore, remains sensibly constant and may be adjusted so that the maximum variation does not exceed $\pm$ 0·5 per cent.

Q. 8. *What is the connection between the speed of transmission of teleprinter signals and the speed at which the teleprinter keyboard is operated ?*

Explain clearly how the speed of transmission of the teleprinter and the number of channels in a voice frequency telegraph systems are related.

A. 8. The telegraphic speed of a teleprinter transmitter is expressed in bauds and is equal to the inverse of the shortest element (expressed in seconds) of teleprinter signal. For teleprinters No. 7A and No. 7B the shortest element is 20 milliseconds, hence the telegraphic signalling speed is equal to 1000/20 = 50 bauds. This speed is constant and is independent of the speed of operating the keyboard. The speed of keyboard operation determines only the rate at which characters are transmitted. Multi-channel voice frequency systems usually operate over normal 4-wire telephone circuits which have an approximately level response over a frequency range 300–2,700 c.p.s. The economic design of a M.C.V.F. system therefore demands that the whole of this available frequency range should be employed in deriving telegraph channels consistent with the practical requirements of stability of working at a specified minimum telegraphic speed. The introduction of M.C.V.F. systems in this country was primarily for the purpose of providing channels of communication suitable for transmission by means of teleprinter instruments. The telegraphic speed of teleprinters is not greater than 50 bauds and the design of the standard P.O. M.C.V.F. system is based upon this requirement. The C.C.I.T. has in fact recommended that systems should be designed capable of transmitting at a speed of 66 bauds in each channel and the P.O. system conforms to this requirement.

For the satisfactory transmission of telegraph signals the communication channel must be capable of transmitting a range of frequencies consistent with the speed of the telegraph transmission required, that is the " baud " speed. Furthermore, when telegraph signals are transmitted by the modulation of a carrier frequency it is desirable that the carrier should build-up to full amplitude within the length of the shortest signal element, otherwise distortion will result from the fact that such signals will only be transmitted with reduced amplitude.

In teleprinter transmission, the " baud " speed is 50 and the shortest element of signal is 20 milliseconds, hence the filters of a M.C.V.F. system should have an effective band-width of not less than 50 c.p.s. and a build-up time of not more than 20 milliseconds.

The build-up time of a band-pass filter can be related to the band width by a simple empirical formula as follows:—

$$t = \frac{1}{f_2 - f_1}$$

where t = the time of build-up of the envelope of the mid-band frequency and f_2 and f_1 are the effective (not theoretical) cut-off frequencies.

Hence it will be seen that for a given telegraphic speed a certain minimum band-width is required, and the effective band-width of the band-pass filters used at the M.C.V.F. terminals to segregate the channels is the factor which controls the maximum number of channels which may be provided from a V.F. circuit.

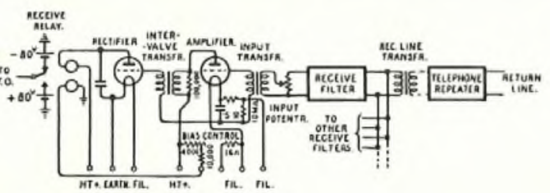
The M.C.V.F. system used by the P.O. has a carrier frequency spacing of 120 c.p.s. and the effective band-width of the filters is approximately 70 c.p.s., giving a build-up time of 14 milliseconds. It is therefore capable of being operated at a speed of 70 bauds with very little distortion.

As already stated normal telephone 4-wire circuits have a range of approximately 300–2,700 c.p.s., so that 18 telegraph channels may be derived using carrier frequencies of:—420, 540, 660, 780, 900, 1,020, 1,140, 1,260, 1,380, 1,500, 1,620, 1,740, 1,860, 1,980, 2,100, 2,220, 2,340, 2,460 c.p.s.

Q. 9. *Explain the operation and give a diagram of connections of a receiving channel of a teleprinter-operated voice frequency telegraph system.*

A. 9. The sketch indicates the connections of a receiving channel of a teleprinter-operated V.F. telegraph system. At the sending end of the channel arrangements are such that V.F. tone is transmitted during marking elements of signal and is suppressed for spacing elements.

Referring to the sketch, the incoming V.F. currents of all channels pass from the receiving terminal repeater to the



primary of a line transformer. The secondary winding of this transformer is connected to the input of the receiving band-pass filters in parallel. The design of the filters is such that each filter offers a low impedance to currents of its particular channel but offers a very high impedance to all other frequencies. The output of the filter is connected to the primary winding of a step-up transformer via a resistance potentiometer which is graduated in steps equivalent to 1 decibel between 0–30 db. limits. The secondary winding of the transformer is connected to the grid circuit of an amplifying valve having a high amplification factor. The amplifier valve is coupled to a rectifying valve by an inter-stage transformer and the output of the rectifying valve passes through the 4-line windings of a receiving telegraph relay (299 AN).

The effect of the received V.F. signals upon the rectifier valve is to cause the anode current to increase or decrease depending whether the signal is a " tone " or " no tone " element. The output of the rectifier valve is thus purely single current, and this necessitates a spacing bias arrangement on the receiving telegraph relay. Bias is obtained by feeding current through the two auxiliary windings of the 299 AN relay from the H.T. anode supply. This method of biasing renders the relay self adjusting to variations in the anode battery voltage.

When marking elements of signal are being received then the rectified current produces a preponderating marking current in the line windings of the 299 AN relay and the tongue of the relay therefore operates to its marking contact. This extends −80 volt battery to earth via the coils of the electromagnet of the receiving teleprinter.

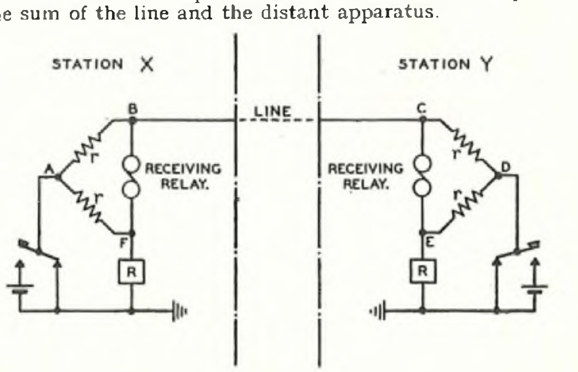
During spacing elements of signal, V.F. tone is suppressed, the rectifier valve anode current decreases and the 299 AN relay operates to space under the preponderating influence of the bias current. This operation extends +80 volts battery to earth via the receiving electromagnet coils of the teleprinter. Hence the teleprinter signal elements of V.F. tone in the channel are converted to equivalent double current ± 80 V signals for operating the receiving teleprinter.

The grid bias voltage for the amplifier and rectifier valves is derived from the voltage drop across an 8 ohm resistance which is in series with the filament of the amplifier. The grids are connected to the filament circuit via a 0·5 μF condenser and 10 megohm leak resistance. V.F. signals after amplification are passed to the grid of the rectifier valve, causing it to become slightly positive; grid current therefore flows via the 10 megohm resistance and the P.D. produced across this resistance is impressed upon the 0·5 μF condenser, causing it to become charged. The negative bias voltage on the amplifier valve therefore increases negatively, thus reducing the amplification. During spacing elements of signal the 0·5 μF condenser discharges but, owing to the high resistance discharge path, viz., 10 megohms, the condenser charge remains sensibly constant for the period of the maximum spacing signals.

Hence automatic gain control is obtained and ± 7½ db. variations in level of incoming V.F. signal are permissible without necessitating readjustment of the M.C.V.F. equipment.

Q. 10. *Give a diagram to illustrate bridge-duplex working and explain the principles underlying this method of operation. On what type of circuit is it used?*

A. 10. The sketch indicates the principle of bridge duplex working between two stations X and Y. The resistance arms AB, AF, DC and DE are all of equal resistance r, and the resistance of the compensation circuits R are each equal to the sum of the line and the distant apparatus.



When the transmitting keys are normal no current flows. When, however, the key at X is depressed current flows from +ve battery at X to point A where it divides equally between arms AB and AF because the resistance of R is equal to the sum of the resistance of the line and Y's apparatus. Since the resistances of AB and AF are equal, points B and F will be at the same potential and therefore no current will flow through the receiving relay at X. At station Y the received line current divides at point C; one portion of the current flows through CD to earth via the back stop of the key and thence to the negative pole of the battery at X, while the remainder of the current flows via the receiving relay to point E and thence to earth via arm ED with R in parallel and acting virtually as a high resistance shunt. The portion of the line current which flows through the receiving relay at Y causes it to operate to " mark." Similarly it may be shown that when the key at Y is depressed and X is normal that the receiving relay at X will operate to " mark " while that at Y is unaffected.

Considering next the condition when the keys at X and Y are depressed simultaneously, then as the battery voltages applied to each end of the line are equal, no line current will flow; both receiving relays operate to " mark," however, from their home batteries. The circuit in this case, considering station X, is from + ve battery to point A where the current divides between arm AF and arm AB with the receiving relay in series. These currents reunite at point F and return to negative battery at X via R. Thus the receive relay at X operates to " mark " from the home battery and similarly at station Y.

When a key, say that at Y, is in an intermediate position when that at X is depressed, then the compensation circuit R at Y is introduced in series with the line circuit. The receiving relay at Y is caused to " mark," however, by the current flowing through the relay shunted by arms CD and DE in series. At X the condition of equipotential between points B and F is upset and X tends to " mark " but, as the line current is considerably less than the normal " mark " current and furthermore, as the condition is only momentary, the relay at X will not be operated.

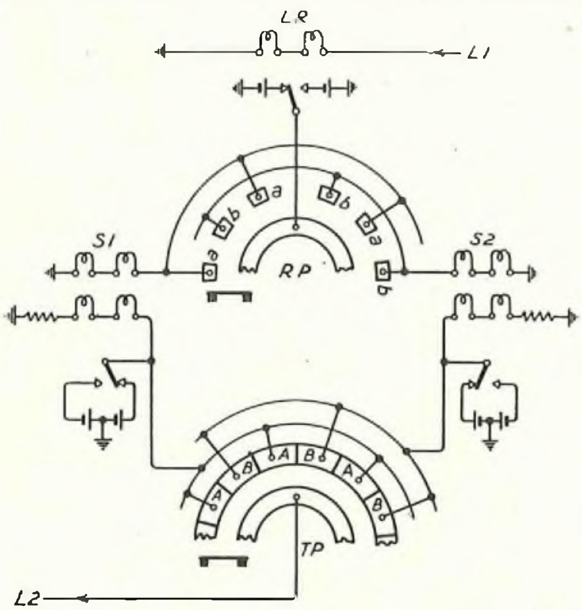
Although in the foregoing description it has been assumed that arms AB, AF, DC and DE are of equal resistance, this condition is not essential. In fact, stated generally, the conditions necessary for bridge duplex working are those required for a balanced Wheatstone resistance bridge, namely :—

AB × R = AF × (resistance of line + distant apparatus) and
DC × R = DE × (resistance of line + distant apparatus),

where AB, AF, DC and DE are expressed in terms of resistance. Bridge duplex working is used invariably for Wheatstone working on long cable circuits having large capacitance. This method enables a higher speed of working to be obtained than is possible when using a differential system.

Q. 11. Describe any form of regenerative repeater with which you are acquainted. What are the conditions in which the use of this type of repeater is necessary?

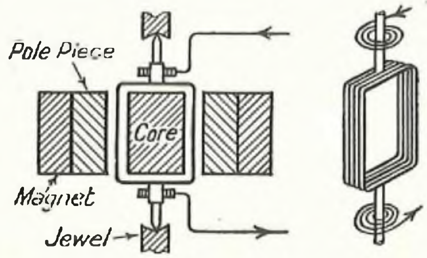
A. 11. A regenerative repeater is a telegraph repeater which accepts distorted signals and retransmits them as reshaped signals essentially free from distortion. The sketch indicates the principle of a synchronous regenerative repeater of the Baudot type. It consists essentially of a synchronous



rotary distributor having a receiving and transmitting plate, a receiving line relay and two or more storage relays. The receiving plate of the distributor RP is provided with a ring of shortened segments which enable the middle portion only of each signal element transmitted to it from the tongue of the line relay LR, to be picked out. The distorted signals thus received are distributed alternately to the two storage relays S1 and S2, the operation of these relays being such that while, for instance, S1 is being set up via the shortened segments of RP S2 is transmitting its stored signal via TP. The output from each of the relays S1 and S2 passes to line alternately via the transmitting plate TP, the output from S1 always passing via segments in the A group and the output from S2 via segments in the B group. Each relay therefore transmits a signal in turn, the transmission taking place when the relay tongue is at rest. The segments A and B on the transmitting plate TP are the full length of a signal element, hence the signals retransmitted are of the correct length and practically free from distortion. Regenerative repeaters are used where, owing to excessive KR in a circuit, for example sea cables, the signal distortion is high and seriously limits the speed of working and/or the range of the circuit. The action of the regenerative repeater in reshaping the received signal enables long cable circuits to be extended via land lines and also permits a higher signalling speed.

Q. 12. Describe the construction and explain the action of a moving coil voltmeter. How could the range of such an instrument be increased and how could it be used as an ammeter?

A. 12. The sketch indicates the essential portions of a M.C. voltmeter, the design and operation of which is based upon that of the D'Arsonval galvanometer.



A coil of fine insulated wire is wound upon a light aluminium or copper former which is rectangular in shape and pivoted between adjustable jewelled bearings. The moving coil thus formed is free to rotate in the intense magnetic field produced by a permanent horseshoe magnet. A soft iron cylindrical core is rigidly fixed within the moving system and concentric with the faces of the pole pieces. Its function is to produce a concentrated and uniformly radial flux distribution in the polar air gaps.

Current is fed to the M.C. by two coiled phosphor-bronze springs which, in addition, form the mechanical controlling forces for the moving system. The springs are wound in opposite directions so that when the moving coil is normal the mechanical torques produced by the springs are equal and opposite ; this arrangement prevents zero errors arising from temperature variations.

When current flows through the coil, electromagnetic forces are exerted on the vertical sides of the moving coil proportional to the product of the intensity of the magnetic field in the air gap and the current flowing. Furthermore, as the current flows in opposite directions in each of the vertical sides of the coil, the direction of the forces will be equal and opposite. A torque is thus produced tending to turn the coil about its axis ; in consequence the coil rotates to a position of equilibirum in which the torque due to the electromagnetic forces is equal and opposite to the mechanical restoring torque exerted by the coiled springs.

As the construction of the magnetic system produces a radial magnetic flux the intensity of which is uniform, the electromagnetic torque exerted on the moving coil will be directly proportional to the current flowing ; also the mechanical characteristics of the control springs are such that the torque is directly proportional to the angle of twist. Hence the angular movement of the M.C. is directly proportional to the current flowing and the scale of the instrument is therefore uniform. The movements of the moving coil are indicated by means of a light pointer fixed to the top of the coil and balanced by adjustable weights. The moving coil is rendered dead-beat by the use of the metal former. The eddy currents produced in the " former " during its rotation are such as to oppose the direction of motion of the coil in accordance with Lenz's law.

It is imperative that a voltmeter should absorb negligible power from the voltage source being measured, and the resistance of a M.C. instrument must therefore be as high as possible consistent with sensitivity. Owing to the difficulty of winding a high resistance M.C. it is usual to make up the required resistance by connecting a non-inductive resistance in series with the coil.

The range of the instrument may be increased by connecting additional resistance in series with the coil. Thus if the range of the instrument is normally E volts and its resistance R ohms, then to increase its range to X volts an

$$\text{additional resistance} = \left[\frac{X}{E} \times R\right] - R = R\left[\frac{X}{E} - 1\right] \text{ ohms}$$

must be connected in series.

The voltmeter may be used as an ammeter by connecting a low resistance shunt Rs and connecting the combination in series with the load under test. The instrument reading will indicate Vs the voltage drop across Rs hence the load current

$Is = \frac{Vs}{Rs}$ (neglecting the small current in the instrument).

Printed by SANDERS PHILLIPS & CO., LTD., The Baynard Press, Chryssell Road, London, S.W.9, and
Published by BIRCH & WHITTINGTON (*Prop. Dorling & Co. [Epsom], Ltd.*), Epsom, Surrey.