EXPERIMENTAL WIRELESS
& The WIRELESS ENGINEER

VOL. V. APRIL, 1928. NO. 55.

Editorial.

Some Further Problems in Potential Difference.

IN our last issue we discussed the question of the meaning of potential difference when applied to alternating current circuits, and we showed that in such cases the ordinary definition of potential difference leads to an ambiguity which can only be removed by adding a proviso to the definition.

The potential difference between two points is still equal to the work done in transferring unit charge from one point to the other, but certain restrictions must be imposed upon the path followed.

We wish now to examine two apparently simple problems, one of which was devised as a trap for junior students of electrical engineering, but in which much bigger game are sometimes found entangled. The first problem will be found in Mather and Howe's "Exercises in Electrical Engineering"; it is as follows: "The North Pole of a magnet is moved towards the open loop *ACB*, as shown in the Figure. Which is at the higher potential, *A* or *B*? The resistance of the loop *AB* is 1 ohm and the ends are joined to form a continuous ring. As the north pole is moved towards it there is at a certain instant a current of 1/20 ampere flowing in it. What is the P.D. at this moment between the joint *AB* and the opposite point *C*?" On moving the magnet pole towards the loop an E.M.F. is induced in the loop tending to drive current around it in an anti-clockwise direction and a small movement of electricity will take place in this direction, charging up the end *A* of the wire positively and the end *B* negatively, thus making *A* at a higher potential than *B*. It is interesting to note the mental process by which many students come to the opposite conclusion; having decided that the current tends to flow in the direction *BCA*, they

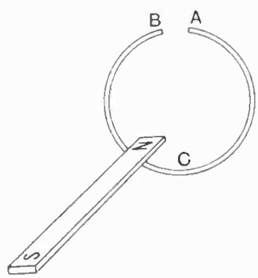


Fig. 1.

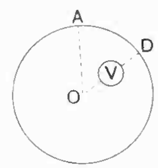


Fig 2.

think that *B* must be at a higher potential than *A*, *because current flows from points at higher to points at lower potential*. Having, by means of a pump, moved water up a pipe from the basement to the attic, they would hardly conclude, however, that the basement was higher than the attic *because water flows from higher to lower levels*.

The second part of the problem is more interesting; the student usually proceeds as follows: A current of 1/20 ampere flows down the left-hand side of the closed ring, and as the whole ring has a resistance of 1 ohm, the joint *AB* must be at a higher potential than *C* by 1/40 volt, but since the current flows up the right-hand side of the ring, the same reasoning leads to the conclusion that *C* has 1/40 volt higher potential than the joint *AB*. This contradictory result compels one to think, and very little thought is required to see that from the symmetry of the arrangement there can be no difference between the electrical condition of different parts of the ring; all points of it are necessarily at the same potential and current is flowing around it, not because of any differences of potential, but because of the electromotive force induced in it equally at every part.

If one wished to measure the P.D. between any two points of the ring, such as *A* and *D* in Fig. 2, the leads to the voltmeter would have to be arranged as shown, that is, radially, and the voltmeter would read zero. If, instead of plunging a permanent magnet into the ring, the changes of flux are produced by varying an electric current in a coil parallel to and co-axial with the ring, it will be seen that the radial voltmeter connections are at right angles to the vector potential. This we have seen to be essential to an accurate measurement of the P.D. in the presence of changing magnetic fields.

The second problem which we wish to consider only differs from the foregoing in that the closed ring is of a dielectric material, such as ebonite instead of copper. On plunging in the permanent magnet or changing the current in the parallel coil, the same electromotive force is induced in the ebonite ring as in the copper ring, but whereas in the latter this caused an electronic stream to flow around the ring, in the former the electrons are only capable of limited elastic displacement from their normal positions. On the application of the E.M.F., something happens in the ebonite, the exact nature of which is not known, but which is almost undoubtedly an elastic movement or displacement of electrons in their atomic orbits. The electric force **E** in the material is obtained in volts per cm. by dividing the total induced E.M.F. in volts by the total length around the ring in centimetres. If a sufficiently great magnetic flux could be changed at a sufficiently great rate, the electric force in the ebonite would presumably break it down.

Now arises the interesting question: is there any difference of potential between different parts of the ebonite ring during the time that the magnetic flux is changing? As in the copper ring it can be seen from the symmetry of the arrangement that there can be no difference between the electric condition of different parts of the ring, and there is no reason why one part should be at any higher or lower potential than any other part. If a voltmeter be properly connected between any two points of the ring, as shown in Fig. 2, the voltmeter will show no potential difference. The mental process by which people sometimes arrive at the opposite conclusion is very similar to that already described for the copper ring and is equally fallacious.

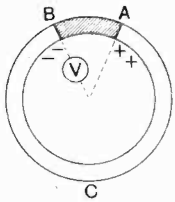


Fig. 3.

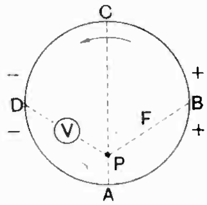


Fig. 4.

We see, therefore, that an electric force or stress in a dielectric may exist without any potential gradient, and that the force may be so great that the dielectric is broken down, although all parts of it are at the same potential. On the other hand, electric force in a dielectric may be, and often is, due to a potential difference. If in Fig. 3 the larger part *ACB* of the ring is made of copper and the smaller part *BA* of ebonite, and the north pole of a magnet is plunged symmetrically into it as in Fig. 1, the same E.M.F. will be induced in it. A momentary current will flow in the copper causing an excess of electrons in the part near *B* and a deficit in the part near *A*. This produces a difference of potential between *A* and *B*, which would be indicated on a voltmeter connected up as shown. Corresponding to this P.D. there will be an electric field both in the copper and in the ebonite, as well as in the surrounding air in the direction from A to B. In the copper the two electric fields, viz., that due to the magnetic induction and that due to the accumulated charges, are in opposition, and the distribution of charges will automatically adjust itself so that the latter, which we may call the electrostatic force, is equal and opposite at every point to the magnetically induced electric force, thus giving zero resultant electric force at every point within the conductor.

In the ebonite section, however, the state of affairs is entirely different; here the electrostatic force due to the accumulated charges at A and B is in the same direction as the magnetically induced electric force, giving a resultant electric force equal to their sum at every point. Moreover, since the resultant force in the copper is zero, that in the ebonite is equal to the total induced E.M.F., divided by the length of path in the ebonite. Hence the total induced E.M.F. acts on the ebonite, that part which is primarily induced in the copper being transferred to the ebonite as a P.D. between its ends. To obtain the electric force in the ebonite one must add to the potential gradient the electric force directly induced in it.

Returning to the ring of copper wire, we shall now consider the effect of plunging the magnet pole into the coil unsymmetrically. In Fig. 4 let P represent the pole entering the coil; the dotted lines may represent lines of force or they may represent lines normal at every point to the vector potential at the point, and therefore the lines along which voltmeter leads must be taken to obtain readings of the P.D. between any points on the ring. If the leads follow other paths electromotive forces will be induced in them which may vitiate the readings. Although the electric force induced in the wire at A is larger than that induced at C, the current is necessarily the same at every part of the ring once the steady state has been established. Since the electrons at A are moving no more rapidly than those at C, they must be subjected to the same force. This apparent contradiction is explained at once by the positive and negative charges which accumulate on the right- and left-hand sides of the ring, as shown in Fig. 4. These charges produce electrostatic forces opposing the induced forces in the lower half and assisting them in the upper half of the ring. The charges will automatically distribute themselves over the ring in such a way that the electrostatic forces exactly counterbalance the inequalities in the magnetically induced force, thus producing a uniform electric force in agreement with the uniform current.

There is now a P.D. between any two points on opposite sides of the line AC. A and C are at the same potential. A voltmeter connected as shown between the points D and B will correctly read the P.D. between these two points if the leads are run *via* $DVPFB$. The P.D. could be calculated for any given conditions; assume, for example, in Fig. 4 that the pole P is passing through the plane of the coil, and that the angle subtended at P by DAB is $\frac{5}{8}$th, and that subtended by DCB is $\frac{3}{8}$th of 360 degrees; then if E is the total E.M.F. induced in the ring at this moment, the E.M.F.s induced in DAB and BCD are $\frac{5}{8}E$ and $\frac{3}{8}E$ respectively, and since the IR drop is $\frac{1}{2}E$ in each half of the ring, the P.D. between B and D is equal to $\frac{5}{8}E-\frac{1}{2}E$ or to $\frac{1}{2}E-\frac{3}{8}E$, depending on whether one considers the bottom or top half. Hence the P.D. between B and D is $\frac{1}{8}E$.

If Fig. 4 be taken to represent a ring of some dielectric material such as ebonite the displacement at A will be greater than that at C, with the result that the ring will become charged somewhat as shown. The effect of the charges will be to diminish the electric force at A and to increase that at C, but their distribution on the ring will not be the same as in the copper ring, since the resultant electric force is not constant around the ring, but depends on the displacement, the variation of which causes the distribution of the electric charge. The conditions are thus much more complicated than in the case of the copper ring. A voltmeter connected as in Fig. 4 will, however, correctly read the P.D. between the points D and B.

These phenomena occur because the dielectric constant or specific inductive capacity of the ring differs from that of the surrounding medium. If it did not the ring would not differ electrically from the surrounding medium, and the displacement at every point would be proportional to the magnetically induced electric force at that point. The dielectric constant ϵ of the ring material can be regarded as consisting of two parts 1 and $\epsilon - 1$, the former being that which the space would have if the ring were not present and the latter the additional part due to the ring material. The former component has no disturbing effect on the concentric displacement produced by the magnetically induced electric force which would exist in the absence of the ring, and we need not consider this component any further. Any charges on the ring and any potential differences must be due to the latter component $\epsilon - 1$, which one must therefore employ in calculating them. These effects will become vanishingly small as ϵ approaches unity.

These problems in the electric potential of dielectric rings have their parallel problems in magnetic potential, the case just considered being very analogous to that of the iron toroid with a winding on one part of it, whilst the case of the symmetrically-induced ring is analogous to the uniformly wound toroid in which there is no difference of magnetic potential and consequently no leakage field.

The questions which we have considered in this and the previous article are fundamental to a proper understanding of electric circuits.

One's difficulties with the electric problems may be cleared up by considering a simple mechanical analogy. The ring is represented by a circular groove or canal cut in a horizontal surface and filled with water to represent a conductor or with jelly fastened to the sides of the groove to represent a dielectric. If a portion of the canal is filled with jelly and the remainder with water it will represent the copper and ebonite ring of Fig. 3.

The electromotive force must be replaced by a material-moving force, such as a circular draught of air, which might be produced by a large number of slanting nozzles just above and all round the canal or by a disc rotating at a high speed and fitted with vanes just above the canal.

A consideration of the difference of pressure or of level between different points of the canal will help to remove any difficulties which one may still have with the electric problems.

G. W. O. H.

The Approximate Theory of the Screen-grid Valve.

By B. C. Brain, B.Sc. (Hons.).

THE object of this paper is to show how the general shape of the characteristic curves and the static constants, viz.: amplification factor, differential anode resistance, mutual conductance, and inter-electrode capacity can be predicted from consideration of the structural constants in the special type of four-electrode valve called the screen-grid valve.

The constants of these valves differ from those of triodes in three principal ways :—

(1) The capacity between grid and anode is very much less.

(2) The mutual conductance is very much higher than is possible in a triode using the same filament and having the same amplification factor.

(3) The amplification factor of a screen-grid valve is not a structural constant, as in the triode, but depends largely on the anode and screen-grid voltages.

Although the writer does not propose to consider the screen-grid valve as a circuit element, it is essential to observe that for high amplification the quantity

$$\frac{\text{Amplification Factor}}{\sqrt{\text{Differential Anode Resistance}}}$$

should be as high as possible assuming ideal circuit conditions.* In general this increases with the anode resistance, but in practice if this is made very high it is impossible to even approximate to ideal conditions.

Van der Bijl and other investigators have shown that the space current in any triode can be calculated by finding the resultant potential in the plane of the grid due to the plate potential and the grid potential, and then treating the case as a hypothetical diode with its anode in the plane of the control grid, and having an anode potential equal to the resultant potential acting in the plane of the grid of the triode. Further, he showed that the anode potential E_a could be replaced by a potential $\frac{E_a}{m}$ acting in the plane of the grid, so that the resultant effective potential is

$$\frac{E_a}{m} + E_g.$$

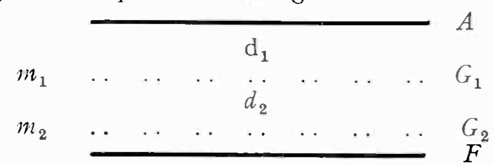
Hence the space current in a triode is given by

$$I = K\left(\frac{E_a}{m} + E_g\right)^{\frac{3}{2}} \quad \ldots \quad (1)$$

K is a constant which depends only on the structure of the grid and filament. It can be obtained by calculation in special cases, but owing to uncertainty in the active length of filament and the effect of initial velocity of emission of the electrons, it is generally preferable to obtain the value of K experimentally.

In the case of the screen-grid valve we have to find the effective voltage in the plane of the control grid due to the combined effects of the screen-grid and anode potentials.

Let us consider a valve having a filament system F, and, parallel to the plane of the filament, the control grid G_2, screen grid G_1 and anode A. The grids are considered to extend to infinity, so that there is no question of leakage of electrons round the sides of the grids or imperfect shielding.



Let d_1 be the distance of the grid G_1 from the anode.

Let d_2 be the distance of the grid G_2 from the grid G_1.

In equation (1) m is the voltage factor of the grid with respect to the anode. In the screen-grid valve we have two grids both of which must have a voltage factor.

Let m_1 be the voltage factor of G_1 with respect to A.

* V. G. Smith, *Inst. Rad. Eng. Proc.*, 15, pp. 525–536, June, 1927.

Let m_2 be the voltage factor of G_2 with respect to G_1.

We have then an effective potential $\frac{V}{m_1}$ acting in the plane of the screen grid due to the anode potential, so that we can consider the tetrode as replaced by a triode with an anode potential of $\frac{V}{m_1} + V_1$, so far as the space current is concerned. V_1 is the screen-grid potential. Hence from equation (1) we have

$$I = K\left[\frac{V}{m_1 m_2} + \frac{V_1}{m_2} + E_g\right]^{\frac{3}{2}} \quad .. \quad (2)$$

This gives us the total current leaving the filament. Since the screen-grid potential V_1 is positive with respect to the filament, a fraction I_g will be collected by the screen-grid, and the remainder I_a will reach the anode.

For the purposes of screening, m_1 is large compared with m_2, so that the current leaving the filament is practically determined by the screen-grid voltage. Hence the space current in a screen-grid valve is roughly the same as that of a triode of the same dimensions having its anode in the plane of the screen grid.

Let us assume for the present that all the electrons which strike the grid or anode are immediately absorbed, also that sufficient grid bias is applied to prevent current flowing in the control grid circuit.

Thus :

$$I = I_a + I_g \quad .. \quad .. \quad (3)$$

where I_a and I_g are respectively the anode and screen grid currents.

It can be shown that when m_1 is high the number of electrons striking the screen grid is nearly independent of V and is proportional to the ratio of the projected areas of grid and anode. Hence if there are n_1 grid wires per unit length of radius r_1, we have

$$\frac{I_g}{I_a} = \frac{2r_1 n_1}{1 - 2r_1 n_1} = p \quad .. \quad (4)$$

From equations (2), (3), and (4), we get

$$I_a = \frac{1}{1+p} \cdot K\left[\frac{V}{m_1 m_2} + \frac{V_1}{m_2} + E_g\right]^{\frac{3}{2}}. \quad (5)$$

$$I_g = \frac{p}{1+p} \cdot K\left[\frac{V}{m_1 m_2} + \frac{V_1}{m_2} + E_g\right]^{\frac{3}{2}}. \quad (6)$$

From equation (5) we get, when $E_g = 0$,

Amplification Factor.

$$M = m_1 m_2 \quad .. \quad .. \quad .. \quad .. \quad (7)$$

Mutual Conductance.

$$G = \frac{3}{2} \cdot K \cdot \frac{1}{1+p} \cdot \left[\frac{V}{m_1 m_2} + \frac{V_1}{m_2}\right]^{\frac{1}{2}} .. \quad (8)$$

Differential Anode Resistance.

$$R_a = \frac{2}{3}\frac{1+p}{K} \cdot m_1 m_2 \left[\frac{V}{m_1 m_2} + \frac{V_1}{m_2}\right]^{\frac{1}{2}} .. (9)$$

Inter-electrode Capacity and Voltage Factor.

Owing to the fact that in order to allow the electrons to reach the anode it is impossible to use a solid shield grid, there are lines of force between the anode and control grid which can never be completely eliminated. In order to calculate the resultant grid to plate capacity we shall make use of a result obtained by Maxwell in the course of his investigations on electrostatic screening.*

We shall assume that the capacity between the grid and plate is the same as would be obtained if G_2 were solid. This assumption is justified so long as the grid wire spacing of G_2 is small compared with the distance d_2. When this is no longer true, the capacity calculated will clearly be higher than the actual capacity.

Let the surface density of charge on G_2 be σ when the anode, screen grid and control grid are maintained at potentials V, V_1, and E_g respectively.

According to Maxwell

$$4\pi\sigma\left(d_1 + d_2 + \frac{d_1 d_2}{a}\right)$$
$$= \left(1 + \frac{d_1}{a}\right)E_g - V - \frac{d_1}{a}V_1 \quad .. \quad (10)$$

where $a = -\frac{1}{2\pi n_1}\log_e(2\sin \pi n_1 r_1)$.

Differentiating (10) with respect to σ and treating V_1 and E_g as constants, we have

$$\frac{\delta V}{\delta\sigma} = -4\pi\left(d_1 + d_2 + \frac{d_1 d_2}{a}\right) \quad .. \quad (11)$$

* J. C. Maxwell, "Electricity and Magnetism," Vol. 1, p. 310.

Similarly, by differentiating with respect to V_1, we have

$$\frac{\delta\sigma}{\delta V_1} = \frac{d_1}{a} \cdot \frac{1}{4\pi\left(d_1 + d_2 + \frac{d_1 d_2}{a}\right)} \quad \ldots \quad (12)$$

From (11) and (12), we get King's result* for the voltage factor of G_1 with respect to A

$$m_1 = \frac{\delta V}{\delta\sigma} \cdot \frac{\delta\sigma}{\delta V_1} = \frac{d_1}{a} = -\frac{2\pi n_1 d_1}{\log_e (2 \sin \pi n_1 r_1)}.$$

If we assume that r_1 is small compared with the wire spacing $\frac{1}{n_1}$ this can be rewritten

$$m_1 = -\frac{2\pi n_1 d_1}{\log_e 2\pi n_1 r_1} \quad \ldots \quad \ldots \quad (13)$$

Also the capacity is $\frac{\delta\sigma}{\delta V}$; hence from (11) putting a in terms of m_1 we have

$$C = \frac{1}{4\pi(d_1 + d_2 \cdot 1 + m_1)} \quad \ldots \quad (14)$$

per unit area.

When the screen-grid is removed, *i.e.*, $m_1 = 0$, we have the well-known result for a parallel plate condenser in vacuo.

Equation (14) means that the effect of the screen-grid is the same as would be produced by increasing the distance between anode and grid in any valve by m_1 times the distance between the two grids. Since d_1 is small compared with $m_1 d_2$ we can say that :—

The capacity is almost inversely proportional to the distance between the screen-grid and control-grid.

Secondary Emission Effects.

We have so far assumed that the only current which reached the anode and screen-grid originated from the filament. This is not justified, however, since the electrons striking the surface of the screen grid and anode dislodge other electrons. Thus, if the anode voltage is higher than the screen-grid voltage, secondary electrons from the grid G_1 will be attracted to the anode. Conversely, if the screen-grid voltage is the higher, secondary electrons from the anode will reach the screen grid.

* R. W. King, paper read at October, 1919, meeting of *Am. Phys. Soc.*, Philadelphia.

We shall, in this paper, only deal quantitatively with the first case, as it is the one which is most frequently met in practice.

The flow of secondary electrons will, of course, be limited by the space-charge due to both primary and secondary electrons. Since the primary electrons will be moving with very high velocities in the neighbourhood of the screen grid, we can safely neglect their space charge. The result of the secondary space charge is that a certain difference of potential will be required to draw all the secondary electrons from the emitting to the collecting electrode. The secondary current i will, therefore, behave in the same way as an ordinary thermionic current in a plane parallel type diode having its electrodes in the planes of screen-grid and anode. When the difference of potential is insufficient to collect all the secondary electrons the current is nearly independent of the total secondary emission, but depends on the distance apart of the electrodes, their effective area, and the field acting between them. When all the secondary electrons are collected the secondary current is equal to the total secondary emission and is independent of the field acting between the electrodes or the distance between them.

Case I. Total Secondary Emission.

The experimental results of investigators, notably Farnsworth,* show that the laws governing the rate of emission of secondary electrons are extremely complicated. When the impinging electrons have a low velocity the emission seems to follow no simple law, but above about 10 volts the curve is approximately a straight line, showing that the ratio of the secondary current to the primary current is proportional to the accelerating potential acting on the primary electrons.

We shall, therefore, assume that the emission of secondary electrons follows the law

$$\begin{aligned} i &= K^1 \cdot I_g(V_1 - V_0) \\ &= K^1 \cdot p \cdot (V_1 - V_0) \cdot I_a \quad \ldots \quad (15) \end{aligned}$$

where K^1 and V_0 are constants depending on the nature of the surface of the screen-grid. This depends very largely on the

* H. E. Farnsworth, *Phys. Rev.*, 20, 358, 1922; H. E. Farnsworth, *Phys. Rev.*, 25, 41, 1925; H. E. Farnsworth, *Phys. Rev.*, 27, 413, 1926.

method of exhaust and the heat treatment given to the surface during exhaust. A getter of magnesium is commonly used in valves of this type, and for a grid in a valve using this getter, the constants are of the order of $K^1 = .01$ and $V_0 = 15$ volts, although valves of the same type show considerable variations from these values. It is possible by specially coating the surface to raise K^1 as high as .05 and also to slightly reduce V_0.

The anode current will now be increased by an amount i given by equation (15) and the grid current reduced correspondingly. This, of course, represents a reduction of waste high tension battery current.

$$I_a + i = \frac{1}{1+p} \cdot K\left[\frac{V}{m_1 m_2} + \frac{V_1}{m_2} + E_g\right]^{\frac{3}{2}} (1 + pK^1 . \overline{V_1 - V_0}) \quad .. \quad (16)$$

$$I_g - i = \frac{p}{1+p} \cdot K\left[\frac{V}{m_1 m_2} + \frac{V_1}{m_2} + E_g\right]^{\frac{3}{2}} (1 - K^1 . \overline{V_1 - V_0}) \quad .. \quad (17)$$

Equations (7), (8), and (9) thus become

$$M = m_1 m_2$$

$$G = \frac{3}{2} \cdot \frac{1}{1+p} \cdot K\left(\frac{V}{m_1 m_2} + \frac{V_1}{m_2}\right)^{\frac{1}{2}} (1 + pK^1 . \overline{V_1 - V_0}) \quad .. \quad (18)$$

$$R_a = \frac{2}{3} \cdot \frac{1+p}{K} \cdot m_1 m_2 \cdot \left(\frac{V}{m_1 m_2} + \frac{V_1}{m_2}\right)^{-\frac{1}{2}} (1 + pK^1 . \overline{V_1 - V_0})^{-1} \quad .. \quad (19)$$

The result, therefore, of a *saturated* secondary current from the screen grid to the anode is to reduce the " R_a " without affecting the " M," thus improving the mutual conductance.

Supposing the " G " previously calculated for a valve was .5 milliamp per volt, then taking $p = .4$ and $V_1 = 80$ volts, the new value of " G " for an average valve would be increased to .63 milliamp per volt, and if the grid were specially treated to give a high secondary emission " G " *might be raised to* 1.2. In this case the screen-grid current would be negative and there would be no wastage of battery current.

There is, however, a very serious obstacle to the attainment of this sort of result. It is that, in practice, impossibly high values of $V - V_1$ have to be used to secure saturation of the secondaries. The most probable explanation of this effect is the theory that was put forward by Langmuir to explain the lack of saturation obtained with oxide coated or thoriated filaments. It can be shown that it is easier for an electron to escape from a sharp point than from a smooth flat surface. Thus, if an emitting surface is irregular in contour the bulk of the current will originate from the peaks. With an increase of field between the electrodes a larger proportion of current will flow from the hollows, and, so as the field is increased, the effective area of the cathode increases and the current increases.

Since in the case we are considering the emitting surface is a grid, it is to be expected that this effect would take place.

Case II. The Secondary Current is Less than Saturation.

The secondary current under these conditions is difficult to estimate since we know very little about the emitting area of the screen-grid. We shall, therefore, investigate the effect of an unsaturated secondary current qualitatively.

Since the secondary current is independent of the total secondary emission, it is independent of the control grid potential, and hence the mutual conductance is unaltered by secondary emission so long as the secondary current is considerably below saturation point. As the secondary current is affected by the total secondary emission at a considerable distance below the bend on the $i/(V - V_1)$ curve, we shall expect a gradual increase in mutual conductance until saturation is reached. We can, however, consider under Case II that G is constant.

The anode conductance $\frac{1}{R_a}$ is the sum of the primary and secondary electron conductances.

Thus if

$$\frac{dI_a}{dV} = X \quad \text{and} \quad \frac{di}{dV} = Y$$

the R_a is

$$\frac{1}{X + Y}$$

$$= \frac{1}{X} \cdot \frac{1}{1 + \frac{Y}{X}}$$

Now $\frac{1}{X}$ is the anode resistance given by equation (9) neglecting secondary emission, so that the R_a is modified by the factor

$$\frac{1}{1+\frac{Y}{X}}.$$

When the secondary emission is unsaturated, it is clear from the construction that the secondary electron conductance must be very high compared with the primary conductance, hence $\frac{Y}{X}$ is large compared with 1 and hence the resultant R_a is much lower than the value $\frac{1}{X}$. As the secondary current approaches saturation, the conductance Y becomes smaller, *so that the R_a increases as the secondary current approaches* saturation, the final value being given by equation (20).

The amplification factor is given by

$$M = m_1 m_2 \frac{1}{1+\frac{Y}{X}}$$

so that the amplification factor will vary in the same way as the R_a, approaching a limiting value given by equation (19) when the secondary current is saturated.

General Conclusions from the Preceding Investigation.

(1) The residual *capacity* between plate and control grid is equal to the capacity between the control grid and screen divided by the " M " of the screen-grid.

(2) The maximum *amplification factor* of a screen-grid valve is the product of the " M's " of the two grids. When there is a secondary emission from the electrodes, the amplification factor is lower than this value. As the difference between the anode and screen-grid voltages increases, the " M " rises asymptotically to the maximum value when the secondary electrons are removed to the anode as quickly as they are emitted.

(3) The *mutual conductance* of a screen-grid valve is equal to that of the corresponding triode (*i.e.*, treating the screen grid as an anode), minus a percentage due to the electrons intercepted by the screen grid. Thus the " G " falls off rapidly as the screen grid mesh is made very close. This percentage reduction can be lowered and even made negative by treating the grid to obtain a high secondary emissivity. The slope of the I_a/E_g curves (when $E_g = 0$) is very nearly independent of the anode voltage and varies with the screen grid voltage and " M " of the control grid in the same way as in a triode.

(4) The *differential anode resistance* is the ratio of the amplification factor to the mutual conductance as in a triode. Since the slope at constant screen-grid voltage is very nearly constant, it follows that the anode resistance varies with the anode voltage in the same way as the amplification factor.

The simple theory outlined above does not pretend to be exhaustive, but the results are in general agreement with the facts as stated by Hull and others.*

My thanks are due to the British Thomson-Houston Co. for facilities in the experimental verification of some of the theoretical results.

* A. W. Hull, *Phys. Rev.*, 27, 439, 1926.
P. T. Beatty, *E.W. & W.E.*, October, 1927.

Mutual Inductance in Radio Circuits.

By L. Hartshorn, A.R.C.S., B.Sc., D.I.C.

(National Physical Laboratory.)

MUTUAL inductance, which is nothing more or less than magnetic coupling, exists in all radio circuits, since almost any two coils or even wires possess a certain definite mutual inductance depending on their position with respect to each other. Thus, if I_p is the current in one wire or coil, then there is an E.M.F. induced in the other wire or coil given by

$$E_s = j\omega M I_p \quad \ldots \quad \ldots \quad (1)$$

where $\omega = 2\pi \times$ frequency, M is the mutual inductance of the two coils or wires, and j is the operator rotating through a right-angle, thus indicating in (1) that the induced E.M.F. (E_s) is in quadrature with the primary current I_p. The simplicity of this equation suggests that mutual inductance should be very useful in radio measurements. For example, it provides a means of obtaining an E.M.F. of any desired amount. A variometer, or two coils, one of which is movable, provides a mutual inductance which is easily variable. If then a definite current I_p is passed through one coil, an E.M.F. given by (1) is induced in the other coil, and the value of M can be adjusted until an E.M.F. of the required value is obtained. This scheme is readily workable at low frequencies, but all who have attempted to use a variometer for measurements of this nature at high frequencies will know that the matter is not so simple. Distributed self capacities of the two coils, and distributed mutual capacity between the coils, complicate matters considerably. In fact equation (1) only holds for the ideal "pure" mutual inductance. In the present article it is proposed to collect together the most useful properties of the ordinary "impure" mutual inductance, and to point out their bearing on the most common forms of mutual inductance in radio work, *viz.*, variometers, coils with tapped points, and transformers.

The General Case.

The distributed self and mutual capacities of two coils may be represented to a first approximation by lumped capacities connecting the ends of the coils. Thus a mutual inductance formed by two coils AB and CD should be considered as consisting of the network shown in Fig. 1, which was first given by Butterworth.* We have to reckon with six capacities, the self-capacities k_1, k_2 of the two coils, and the four cross-capacities k_3, k_4, k_5, k_6. The properties of this system are rather complicated, and in practice it is usually advisable to simplify it by making one point of the primary, and one of the secondary, common. Thus let the points A and E be connected together. The capacity k_3 is now short-circuited and disappears, k_1 and k_6 are thrown in parallel, and may be represented by a single capacity C_1, k_2 and k_5 similarly form the single capacity C_2, and we have the system of Fig. 2 in which $C_{12} = k_4$. We have now only three capacities, a single cross capacity C_{12}, and the two effective self capacities C_1 and C_2. (These are evidently larger than the self capacities k_1 and k_2 of the coils when far removed from each other.) In the paper already referred to, Butterworth has given a convenient method for the mathematical investigation of the properties of this network, and has deduced a number of useful formulæ. A paper by the present writer,† following up Butterworth's work, deals with some additional properties. The most useful of the formulæ will be quoted here. For proofs the original papers should be consulted.

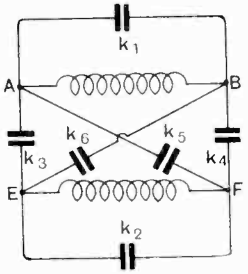


Fig. 1.

Mutual Inductance Equations.

Let the coil AB carry alternating current

* Butterworth, *Proc. Phys. Soc.*, Vol. 33, p. 313, 1921.

† Hartshorn, *Proc. Phys. Soc.*, Vol. 38, p. 303, 1926.

of frequency $\omega/2\pi$. Owing to distributed capacities, the current will not have the same value in every element of the coil, and therefore the exact value to be assigned to "the current passing through the coil" is a matter for definition. The only currents we can measure directly are those flowing into the terminal A, or out of the terminal B. These two currents will have the same value provided earth capacity effects are negligible, and when we say that a current I_p flows through the coil, this terminal current is the one referred to. Referring to Fig. 2, I_p will evidently include the current through C_1.

Let L_1 and R_1 be the self-inductance and resistance of the primary coil AB, L_2 and R_2 those of the secondary coil AF, and M_0 be the geometrical mutual inductance of the two coils. This is the value of the mutual inductance obtainable by calculation from the dimensions of the coils, the number of turns, and their position with respect to each other. It is practically the same as the value measured at low frequencies.

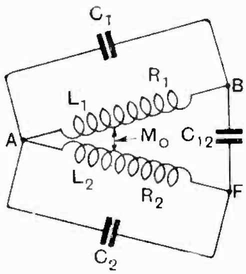


Fig. 2.

The potential difference developed at the secondary terminals is now given approximately by

$$V_s = (\sigma + jM\omega)\, I_p$$

where

$$M = M_0 + \Delta M = M_0 + C_{12}R_1R_2 + \omega^2\{C_1L_1M_0 + C_2L_2M_0 - C_{12}(L_1 - M_0)(L_2 - M_0)\} \quad (3)$$

$$\sigma = \omega^2[C_1R_1M_0 + C_2R_2M_0 - C_{12}\{R_1(L_2 - M_0) + R_2(L_1 - M_0)\}] \quad (4)$$

Equation (1) gave the secondary E.M.F. (E_s) in the ideal case. Equations (2), (3), (4) give the secondary P.D. (V_s) which is observed in practice. This is not quite the same as the E.M.F. actually induced in the secondary coil, but as the P.D. is the only quantity we can measure, it alone need be considered. This P.D. is no longer exactly in quadrature with the current I_p. There is an in-phase component σI_p which is proportional to the square of the frequency, and which may thus become very important at radio frequencies. Further, the effective mutual inductance M differs from its value at low frequencies (M_0) by an amount ΔM which is proportional to the square of frequency.

From (3)

$$\Delta M = \omega^2\{C_1L_1M_0 + C_2L_2M_0 - C_{12}(L_1 - M_0)(L_2 - M_0)\}$$

These "frequency" effects all increase with increasing capacities.

It must be borne in mind that the direction of the E.M.F. induced in a coil is reversed if the direction of winding of the coil is reversed. Thus a mutual inductance M can be regarded as possessing either a positive or a negative sign. In equations (3) and (4) a positive sign must be given to M_0 if the direction of winding is such that the mutual inductance opposes the self-inductance of the two coils when current is passed through the combination via the open ends.

Application to Variometers.

In a mutual variometer for use in radio measurements it is desirable that the effective mutual inductance at any point of the scale should have a definite constant value for all working frequencies, and that as the moving coil is turned, the effective mutual inductance should decrease to zero. Equation (3) shows that owing to capacity effects, the effective mutual inductance contains a term which is proportional to the square of the frequency, and therefore it is essential that this term be made small if the instrument is to have a constant calibration for all frequencies. This frequency term consists of the difference of the two self-capacity terms

$$C_1L_1M_0 + C_2L_2M_0$$

and the mutual capacity term

$$C_{12}\,(L_1 - M_0)\,(L_2 - M_0).$$

Now generally $L_1 > M_0$ and $L_2 > M_0$ numerically. Thus, provided the direction of winding is such as to make M_0 positive, the effect of mutual capacity opposes that of self-capacity. If, however, the other direction of winding is used the "frequency coefficient" or ΔM becomes much larger, since the mutual capacity effect is added to that of self-capacity. For this reason if a scale showing both + and − mutual inductance is used, it is not likely to be quite symmetrical about the zero point. It is evident by inspection of the expression for the frequency coefficient that the conditions to be satisfied by a good design are :—

1. The coils should be as small in self-inductance as possible.

2. They should possess self-capacities as low as possible.

3. The primary and secondary coils should be connected together at one end, and where possible the direction of winding should be such as to make the mutual inductance oppose the self-inductance.

Conditions (1) and (2) make the terms $C_1L_1M_0$ and $C_2L_2M_0$ small. Condition 3 makes the term $-C_{12}(L_1-M_0)(L_2-M_0)$ of opposite sign to $C_1L_1M_0$ and $C_2L_2M_0$, if, as is usual, M_0 is less than L_1 and L_2. It is interesting to note that screening, which may be carried out by interposing an earthed "resistance net" between the two coils, will not reduce the "frequency effects" to zero, since although it may make $C_{12} = 0$, it may increase the values of C_1 and C_2 considerably. The impurity "σ" is usually less important than ΔM, since it depends largely on the resistances R_1 and R_2, and these are always made as small as possible. Butterworth has shown that σ may be largely increased by eddy current effects, and on this account it is necessary to use stranded wire. When the two coils are set in their conjugate position so that M_0 is zero, we see from (3) that the effective mutual inductance is

$$C_{12}R_1R_2 - \omega^2 C_{12}L_1L_2,$$

of which the first term is always negligible. The value of σ in this case is

$$-\omega^2 C_{12}(R_1L_2 + R_2L_1)$$

and thus the secondary P.D. is (approx.)

$$V_s = -\omega^2 C_{12}\{R_1L_2 + R_2L_1 + j\omega L_1L_2\}.$$

Thus the secondary P.D. cannot be reduced to zero unless C_{12} is reduced to zero by perfect screening, and the minimum secondary P.D. will increase rapidly with increase of frequency and of self-inductance of the coils.

Effective Resistance Equations.

Referring again to Fig. 2 the effective resistance of this network between the points AB is shown by Butterworth to be approximately

$$R_1[1 + 2\omega^2\{C_1L_1 + C_{12}(L_1 - M_0)\}] \quad (5)$$

Similarly the effective resistance between the points AF is

$$R_2[1 + 2\omega^2\{C_2L_2 + C_{12}(L_2 - M_0)\}] \quad (6)$$

and it is easy to show that the resistance between the points BF is approximately

$$R_1 + R_2 + 2\omega^2[R_1L_1C_1 + R_2L_2C_2 + C_{12}(R_1 + R_2)(L_1 + L_2 - 2M_0)] \quad (7)$$

Equations (5) and (6) give the effective resistance of a coil which is connected to a second coil magnetically coupled to it, the ends of the second coil being left open.

An inductance coil with a tapped point is a common example of such a system, and the equations show at once the "dead end" effect in the case of a coil BAF, of which the portion BA is tapped off. The resistance of the portion BA in the absence of AF is $R_1(1 + 2L_1k_1\omega^2)$ approx. When AF is present the effective resistance is given by (6), but in this case the sign of M_0 must be taken as negative, since the mutual inductance of the two parts of the coil always adds to the total self-inductance. Thus the numerical value of the "dead-end" effect is $2\omega^2R_1\{L_1(C_1 - k_1) + C_{12}(L_1 + M_0)\}$. The capacity C_1 (Fig. 2) is the resultant of k_1 and k_6 (Fig. 1), but $(C_1 - k_1)$ is nearly always less than k_6, since the capacities k_1 and k_6 represent electrostatic actions across dielectric paths which are partly coincident, so that they are not strictly additive.

A point to be noted is that if we have two coils BA and AF in series, their total resistance given by (7) is not exactly equal to the sum of their individual resistances given by (5) and (6). In fact, if the individual resistances are R_α and R_β it may be shown that the total resistance is

$$R_\alpha + R_\beta - 2\sigma \quad .. \quad (8)$$

where σ is given by equation (3). (This is exactly analogous to the expression for the total inductance $L_\alpha + L_\beta - 2M$.) The expression (8) only holds when the individual resistances R_α and R_β are measured with both coils in position. If the coils are separated the self-capacities again become k_1k_2, as in Fig. 1, and thus the effective resistances are altered. These points must be borne in mind in applying the method of measuring the effective resistances of condensers due to Prof. R. R. Ramsey and described by C. D. Callis.* It is evident that the quantity 2σ in (8) represents the

* C. D. Callis, *Phil. Mag.*, Series 7, Vol. 1, p. 428, 1926.

error of the method when these effects are overlooked as was done by the original author.

Self-capacity Equations.

Consider again an inductance coil with a tapping point. When part of the coil only is being used, the rest of it acting as a "dead-end" increases the effective self-capacity of the coil, and the amount of this may be expressed as follows. Represent the coil by Fig. 2 so that BAF is the complete coil, and A the tapping point, L_1 and L_2 are the self-inductances of the two parts and $L_1 + L_2 - 2M_0$ is the total self-inductance. (In accordance with the usual convention M_0 must be regarded as negative for the two parts of a continuously wound coil.) If now the portion AB is connected to a condenser, and the circuit formed is tuned to various standard frequencies, and the effective self-capacity found in the usual way, then the writer has shown* that the self-capacity of the part AB is given to a close approximation by

$$C_{AB} = C_1 + C_2\frac{M_0^2}{L_1^2} + C_{12}\frac{(L_1 - M_0)^2}{L_1^2} \quad (9)$$

Similarly the self-capacity of the part AF is given by

$$C_{AF} = C_2 + C_1\frac{M_0^2}{L_2^2} + C_{12}\frac{(L_2 - M_0)^2}{L_2^2} \quad (10)$$

while the self-capacity of the whole coil is given by

$$C_{BF} = C_{12} + C_1\frac{(L_1 - M_0)^2}{L_t^2} + C_2\frac{(L_2 - M_0)^2}{L_t^2} \quad (11)$$

L_t being the total self-inductance

$$L_1 + L_2 - 2M_0.$$

These equations are illustrated by results obtained by the writer for a very large coil of total inductance 50 mH. wound in three parts which could be disconnected from one another. Taking the centre portion (12 mH.) and determining its self-capacity under different conditions, the following values were obtained :—

(*a*) With the two overhanging portions connected so that M was positive :
Self-capacity = 32 $\mu\mu$F.

(*b*) With the two overhanging portions connected so that M was negative.
Self-capacity = 170 $\mu\mu$F.

The large difference is evidently due to the change in the value of $\frac{(L_1 - M_0)^2}{L_1^2}$, when M_0 changes its sign.

These values of effective self-capacity are, of course, values obtained on the assumption that the inductances of the coils are unaffected by changes of frequency. The actual physical fact with which we are concerned is a change in the reactance of the coil system with change of frequency. In this paragraph the change is regarded as entirely due to a capacity shunting the coil system, the inductances remaining absolutely constant. Alternatively, we may regard the inductance as variable with frequency, and express the same changes as changes in inductance. This is done in a subsequent paragraph headed Self-inductance Equations.

Determination of the Component Capacities of Transformers.

Equations (9), (10) and (11) may be used to determine the component capacities C_1, C_2 and C_{12} of a system of coils of this nature, for example, of a transformer, for if the self-capacities C_{AB}, C_{AF}, C_{BF} can be determined and the true inductances L_1, L_2 and M_0 are measured, then substituting the results in equations (9), (10), and (11), we obtain three equations, which are sufficient to determine the three unknowns, C_1, C_2, C_{12}. This method was successfully used by the writer in determining the component capacities of the subdivided 50 mH. coil previously referred to. It could possibly be used for analysing the capacities in a L.F. intervalve transformer, though the conditions in this case are rather difficult, since the primary and secondary coils are usually of enormously different inductances, and the presence of the iron core makes the application of Fig. 2 to the system only possible under conditions which might not permit the necessary self-capacity measurements being made.

Self-inductance Equations.

The properties of the system as regards self-inductance have yet to be considered. Butterworth* showed that the effective

* *Loc. cit.*

*Butterworth, *loc. cit.* A term given by Butterworth depending on the resistance has been omitted, since it is negligible in all practical cases.

self-inductance between the points AB (Fig. 2) is to a first approximation given by

$$L_{AB} = L_1 + \omega^2\{C_1L_1^2 + C_2M_0^2 + C_{12}(L_1 - M_0)^2\} \quad .. (12)$$

and, similarly,

$$L_{AF} = L_2 + \omega^2\{C_1M_0^2 + C_2L_2^2 + C_{12}(L_2 - M_0)^2\} \quad .. (13)$$

In a paper already referred to, the writer has also shown that the overall inductance L_{BF} is given (approximately) by

$$L_{BF}=L_1+L_2-2M_0+\omega^2\{C_1(L_1-M_0)^2 + C_2(L_2-M_0)^2+C_{12}(L_1+L_2-2M_0)^2\} .. (14)$$

Equations (12) and (13) may be regarded as showing how the effective inductance of a portion of a coil which is tapped off is increased by the " dead-end " effect. Again, they show how the effective inductance of a transformer primary or secondary is increased by self-capacity in both the primary and secondary windings, and also by mutual capacity between them. In this connection it must be realised that the expressions are only approximate. They no longer hold when the frequency becomes so high that the coils are near their self-resonance points. Thus they will not hold for L.F. intervalve transformers except at the lower frequencies, since such transformers possess self-resonance points in the working range. More complete equations for such cases have been given by Dr. Dye in his well-known paper* on intervalve transformers. The present equations do bring out a point emphasised by Dr. Dye. *viz.*, that the effects of secondary self-capacity and mutual capacity are exactly similar, and the one may readily be expressed in terms of the other. With regard to the sign of M, the same convention as before is to be adopted, that is, M is taken as positive when the directions of winding of the two coils are such that the flux due to the two coils traverses the magnetic circuit in opposite directions when current is passed through the coils in series. It is evident from equations (12) and (13) that the effect of mutual capacity is minimised when this direction of winding is adopted, which explains why the properties of a transformer can be altered very considerably by altering the common point on the two windings or by reversing the secondary coil.

* D. W. Dye, *E.W. & W.E.*, September, 1924.

The Design and Distribution of Wireless Broadcasting Stations for a National Service.

Paper read by Capt. P. P. Eckersley, M.I.E.E., before the Wireless Section I.E.E., on 1st February, 1928.

ABSTRACT.

PART I.

Historical.

IN this introductory section the author briefly traces the history of the development of the B.B.C. stations. The establishment of the main and relay stations was regarded as bringing the urban population of Britain within reach of an uninterrupted service, while the long wave Daventry 5XX brought the percentage of the population living within the service area of a station up to 85 per cent. It is estimated that 50 per cent. of listeners rely upon 5XX, and that no other station is listened to in 90 per cent. of the rural areas.

Recently the "regional scheme" has been experimentally started by the high power medium-wave station at Daventry 5GB, giving programmes contrasted with those of the older long-wave station.

Service Area.

The "service area" of a station is regarded as an area around the station within which certain guarantees of service can be given. The author defines service areas in terms of field strength (millivolts per metre), definitions which, although arbitrary, have been accepted by the Technical Committee of the Union Internationale de Radiophonie.

Definitions.—Service areas are defined under four categories:—

(1) "Wipe Out" area, in which the field strength s over 30 mv/m.

(2) "A" service area, in which the field strength is over 10 mv/m. Service can be guaranteed even near the usual sources of electrical interference, trains, electric signs, etc.

(3) "B" service area, in which the field strength is over 5 mv/m. Crystal reception can be guaranteed with a good outdoor aerial.

(4) "C" service area, in which the field strength is greater than 2.5 mv/m. Listeners will be subject to interference from spark sets, trains, atmospherics, etc., but in time should be assured of an 80 per cent. service because it is hoped that some of these sources of interference will be eliminated at the source.

As fading may set in at 80 to 100 miles, the ideal would be to make a "B" service area have 100 miles radius.

Prediction of Service Area.—The extent of service area is difficult to predict, and is influenced by wavelength, type of ground around a station and the design of the transmitting aerial.

There is evidence to show that between the frequencies of 500 kc. and 1,500 kc. (600 to 200 m.) of the broadcast range there is considerable difference between the attenuation at the higher and lower frequencies. The curves of Fig. 1* illustrate the effect.

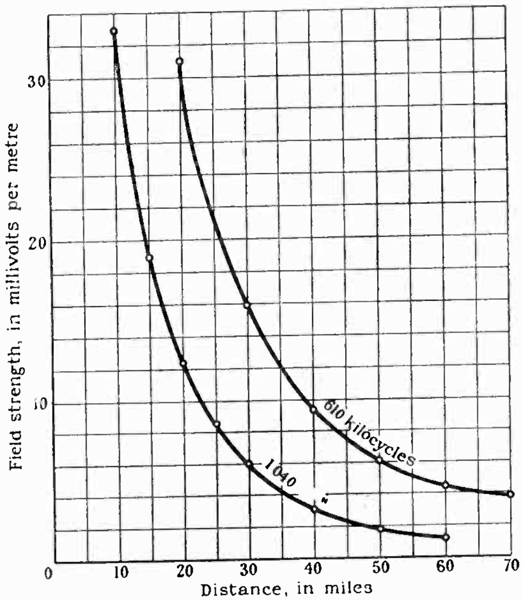


Fig. 1.

As regards the effect of the ground round the transmitter, the author refers to Mr. R. H. Barfield's recent contour map of the field strength round 2LO (see *E.W. & W.E.*, January, 1928), where trees were shown to add greatly to the attenuation, while he also quotes measurements made in Sweden in which the effect of forests is clearly shown.

In the design of the aerial, the object should be to radiate as much as possible horizontally and as little as possible in other directions, *i.e.*, low-angle radiation is to be preferred. The efficiency of the aerial should also be a maximum.

A vertical $\frac{1}{2}\lambda$ aerial is generally assumed to have the flattest vertical polar diagram at about 1,000 kc., but an aerial of this type for 500 metres would have to be 750 ft. high. A mast of about 300 ft.

* The author's original figure numbers are adhered to throughout this abstract.

is more practicable, and in this case it would be preferable to use a **T** aerial having a natural wavelength as nearly as possible twice that to be radiated. This would be obtained with a horizontal part of about 250 ft. Tests with a **T** aerial 250 ft. long on 110 ft. masts, and with a **T** aerial 600 ft. long on 500 ft. masts showed a mean field strength at 70 miles of 30 to 50 per cent. in favour of the higher masts. The half wavelength aerial produces larger interference at comparatively long ranges at night, due to the low-angle radiation causing a small angle of reflection from the Heaviside layer.

To increase the effective height of aerials it is convenient to separate the aerial system from the transmitting station buildings, and experiments on the use of feeders for this purpose at 5GB are described.

represent a more economical method of distribution than a single high-power station to cover the same area.

The author compares the advantages and disadvantages of using frequencies of about 200 kc. (*i.e.*, as of Daventry 5XX), and concludes that the ideal broadcasting system combines the use of medium-frequency and low-frequency distribution, and employs each according to its merits.

Limitation of Wavelength.

To avoid heterodyne interference, the only reliable principle is by separation of the fundamental frequencies between stations less than 3,000 miles apart. Since all frequencies up to 10 kc. require to be present in the modulation, the maximum difference between sidebands and fundamental must be ± 10 kc. To prevent the sidebands

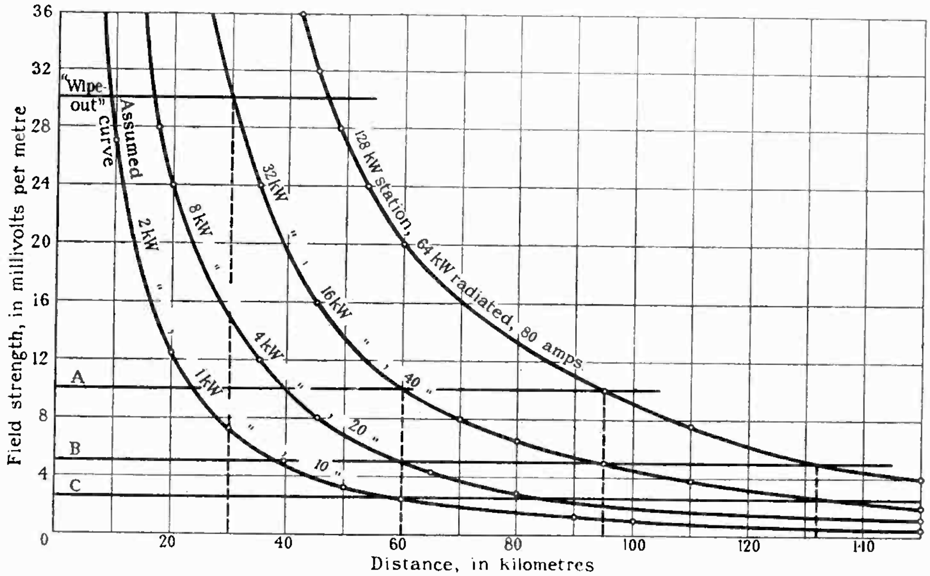


Fig. 2.

The effect of masts is also considered. The desirable polar curve of the radiating system may be distorted, and the effective height of the aerial reduced. The author concludes that it would appear best to arrange insulated masts as far from the aerial as possible, so as to minimise their effects both by eliminating resonance and strong induction.

The above factors introduce so many variables that a vast amount of data must be collected before the exact prediction of service area can be undertaken with any degree of confidence.

An approximate measure of the "A," "B" and "C" service areas against power used is shown in Fig. 2. The high-power station is more economical per unit of "B" service area than the low-power station, if each unit of area is assumed to give the same yield in licence revenue. Owing to non-uniformity of population, however, several low-power stations located in populous areas

heterodyning with another carrier, a separation of 20 kc. would be required, and to prevent sidebands heterodyning with sidebands 30 kc. separation would be called for.

This would leave an inadequate number of channels in Europe and would involve a large increase of power.

A separation of 10 kc. between fundamental frequencies allows for 101 stations in Europe within a frequency gamut of 1,500 and 500 kc. (200 to 600 m.). According to the Geneva plan, of the 100 available wavelengths, 84 were allotted for the exclusive use of the more important European stations, while the remaining 16 were to be shared between the surplus stations. Small power stations widely separated in geographical distance and working on the same wavelength would certainly produce little interference outside their service areas. If, additionally, they were working exactly or very nearly at the same frequency, their note of interference would be so low in pitch as to be almost inaudible.

The compromise thus arrived at provides a means to allow organisations to erect and maintain certain "local" stations without interference.

According to the Geneva plan, Britain has nine exclusive wavelengths, while 5XX makes ten channels in all available for British broadcasting.

The Provision of Alternative Programmes.

The author considers that the provision of alternative programmes more than doubles the value of a broadcasting service. To make selection between alternative programmes as simple as possible, the two transmissions must be of equal strength. Thus, if a listener lives in the "B" service area of one programme, he should also be in the "B" service area of the alternative. This is tantamount to saying that the two transmissions should be radiated from the same point.

In order to predict the effect upon existing receivers, a study was made of the use of twin wavelength stations producing roughly coincident field strengths over the service area of the stations.

The author's conclusions, amongst others, are (1) That if the frequency separation of two equal-strength transmissions is greater than 100 kc., the amount of further separation makes little difference to the extent of the interference between them. (2) That in most types of set met with it is impossible to produce sufficient selectivity to select between two equal-strength transmissions without some distortion of the frequency characteristic, and that many valve sets at present in use introduce distortion of this kind to some degree. (3) That the best and, in most cases, the only solution of the problem is to introduce some form of band filter. In its very simplest form this consists of a closed circuit in series with the aerial and tuned to the unwanted transmission.

After discussing methods of selectivity the author suggests that the next advance in receiver technique is to design the high-frequency side so that a square filter curve results, giving linearity of response over the desirable 10 kc. but selectivity by abrupt cut-off. He does not fear that the distortion of frequency characteristic to get reasonable selectivity (which occurs in the majority of present-day receivers) can be cited as a fundamental objection to the twin-wavelength transmitter system. The effects are slight and not irremediable.

Linking Together of Stations.

In this section, the author states that it is not necessary to discuss the many problems incident to landline linking. Experience has proved that it is perfectly feasible to rely upon the use of such connection, and that no serious loss of quality need be feared if the proper precautions are taken.

As regards the linking of national systems by wireless, he considers that short waves will prove most fruitful in yielding the required link. The problem is one of reception rather than transmission, and is largely bound up in the discovery of methods to equalise the intensity of the received signal.

In some experiments by Mr. G. M. Wright of the Marconi Company it was shown that reception conditions at two stations a mile apart were entirely different at the same moment. The strength might go up at one station and down at the other. This suggests that several receiving stations might combine to give a sensibly constant output, and the Marconi Company and the B.B.C. are stated to be collaborating in experiments to test the value of this theory in practice.

Continued experimental work upon a larger scale, using higher power, "beam" receivers, spaced aerials, suitable wavelengths, absolute constancy of transmitter frequency, etc., seems to be called for.

Single Wavelength Working.

The provision of alternative programmes would be simplified by several stations doing the same programme on the same wavelength, and in this section the author discusses some experiments that have been conducted working two stations in this manner.

Theoretically we should expect to find nodes and antinodes.

In the experiments, the Sheffield and Bradford stations (30 miles apart, 200 watts power) were both controlled in frequency by a 1,000-cycle source sent to each *via* landline and raised by valve frequency-multipliers. Radiating the same programme on the same wavelength, the quality was hopelessly distorted outside two or three miles of each transmitter. The trouble was attributed to phase changes in the line link, and the poor quality experienced was compared to night distortion observed when listening to distant stations.

It is stated, however, that experiments in America, Sweden and Germany, using high master-frequencies (about 20 kc.), have encouraged those responsible to put single wavelength operation into service. The author has initiated experiments in which the master drive is to be supplied from a low-frequency wireless station.

Distribution of Broadcasting Stations for a National Scheme.

In this final section of Part I, the author sums up the considerations given above, and discusses the proposed so-called regional scheme for broadcasting in Britain in which existing stations will be done away with and substituted by high-power twin-wavelength stations outside cities previously possessing single transmitters. The scheme assures to every listener an alternative programme, gives to the selective valve-set user a choice of as many programmes as may be occurring simultaneously—albeit some will fade and be interrupted—and makes the field strength over the country as uniform as it can possibly be under existing conditions.

PART II.

The Design of Broadcasting Transmitters.

The conditions for ideal performance of a broadcasting transmitter are :—

(*a*) The frequency/amplitude characteristic of the whole system shall be level. More exactly, for equal input of alternating voltage to the system, at any frequency between 30 to 10,000 cycles per second, there must be an equal modulation of the amplitude of the high-frequency aerial current.

(*b*) At any frequency between the limits stated, the modulation of the high-frequency aerial currents must be proportional (between the limits of practical full and minimum modulation) to the input voltage of modulation.

(*c*) The cost of maintenance in power charges should be taken seriously into account. Power economy for ideal performance should, in fact, be studied in comparing different types of transmitter.

(*d*) It should be possible to modulate the high-frequency aerial currents to the fullest possible extent without introducing distortion.

(*e*) Visual methods of detecting both the depth of modulation at any time, and any distortion, should be part of the equipment of every station.

(*f*) Great constancy of fundamental carrier-wave frequency is essential; in particular, the frequency of the carrier wave should be free from momentary "wobble" under conditions of modulation.

(*g*) As in every wireless station, freedom from harmonics in the emitted radiation is essential.

Types of Transmitter Discussed.

The two types of transmitter here discussed employ choke-control of modulation, and are called "high-power" and "low-power" choke modulation transmitters respectively. The former system controls the aerial oscillations directly from a control circuit using a power equal to or greater than that employed in the last H.F. stage, while the "low-power" system modulates the high frequency at low power and uses the H.F. magnification to bring up the modulated high frequency to full power.

Choke Modulation.

The author then considers the question of choke control, more especially as regards the high-power modulation system.

Condition (*a*).—The conventional diagram of choke control is given in Fig. 4, and its equivalent circuit

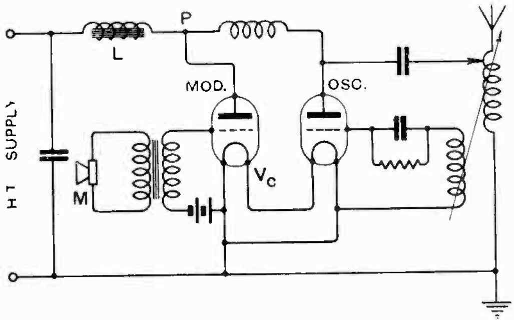


Fig. 4.

is discussed in detail. It is pointed out that the choke has to have large impedance at low frequencies, and that the by-pass condenser is often of such value as to give a cut-off at the higher audio frequencies, *e.g.*, 6,000 cycles. Difficulties of iron saturation in the core increase with power, and the circuit of Fig. 6 (due to Capt. Round) is given as showing a method of neutralising the effect of D.C. in the choke. The transformer arrangement is of 1 : 1 ratio and the D.C. magnetisation of the core is made nil by a reversal of the winding direction or the direction of the D.C.

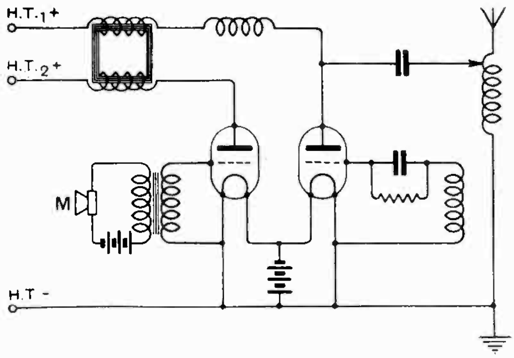


Fig. 6.

The high-frequency circuits, if of too low damping, cause a cut-off at the higher frequencies of modulation. By suitable aerial design this can be eliminated in the 1,500-500 kc. band, but is noticeable on the long wave of 5XX. A partial solution has been found by mistuning the aerial relative to the closed and drive circuits by 3 or 4 kc.

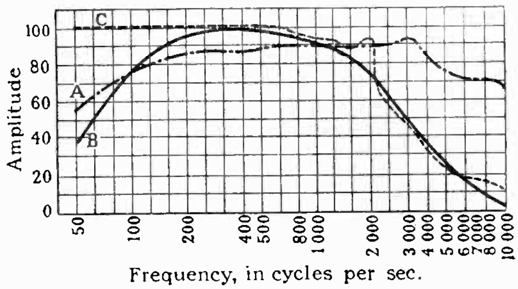


Fig. 7.

Inter-electric capacity may also add to distortion. In Fig. 8 the anode-grid capacity C_v of the final modulating valve will apply to the grid of V_m a voltage in partial antiphase to that from the coupling from V_s. "Neutrodyne" condensers used as a remedy have been found to introduce instability and it is concluded that this effect is best minimised by reducing the overall impedance of the L.F. amplifying system and to sacrifice high amplification per stage.

Distortion in the frequency/amplitude characteristic can often be traced, also, to a too small value of smoothing condenser, especially when V_s (Fig. 8) is supplied from the same source as V_m.

The frequency characteristics of 5XX and 2LO are shown in Figs. 7 and 9 respectively.

Condition (*b*).—In general a valve H.F. generator can be adjusted to give, between certain limits, a strict proportionality between H.T. voltage and aerial current. The study of the linearity of response is best made by a cathode ray oscillograph.

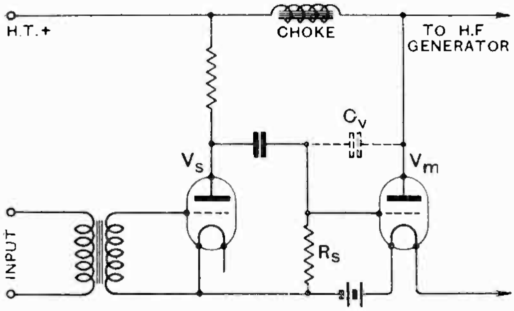


Fig. 8.

If the modulated H.F. component is applied to the *Y* axis and the input modulating voltage to the *X* axis, the result should be a triangular shape of pattern with the tip more and more cut off as modulation decreases (Fig. 10a).

In an experiment in which the H.F. voltage applied to the *Y* axis was compared at several values with the deflection of the cathode stream, it was found that there was a threshold voltage which, until passed, caused no deflection of the cathode stream (at such frequency as a million

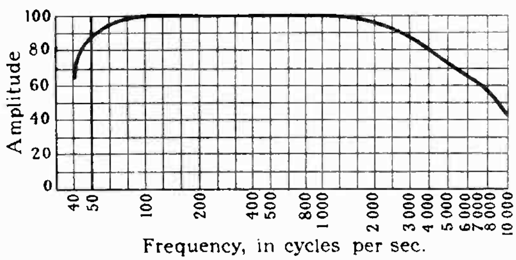


Fig. 9.

per second). This threshold voltage effect explains why, on occasions, the triangle picture (Fig. 10b) may extend its tip to an actual "crown," formed by the continuance of the intersecting sides. So long, however, as there is proportional modulation, the pattern must show straight sides. Fig. 10 (c and d) gives examples of how it may show non-linearity of response.

Grid current in choke modulation is a prevalent source of distortion. Present practice eliminates grid current as far as possible by adopting a considerable factor of safety and suitable grid bias.

It has been suggested to use a 100-kW transmitter at half or less power for normal modulation and to let greater modulation accrue when the music dictates. This, however, would introduce carrier wave "mush" in the receiver, and while "blasting" might be eliminated at the transmitter during a sudden *forte*, the receiver might not have the same factor of safety.

Curvature of valve characteristic may introduce distortion, but by choosing a considerable factor of safety in the modulator valves the effect in practice would seem negligible.

A slight distortion due to the drive circuit coupling directly to the aerial has been minimised by an anti-reaction coil, but a better method, used in the B.B.C. relay stations, is by a neutrodyne capacity connection shown as Fig. 15 in the author's paper.

Condition (*c*).—It is important to find a factor for every type of transmitter which gives the ratio between the total power absorbed from the output terminals of the power supply to the power in the aerial. The figures in Table 1 are based on the design of a 10-kW high-power modulation choke

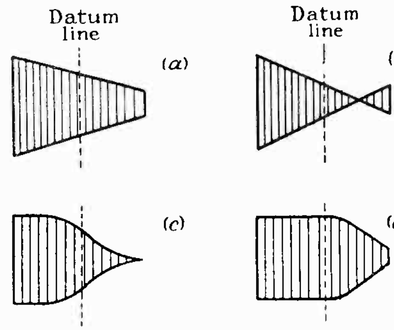


Fig. 10.

transmitter. What is defined as the power-conversion efficiency does not vary a great deal with different-powered stations:—

TABLE 1.

HIGH-POWER CHOKE-MODULATION TRANSMITTER.

Circuit.	Efficiency.	Power taken.
	per cent.	kW.
High-frequency magnifiers	70	14
Drive		2
Control valves H.T. . .		16.8 (14+20 per cent.)
Sub-control valves H.T.		1
Valve filaments (7 water-cooled valves; 20 volts, 50 amps.) . .		7
Miscellaneous valves . .		0.2
		41.0

Power conversion efficiency $\frac{10}{41} = 24.5$ per cent.

Condition (*d*).—After discussing the voltage relations in Fig. 4 and its equivalent circuit, the author states that a very high degree of modulation can only be obtained in practice by using extra power in the control system. The scheme of Fig. 6 gives a greater efficiency of conversion because the voltage supply to the modulator anodes may be raised and the grid sweep increased by larger grid bias than when the H.T. supply was common, while this can also be made to balance the D.C. currents in the windings.

Condition (*e*).—Experience indicates that visual rather than aural indicators are essential to help the controller in his work. The control table, which is always remote from the transmitter, is equipped with two meters—one to indicate a maximum which must not be passed, the other to indicate a momentary volume. The former is arranged as follows: A sensitive milliammeter is connected in series with the anode of a small receiving valve, called the slide-back valve. The grid of this slide-back valve is backed off by a negative potential and is connected to the output terminals of the amplifier connected to the land line feeding the transmitter. It can be arranged that when the positive kick due to this output transformer is just so great as to give a flick of grid current (measured by a milliammeter in the grid circuit) at the transmitter, it also cancels the applied negative on the slide-back valve grid to such an amount that the anode milliammeter gives a flick also. Grid-current flick at the transmitter can, in fact, be synchronised with anode-current flick in the slide-back valve. "Volume," *i.e.*, R.M.S. or mean value of modulation, can be read by a hot-wire ammeter connected to the output valve of a conventional receiver through a step-down transformer, or by a milliammeter in series with the anode of a rectifying valve; these can be calibrated under steady sine-wave modulation against the voltage across the transmitter speech choke. The R.M.S. voltage of modulation at the actual transmitter in a choke-modulation system can be read by an electrostatic voltmeter or a straight-line valve rectifier and series milliammeter connected directly across the main choke of the transmitter. The latter system is better, as the scale is more open, the insulation easier and the movement more "dead-beat."

Condition (*f*).—In general, one may quite definitely state that the single "drive" with choke modulation is not sufficient to ensure the desired constancy of frequency. A load on the drive is caused by grid current in the high-frequency magnifier valves. This grid current varies with the anode voltage on the modulated valves. This throws a variable load on the drive circuit, and hence wave-wobble may result.

It is desirable, therefore, to separate the drive from the modulated valves by another stage. This double-drive circuit, or drive circuit using a "separator," is quite sufficient for all needs, since it not only ensures an excellent day-to-day and hour-to-hour constancy but is an insurance against wave-wobble under modulation. Tuning-fork and crystal drives give a greater constancy, but the author fails to see the need for them (pending single-wavelength working) if the simpler methods give stability and an accuracy sufficient for avoiding interference with other stations. It is essential that all stations shall be equipped with a very accurate wavemeter.

Condition (*g*).—To obtain reasonable efficiency harmonics must necessarily be produced, but these can be removed by suitable design of output circuit without serious losses at the fundamental frequency. The methods are well known and were discussed in Mr. E. H. Shaughnessy's paper on the Rugby Station.

Low-Power Choke-Modulation Transmitters.

Condition (*a*).—The low-power choke-modulation system can be made perfect as regards modulation provided no fresh difficulties occur in designing the H.F. amplifier. The cascade connection of tuned circuits might produce sideband cut-off, but this has been eliminated in practice by using suitable dampings and tight couplings.

Conditions (*b*) and (*c*).—These conditions are intimately related. The main power amplifier must be linear. If grid current is allowed a larger sweep is available, but this tends to produce non-linear characteristics unless certain precautions are taken. The most effective way is to make the impedance across the grid circuit so low that the voltage regulation is good, *i.e.*, so that the relation between the voltage applied to the input circuit and the voltage delivered to the grid is linear. Not only must the impedance be low at radio frequencies, but particularly at audio frequencies as currents at different frequencies are generated by the rectifying action of the grid. This is accomplished by the circuit of 5GB shown in Fig. 17, in which R_h is the shunt resistance and L_h is an air-cored choke.

The power-amplifier preceding the main magnifier is worked without grid currents.

It is instructive now to study the power-conversion efficiency based on a 10-kW transmitter and compare this with the factor for high-power modulation. This is shown in Table 2.

TABLE 2.

Circuit.	Efficiency.	Power taken.
	per cent.	kW.
Final power amplifier ..	32	31.3
1st power amplifier, 15 kW output	20	2.5
Modulation amplifier, 100 watts output	70	0.1
Modulators, etc.		0.4
Master oscillator		0.2
Separator		0.2
Power amplifier filaments		3.0
1st power amplifier filaments		1.0
Other filaments		0.4
		39.1

$$\text{Power conversion efficiency} = \frac{10}{39.1} = 25.5 \text{ per cent.}$$

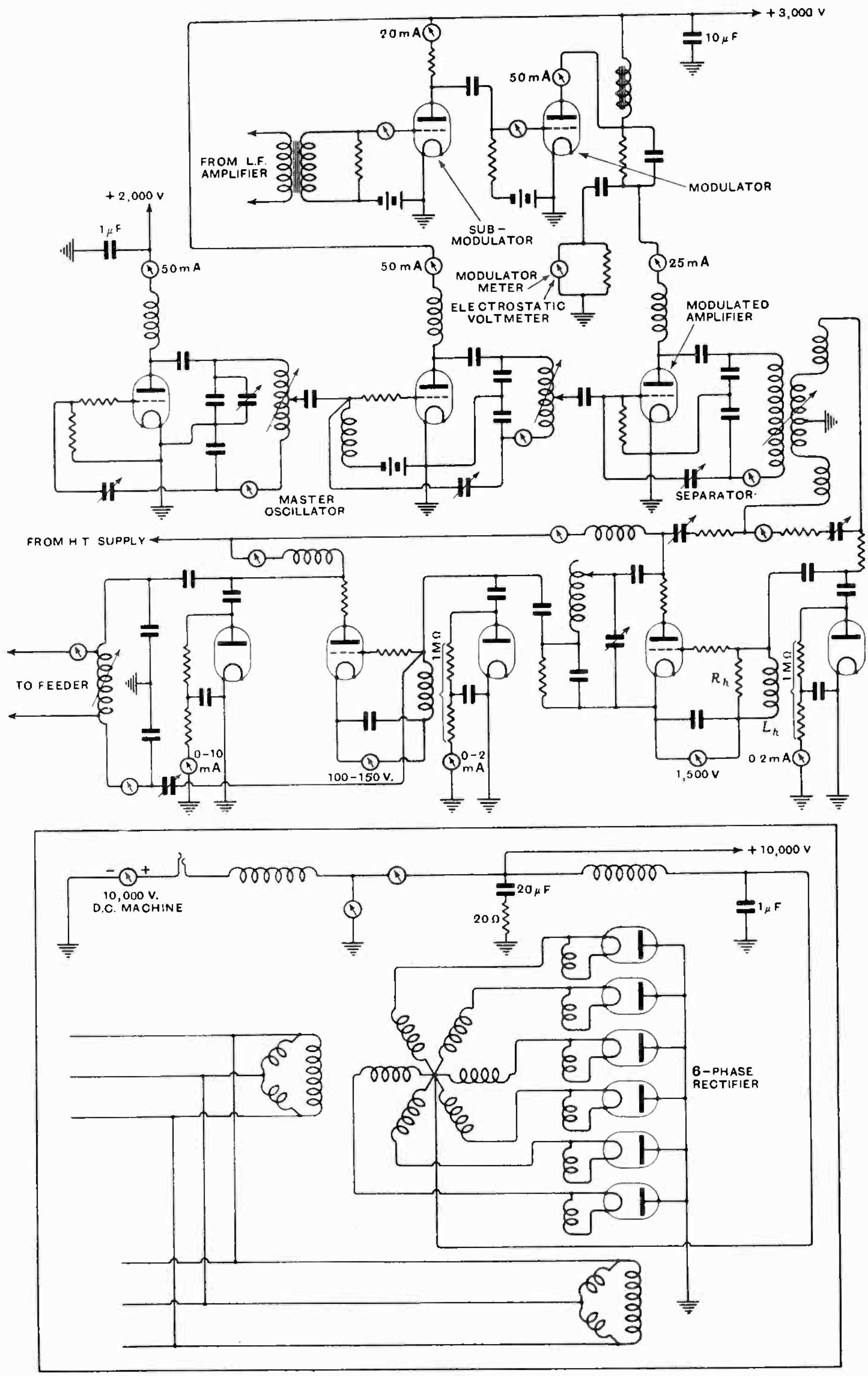


Fig. 17. *The circuit of the 5 G B (Daventry Experimental) Transmitter.*

Condition (*d*).—This is fulfilled more easily than in high-power modulation. Inefficiency is of less importance at low power and the modulator valves can be worked completely over the linear portion of their curves without grid current.

Condition (*e*).—The slide-back valve can no longer be calibrated against grid current in the modulator valve but against the peak voltage ratio of the final stage or the peak voltage modulation as read on a suitable modulation meter, *e.g.*, that of van der Pol and Posthumus.*

Condition (*f*).—This is easier than at high power. The master oscillator and separator are at low power less; screening is simple and efficient.

Condition (*g*).—The reduction of harmonics to a negligible amount is a matter of design of circuits, and very simple circuits of suitable and well-known design are quite effective in practice.

Fig. 18 shows the frequency/amplitude characteristics of the 5GB transmitter shown in Fig. 17. Curve *A* shows the sideband cut-off due to low resistance aerials; no steps have been taken to improve this effect because new aerials are being built which will remove it.

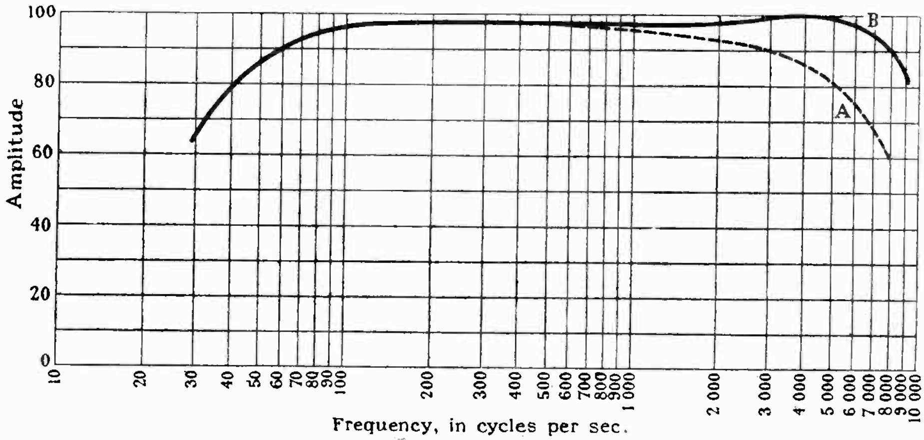


Fig. 18.

Comparison Between the Two Methods Described.

In summarising, the author believes that low-power modulation is superior to high-power modulation for the reasons:

(1) Better frequency characteristic.

(2) Greater factor of safety and greater stability.

(3) Requires to deal at high power with a frequency gamut of from 1.04 : 1 to 1.02 : 1 (using medium waves), while the high-power modulation system has to deal with a frequency gamut of 200 : 1 at high power.

(4) Efficiencies of power conversion are sensibly equal.

(5) Probably more flexible in changing from linear to non-linear modulation when this, by accident, may occur.

Valve Point Discharge.

Reference is made here to valve flash-over, which has been experienced at the broadcasting stations, but has presented less difficulty with high-power modulation than with low power.

Anode Power Supply.

In this final section, some interesting figures are given on the cost of anode supply power. A 50 kW station absorbs something like 300 kW, costing nearly £4,000 per annum for 3,000 hours' work per annum. The gain of efficiency in using a D.C. machine (83 per cent.) as compared to a rectifier system (60 per cent.) represents about £1,900 per annum. Even with the greater capital cost the use of D.C. generators represents a saving of £12,000 per annum on a scheme such as that proposed for Great Britain.

DISCUSSION.

In opening the very lengthy discussion which followed the reading of the paper, Mr. P. K. Turner referred to the immense value of the paper as a statement of policy. His first point of divergence was that he thought the author was pessimistic on the possibilities of the average set of to-day and to-morrow. In connection with the need of a frequency gamut of 30 to 10,000 cycles, he quoted a case where the loud-speaker was undoubtedly falling off at 50 cycles, but, while this was so, it was noticeable that the performance was improved when the range of the set preceding the speaker was extended from 50 to 30 cycles. As regards the suggestion of a band-pass filter with a sharp cut-off, he had used such a filter where the band, although fixed in width, was readily varied in its frequency position. The arrangement appeared full of promise. He asked whether it was practicable to transmit 30 to 10,000 cycles over land lines. As regards the depth of modulation at the transmitter, the detectors available could handle small modulation but could not

* *E.W. & W.E.*, 1927, Vol. 4, p. 140.

deal with heavy modulation. "Control" of the level at the transmitter was a thing that could easily be overdone.

Mr. Mason thought the paper could not fail to give assistance to those concerned with the design of broadcasting transmitters. He was glad to see that the author was in favour of low-power modulation. His company had adopted this principle for transmitters of over 1 kW for some years. Capt. Eckersley hardly did justice to the low-power modulation system. He next turned to the matter of valve flash-over. There was less of this with rectifier supply, and the effect varied with the number of valves used in parallel. Could the author say if valves earlier in the cascade than the final power stage gave trouble? He disagreed with the author's figures about rectifier efficiency and gave 70-72 per cent. as a value. In the case of a D.C. generator, all the power supply was concentrated in one machine and provision against failure must involve complete duplication. On calculations on this basis he differed from the author on the respective costs of rectifiers and machine supply. As regards the frequency gamut, a transmitter had been designed in America for use in television with a flat frequency characteristic from 20 to 20,000 cycles.

Mr. A. J. Gill suggested that wooden masts were not an impossible solution of the effects of iron masts already experienced. Wooden masts at Rome and Horsea were examples. As regards the width of band necessary he showed a slide comparing the band *B* (of Fig. 7) with the band of 400-3,000 cycles used at Rugby on transatlantic telephony, and said that the Rugby arrangement gave excellent speech. He had, in fact, passed broadcast reception through a filter with a sharp cut-off at 3,000 cycles and could not tell the difference.

Mr. Minter said that while the author spoke of interference from spark sets, interference from a valve transmitter was well known in London, in an A service area, while he also quoted other cases of interference from valve sets. He was surprised that there was no measurement of the field round the transmitter. The Post Office had done so at Leafield. He thought the Rugby width of band might be quite applicable.

Mr. Ames asked for more information about Fig. 1. Had multiple-tuned aerials been tried? This method represented high efficiency at low cost. Was information available as regards the loss due to the effect of buildings as against that of transmission line feeders? In connection with masts, he suggested a metal mast on concrete and porcelain and the whole mast tuned by a coil. This could also be used as a multiple-tuned aerial.

Mr. R. A. Watson Watt asked for information as to the author's figures of the effect of the cathode ray oscillograph in examining modulation. What were the constants of the abscissæ against which the tube deflection was plotted? He inferred the figures as indicating a threshold of 8 to 12 volts.

Mr. E. B. Moullin spoke in favour of transmitting levels of field strength which permitted simple reception. He thought the field strength allowance indicated was liberal. At Cambridge the level was more of the order of $\frac{3}{4}$ mv/m. He would like more information on the effect of the aerials and upon the meaning to be drawn from the curves of Fig. 1.

Mr. Braendle spoke of the working of two stations on one wavelength, and asked how this affected sideband distortion. In the difficulties experienced, might not phase change occur in the transmission line conveying the modulation?

Mr. M. J. Scroggie referred to experiments in tuning when he had used a large aerial and a tap low down on the tuning inductance, an arrangement which gave considerable increase of the wanted signal strength. An aerial circuit even without reaction could be sufficiently sharp to cut off sidebands, and he quoted experimental figures which he has measured in this connection. In Fig. 17, 6-phase A.C. was shown. For what purpose was this used?

Dr. R. L. Smith-Rose referred to the matter of mast insulation, and the facilities provided at Rugby for either insulating or earthing. Neither seemed to make much difference. The distortion of polar diagram might, he suggested, be improved by a number of masts, say four. He questioned the soundness of rating a transmitter in terms of aerial power, since, without further specification of the radiation resistance, this gave no measure of the performance.

Capt. H. J. Round briefly referred to the comparison of $\frac{1}{2}\lambda$ and $\frac{1}{4}\lambda$ aerials. As regards depth of modulation, the inability of the detector to handle heavy modulation, there was need for improvement in the rectifier at the receiver. He thought the author was rather hard on the high-power choke control. The decision as between the two systems must be made on which was the most hopeful in practice. In the case of low-power modulation there was more possibility of overloading the final H.F. amplifier than of passing the limits of modulation in the high-power system. Economy of power suggested a push-pull choke method.

Capt. Eckersley briefly replied to the discussion, more especially to some of the points raised by Messrs. Turner, Mason, Gill, and Round.

On the motion of the Chairman (Lt.-Col. A. G. Lee, O.B.E., M.C.), the author was cordially thanked for his paper.

Characteristic Curves of the Four-electrode Valve

By N. R. Hall, A.R.C.S.

SINCE the introduction of the four-electrode valve for the reduction of the anode voltage, some experiments have been made using higher anode voltages and various voltages on the grids, but the second grid so greatly increases the combination of voltages which can be applied to the various parts of the valve, that a set of characteristic curves is almost a necessity for useful experimental work.

The following curves have been drawn from a valve known as the U.C.5, which has two concentric spiral grids and a spiral anode, and takes 5 volts on the filament.

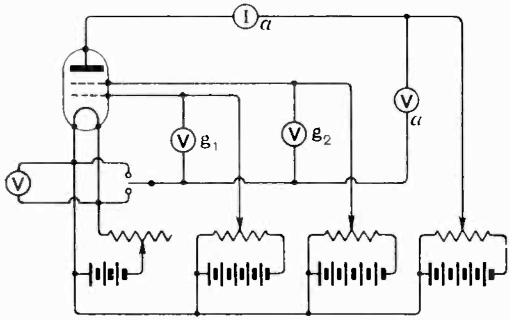
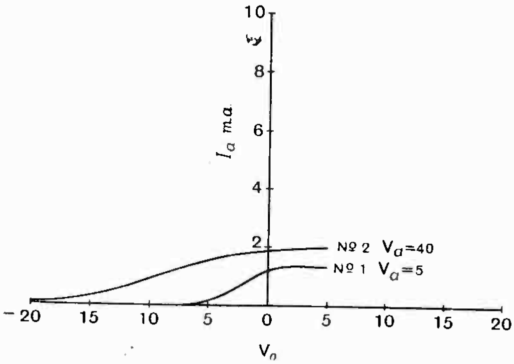


Fig. 1.

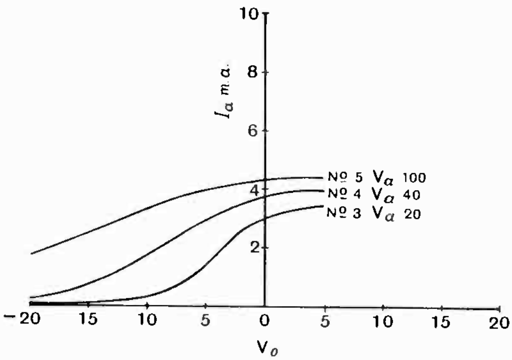
The characteristics of the three-electrode valve are generally given by a set of curves, connecting the anode current and grid voltage, the anode voltage being kept constant. This gives a separate curve for each value of the constant anode voltage. The amplification factor is obtained from these curves by finding the value of $\frac{\Delta V_a}{\Delta V_g}$ for a given rise of I_a, and limiting the values ΔV_a and ΔV_g to the straight parts of the curve. The grid resistance is given by the reciprocal of the slope of the curves, and the anode resistance is found by multiplying this by the amplification factor.

Another useful curve is that in which the anode voltage is plotted against the grid voltage for a constant value of the anode current. The slope of this curve at any point gives the amplification factor.



Curve 1.—*In these curves the inner grid is kept constant at 5 volts.*

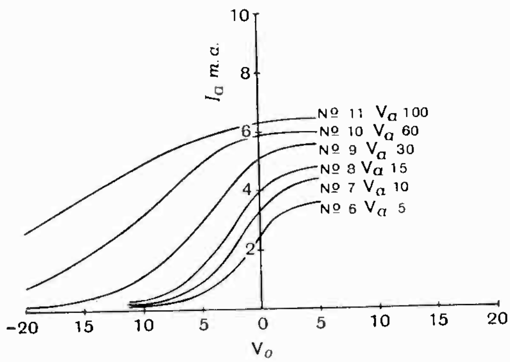
The four-electrode valve can be treated in the same way, but the curves must first be divided into two groups, in one of which the inner, and in the other the outer, grid is kept at constant potential. Having divided the curves into these preliminary groups, there will be a complete set of I_a, V_g curves for each value of the constant grid voltage. There will be two amplification factors, one for the outer grid and anode with the inner grid constant, and the other for the inner grid and anode with the outer grid constant.



Curve 2.—*Inner grid constant at 10 volts.*

The four-electrode valve is the same as the ordinary valve in appearance except that it has two concentric grids between the filament and the anode. The apparatus used for drawing the characteristics will therefore require another potentiometer to supply the extra grid. It is shown in Fig. 1.

The introduction of the second grid greatly increases the number of curves which have to be drawn to represent the behaviour of the valve; and some method will be useful in their arrangement. Taking the anode current as the dependent variable, there are three independent variables: the anode voltage and the two grid voltages.



Curve 3.—*Inner grid constant at 15 volts.*

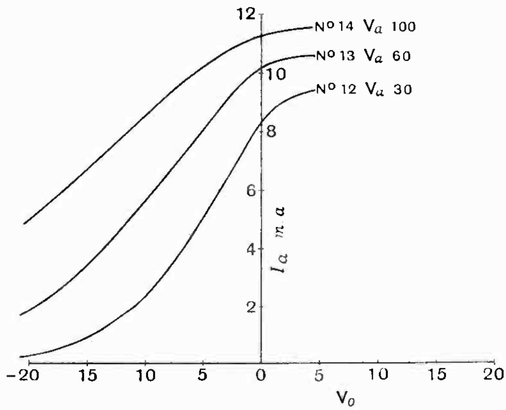
The curves have been divided into two groups, according to which grid is kept constant.

GROUP I—INNER GRID CONSTANT.

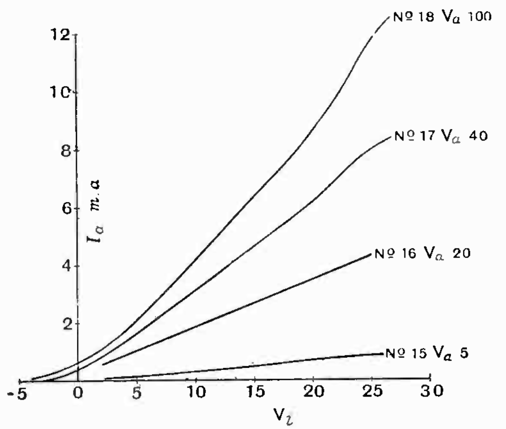
V_i	V_a	No.	R_a	Amp. factor.
5	5	1	10,000	2.8
	40	2	37,000	5.4
10	20	3	13,000	5.4
	40	4	22,000	5.4
	100	5	32,000	5.4
15	5	6	6,000	3.0
	10	7	6,400	3.7
	15	8	8,000	4.3
	30	9	10,500	4.5
	60	10	13,000	4.5
	100	11	20,000	4.5
25	30	12	6,200	3.8
	60	13	8,300	3.8
	100	14	10,000	3.8

GROUP II—OUTER GRID CONSTANT.

V_0	V_a	No.	R_a	Amp. factor.
0	5	15	—	—
	20	16	—	—
	40	17	13,400	4.3
	100	18	144,000	61.0
5	5	19	9,500	2.2
	10	20	17,000	4.8
	20	21	18,000	5.5
	40	22	144,000	63.0
	100	23	132,000	63.0



Curve 4.—*Inner grid constant at 25 volts.*



Curve 5.—*In these curves the outer grid is at zero potential.*

In the three-electrode valve we have:—

$$\text{Anode Resistance} = \left(\frac{dV_a}{dI_a}\right) V_g \text{ constant.}$$

$$\text{Grid Resistance} = \left(\frac{dV_g}{dI_a}\right) V_a \text{ constant.}$$

Voltage Amplification Factor

$$= \left(\frac{dV_a}{dV_g}\right) I_a \text{ constant.}$$

Using the same convention with the four-electrode valve :—

Anode Resistance $= \left(\frac{dV_a}{dI_a}\right) V_i$ & V_0 constant.

Inner Grid Resistance

$$= \left(\frac{dV_1}{dI_a}\right) V_a \ \& \ V_0 \text{ constant.}$$

Outer Grid Resistance

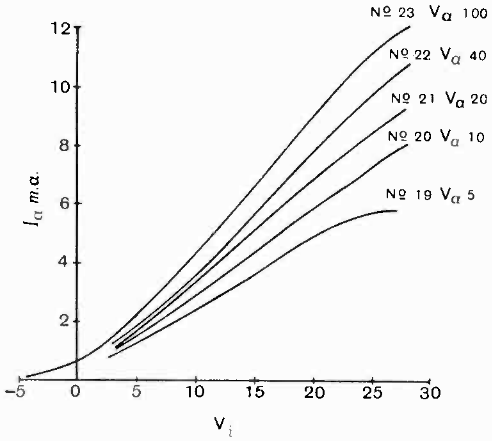
$$= \left(\frac{dV_0}{dI_a}\right) V_a \ \& \ V_i \text{ constant.}$$

Inner Grid Amplification Factor

$$= \left(\frac{dV_a}{dV_i}\right) I_a \ \& \ V_0 \text{ constant.}$$

Outer Grid Amplification Factor

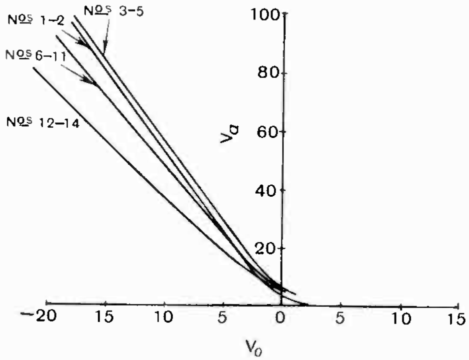
$$= \left(\frac{dV_a}{dV_0}\right) I_a \ \& \ V_i \text{ constant.}$$



Curve 6.—*Outer grid constant at 5 volts.*

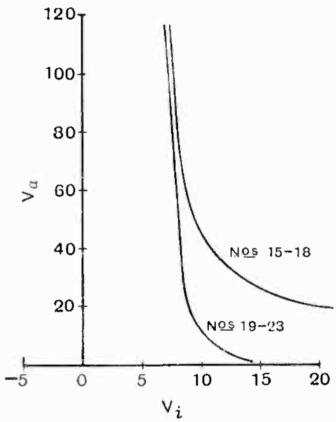
The first group of curves drawn with the inner grid constant are much the same as those of the three-electrode valve, except that amplification begins at a lower anode voltage. The first curve gives an amplification of 3 when the anode potential is only 5 volts, a voltage which can be supplied by the filament battery. The only other curves of this group which are remarkable are Nos. 6 and 7, which have the characteristic of a power valve with the very low voltage of 5 and 10 volts.

It is in the next group, in which the outer grid is constant, that the most interesting results are obtained. These curves differ from the three-electrode curves in that they are almost entirely on the positive side of the graph, and they are not at all parallel, resulting in an unequal amplification for different parts of the curve. The most interesting point is, however, that an



Curve 7.—*In these curves the inner grid is kept constant and the slope at any point given the "outer grid voltage amplification factor."*

amplification of over 60 is reached in Nos. 18, 22 and 23. This, it might be thought, is only due to the proximity of the inner grid to the filament, and could be obtained equally with an ordinary valve having a grid placed very near to the filament. But in No. 18 the outer grid is kept at zero potential, and an amplification of 60 is reached only



Curve 8.—*In these curves the outer grid is kept constant and the slope at any point given the "inner grid voltage amplification factor."*

when the anode potential is over 100 volts. No. 22, on the other hand, gives an amplification of 60 with only 40 volts on the anode, showing that the outer grid influences the results to a great extent. As might be expected, the outer grid current is considerable.

Calculations for Resistance Amplifiers.

By A. L. M. Sowerby, M.Sc.

THERE are occasions when the design of a resistance amplifier, even apart from the calculations of low-note and high-note loss, is not quite the simple matter that one expects it to be. Particularly is this the case when it is necessary to deal with large signal voltages, and the high anode potentials that they entail. The writer recently found himself confronted with the questions that arise in this way, and, having no experience to guide him, proceeded to do calculations instead. It is hoped that, despite several simplifying assumptions, these calculations may perhaps be of use to others who may find themselves in a similar position.

The kind of problem that arises can be most quickly seen from the diagram of Fig. 1. If, for example, T_2 is an L.S.5a valve with 80 volts of grid-bias, it follows that T_1 has to give a signal output V of peak voltage 80 volts without overloading. It is not easy to decide, at sight, whether any particular valve that one may have in mind will or will not give this output; it is still less easy to guess correctly the value of the anode resistance R that, with the available anode voltage E, will make the output V a maximum. Within certain limitations, these are all matters susceptible of easy calculation.

Let Fig. 2 represent the anode current-anode voltage characteristic of a valve (T_1 of Fig. 1). It is straight, or very nearly so, above a certain plate voltage, and over this range the resistance R_0 of the valve is constant, for it is equal to $\frac{dE_a}{dI_a}$. Producing the straight part backwards, it cuts the horizontal axis in P, at a distance E_0 from O. If we now look upon P as a "zero point" from which to reckon plate volts, and call (E_a-E_0) the "effective plate voltage," *we can treat the valve as though it had a constant D.C. resistance equal to* R_0. But we must bear in mind, through all calculations based on this, that our conclusions will be untrue for all plate currents less than a certain minimum I_{min} at which the real curve begins to drop away from the straight line that we have arbitrarily substituted for it, and that in place of the *actual* plate volts E_a we must use for calculation the *effective* plate volts (E_a-E_0).

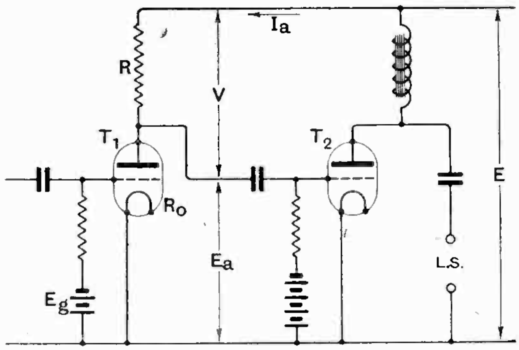


Fig. 1.

The method of determining E_0 experimentally is sufficiently obvious from Fig. 2.

If R_0=A.C. resistance of valve over straight portion of characteristic.
E =Voltage of anode current supply.
E_a=Voltage applied to anode of valve.
I_a =Anode current.

we can write :—

$$I_a = \frac{E_a - E_0 + \mu E_g}{R_0}.$$

If a resistance R is inserted in the plate circuit, then the plate current becomes :—

$$I_a = \frac{E - E_0 + \mu E_g}{R + R_0} \quad \quad (1)$$

For distortionless amplification, the plate current of the valve can vary up to the maximum given by putting E_g=0 in the above equation; higher values than this imply that grid current flows. It can vary down to a minimum value I_{min}, at which point the characteristic begins to curve appreciably (Fig. 2). The total permissible swing of plate current is therefore given by the difference of these two currents, while the peak value attained is *half* this difference.

Max. change of I_a from steady value

$$= \tfrac{1}{2}\left\{\frac{E - E_0}{R + R_0} - I_{min}\right\}.$$

This develops across R a varying voltage V of peak value

$$V = \tfrac{1}{2}R\left\{\frac{E - E_0}{R + R_0} - I_{min}\right\} \text{ volts} \quad .. \quad (2)$$

and this is also the numerical value of the grid voltage that must be applied to the succeeding valve to enable it to deal with the signals without distortion.

This equation (2) enables us to calculate the maximum output that can be obtained from a valve of known constants, with a battery voltage E and an anode resistance R.

Our next concern must be to develop a formula for finding that value of R which makes V a maximum. This is done by differentiating the above expression for V with respect to R, and equating the result to zero :

$$\frac{R_0(E - E_0)}{(R+R_0)^2} - I_{min} = 0,$$

whence $$(R + R_0)^2 = \frac{R_0(E - E_0)}{I_{min}} \quad .. \quad (3)$$

It will be appreciated that it makes for simplicity in use to leave the equation in this form rather than to attempt to find from it an expression for R ; the latter is found from $(R+R_0)$ by subtraction.

We can also find the grid-bias required under working conditions ; it must be half-way between the grid voltages corresponding to the two extreme values of plate current. It will be, therefore, E_g in the following modification of (1) :

$$I_{min} = \frac{E - E_0 + 2\mu E_g}{R + R_0}$$

whence

$$-E_g = \frac{1}{2\mu}\left\{E - E_0 - (R + R_0)I_{min}\right\} \quad .. \quad (4)$$

Finally, we can find the working value of the plate current from (1) ; it is

$$I_a = \frac{E - E_0 + \mu E_g}{R + R_0} \quad .. \quad (5)$$

We may note also that :

$$E_a = E - I_a R \quad .. \quad .. \quad (6)$$

and that the overall amplification produced by the stage is :—

$$A = \frac{V}{E_g} \quad .. \quad .. \quad (7)$$

That is the last of the equations, but in order to make quite clear the way in which they are used, and the type of case to which they are applicable, one example will be given.

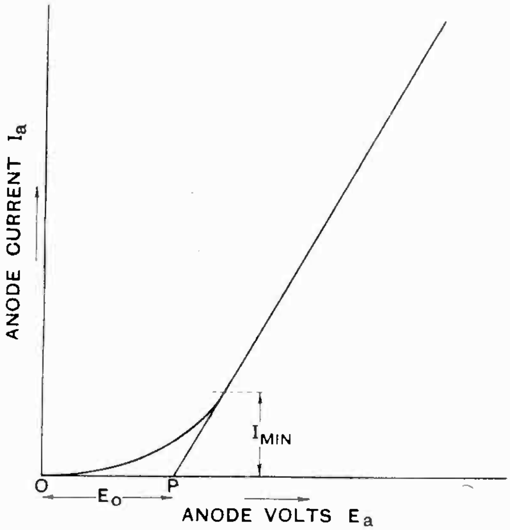


Fig. 2.

If T_2 of Fig. 1 has a grid-bias of 80 volts, and E is 300 volts, which will be the better valve to employ as T_1, a D.E.5 valve or a D.E.5b ?

From the published curves of these valves, the following data are taken :—

	D.E.5b.	D.E.5.
μ	20	7
R_0	35,000	8,000 ohms.
E_0	50	26 volts.
I_{min}	1	2 milliamps.

First we turn to equation (3), and find from it R. The values of $(R+R_0)$ come out at 105,000 and 33,000 ohms respectively for the two valves, so that the anode resistances to employ will be 70,000 or 25,000 ohms. Armed with these values, we turn to equation (2) and find V, the maximum output that can be obtained. For the D.E.5b valve this is found to be 49 volts only, so that it is quite clear that we cannot hope to feed T_2 from a D.E.5b, and that we must forgo the high amplification that this valve can offer us.

But the value of V found from (2) for the D.E.5 valve is 79 volts, which is quite near enough to the 80 volts required. This valve may, therefore, be incorporated in the amplifier, with its plate resistance of 25,000 ohms.

Equation (4) gives us the correct value of grid-bias to employ; it is 15 volts. Putting this value in equation (7) the actual amplification afforded by the stage is found to be 5.3 times. Finally, the working value of anode current, and the voltage that is applied to the plate of the valve itself, can be obtained from equations (5) and (6); they are respectively 5.2 milliamperes and 170 volts.

We have now satisfied ourselves that the valve in question is suitable for its purpose, and are in possession of the fullest working data for the valve as part of the amplifier. There remains nothing but to emphasise that the equations given are only valid when the anode voltage is sufficiently high, and the valve resistance sufficiently low, to ensure that the working value of the latter is not appreciably higher than the maker's rating. This will, in general, not be the case when valves of high resistance are used with high anode resistances, but if the value of E_a is found from equation (6) to be not less than about 100 volts, it may be concluded that the necessary conditions have not been violated.

Book Reviews.

THERMIONIC VACUUM TUBE CIRCUITS. By L. J. Peters, 244 pp. with 81 Figs. McGraw-Hill Publishing Co., London. Price 15s.

Starting with elementary thermionic theory including numerical examples, the author shows how the characteristic curves of two and three electrode valves arise. Passing on to elementary amplifier theory, he develops formula for power and voltage magnification, using resistance coupling. Conditions for maximum amplification are also determined. Reactance coupling is then treated for a single stage. Following this is a treatment of multi-stage amplifiers, the underlying mathematical theory being developed. The neutralisation of resistance by the aid of triodes and the analytical relationship concomitant with certain phenomena are treated in detail. Then follows the use of the triode as a generator of sustained oscillations; the usual expressions for oscillatory current and power are also given.

The reception of radio signals with its application to triode circuits receives attention. Formulæ are given for calculating the selectivity curve of a tuned circuit, and the problem of immunity from interference and atmospherics is broached.

After treating the problem of carrier wave modulation and showing analytically how the side bands originate, the process of rectification and the various frequencies associated therewith is sketched.

Finally, the theory and design of amplifiers is treated analytically, the input grid impedance being included. This latter is a feature we heartily welcome, since it is usually conspicuous by its absence. Unfortunately, the treatment of transformer coupling is marred by omitting leakage and the self- and mutual-capacities of the windings. As these factors control the performance of transformers at the higher audio frequencies, the analysis is only of value at the lower frequencies where the effect of inductance preponderates. It does, however, afford real interest, since it is at these frequencies that negative resistance effects (input impedance) play their shady part.

The book is mathematical throughout and ends with three appendices.

N. W. M.

PRACTICAL RADIO CONSTRUCTION AND REPAIRING. By Moyer and Wostrel. Pp. 319 and 157 Figs. McGraw-Hill. 10s.

This is an American book addressed to amateur constructors and repairers and to the radio dealer who has to test and repair sets. General workshop tools and methods are described, and elementary instructions given for testing valves and other accessories, instructions are given for the manufacture of a number of sets of various types, and also for making loud-speakers and battery eliminators. A chapter is devoted to what is called "trouble-shooting." A glossary of radio terms is given as an appendix, and we note that "M.U. = amplification constant." We suspect that this is someone's effort at "μ."

Although well adapted to the purpose for which it is written, we do not think that it will appeal so much to English amateurs, partly because of the difference of terminology, but mainly because the recommended components are often unknown in this country.

G. W. O. H.

American Geophysical Union—Abstract of Reports and Papers presented at the Annual Meeting of the Section of Terrestrial Magnetism and Electricity. April, 1927. 70 pp. Bureau of Standards, Washington, U.S.A.

This is a symposium of the correlation of various radio phenomena with solar and terrestrial magnetic and electrical activities. It contains 11 papers, including one by Pickard on radio-reception and solar activity, and another by Austin on the same subject. The concluding paper is a Summary of the others by Dr. Dellinger.

Elements of Radio Communication. By Ellery W. Stone. Third Edition, revised and enlarged. Pp. 433, with 220 Figs. Chapman & Hall, Ltd. 10s. 6d.

This is an American book written by an officer of the U.S.A. Navy primarily for the use of naval students. It is of an elementary non-mathematical character and deals with the subject from an historical point of view; it goes fairly fully into descriptions of the various types of spark-gap, devotes considerable space to the Poulsen Arc, and never mentions the thermionic valve until one reaches page 331. Chapter 3 opens as follows: "Radio communication was made practical by Guglielmo Marconi, an Italian, who spent a great many years of his life in England and did most of his scientific work there. His greatest contribution to the art was the adoption of the grounded antenna, which is in use at the present time. Prior to Marconi, Hertz, a German, had employed ungrounded waves for radio purposes, but their range of transmission was limited," and then, after describing the plain aerial we are told: "However, this Marconi transmitter had one redeeming feature—it was a single circuit transmitter. That is to say, there was but one oscillating circuit. As such, it gave rise to waves of but one frequency or length, and was thus greatly superior to a later Marconi transmitter, which employed two oscillating circuits and thus radiated waves of double frequency." On page 331 we are told that "in 1883, or earlier, the American scientist Thomas A. Edison made known an interesting phenomenon which was observed in the manufacture of the *metal* filament electric lamp which he invented." This is a surprising thing to find in a third edition. The book is well illustrated and contains a lot of information expressed in simple language; it has evidently had a good sale in the States, but would not appeal so much to English readers.

G. W. O. H.

Electric Rectifiers and Valves. Translated from the German of Güntherschulze by N. A. de Bruyne. Pp. 212+ix. and 94 Figs. Chapman & Hall. 15s.

The name of Güntherschulze is well known to those who are acquainted with the German literature of the subject, and we welcome this translation of his book *Elektrische Gleichrichter und Ventile*. The translator points out in his preface that he has made a large number of alterations, the material for which was generally supplied by the German author; the translator has added paragraphs on the tantalum rectifier and the Moullin voltmeter. The word "valve" in the title is to be understood as applying to a piece of apparatus which lets the current pass one way only; the book is not concerned with three-electrode thermionic valves, and the Moullin voltmeter looks somewhat of an intruder. The subject is treated from the point of view of the physicist wishing to study the processes underlying the phenomena of rectification, the first half of the book being devoted to the physical theories and the second half to the technical applications of the various methods. Gas valves of the Tungar type, electrolytic valves, and mercury arc rectifiers both in glass and metal containers are all discussed fairly fully. Some mechanical types are described, but the translator regrets that he cannot give full details of Hartmann's mercury jet rectifier. This is unfortunate, as it was fully described and exhibited in operation at the British Association meetings in the first week of September, and the translator's preface is dated 25th August. We miss any reference to the copper-oxide rectifier which was on the market, and had been fully described in technical journals. These are minor matters, however, and the book contains a large amount of valuable information for those desirous of studying the physics of the subject, a mathematical discussion of the currents and powers in the electric circuits of polyphase rectifiers, and constructional details of various commercial types.

Sometimes things might be explained more fully, as, for example, on page 6, where it is stated that "with an elastic impact the energy given up by a colliding electron to a particle, which was stationary before the collision, is equal to 2 mm., where m = mass of electron and m_1 = mass of atom, *i.e.*, the energy given up is independent of the velocity of the electron, which is not correct, and is not what is intended. We noticed this tendency to carelessness of wording in several places. In the preface the translator says, "Lest this book should fall into the hands of a purist, I will forestall his criticism by admitting that he will probably find much in it to offend his prejudices; but in a scientific book clearness is worth an occasional redundancy, and exact expression is more important than elegance of style." At the risk of being called a purist, I maintain that sentences such as the following: "A much greater voltage is necessary to send a given current strength through the gas *as* when free electrons are available," while certainly sacrificing elegance of style, add nothing to clearness. Exact expression and elegance of style are not so inconsistent as the translator believes.

G. W. O. H.

The Four-Electrode Valve. By Fred Goddard. Pp. 104 with 64 Figs. Mills & Boon. Price 3s. 6d. net.

Only about 11 pages of this book are really concerned with the principles underlying the four-electrode valve. The last 70 pages are devoted to "some four-electrode valve circuits." We could find no mention of the screened valve, the only four-electrode valve about which most readers are concerned at the present time.

In the preface the author says that he is convinced that there is a need for something of this sort. We agree that there is room for a book on the four-electrode valve, but we should prefer something of a different sort.

G. W. O. H.

A Short Survey of Some Methods of Radio Signal Measurement.

By K. Sreenivasan, B.Sc.

The Paper is divided into the following sections :—

SECTION A.

SECTION B.

Section A.

1. In the theory and practice of radio communication, the measurement of the field strength of received radio signals due to a distant transmitting station is gradually attaining an importance that can be hardly exaggerated. The phenomena attending radio communication are very numerous and complicated and not yet completely understood. In the design of apparatus to secure a reasonable degree of accuracy, compromise has to be made between a number of conflicting requirements. The variety of apparatus at present in use in various countries by different investigators only goes to show the degree of compromise that was considered necessary in the different cases.

2. The problem in its essentials is simplicity itself. Given a transmitting station T with a current I at the base of its aerial of height h, what is the intensity of the signal received at a receiving station R at a distance d from T? The ready answer to this question is: put up an aerial of known constants and measure the current in the aerial by some means and deduce therefrom the field strength. In principle, this is exactly what is done by every experimenter.

All the difficulties in the measurement arise from three causes: (*a*) the constants of the receiving aerial; (*b*) the method of measuring the current in the receiving aerial because of its extreme smallness; and (*c*) interference due to other stations and atmospheric disturbances. The current in the aerial is usually of the order of a few microamperes and the energy taken by it, of the order of a few billionths of a watt.

The number of investigators in this field is a fair indication of the complexity of the problem. Physicists, mathematicians and radio engineers all over the world have made and are still making great efforts towards the solution of this problem. Hertz set the ball rolling in his classical experiments, the starting point of all radio work and progress. From 1902 onwards, attempts have gone on with a gradual increase in the number of investigators and a rapid improvement in the apparatus used. Prominent among the names of those who have attacked the problem theoretically are Heaviside, Larmor, Eccles, G. N. Watson and H. M. Macdonald in the British Isles, Sommerfeld and van der Pohl in the European continent, G. W. Pierce, A. E. Kennelly, H. W. Nichols and J. C. Schelling in America, and Nagaoka in Japan. On the experimental side, there are L. W. Austin and Louis Cohen, Fuller, Englund, Bown and Friis in the United States, Vallauri in Italy, Lt. Guierre and René Mesny in France, Duddell and Taylor, Eccles, the Marconi Research Staff, and Hollingworth in England, and Max Reich and Baumler in Germany.

3. *The Earliest Experiments.*—If we consider the ideal Hertzian oscillator, consisting of two equal and opposite charges varying harmonically with time so far as their

magnitudes are concerned, then the intensity of the energy density decreases in proportion to the inverse of the square of the distance. This is from purely theoretical considerations.

In practice, however, the inverse square law is found to hold good when the distance does not exceed 50 miles. Beyond this limit, marked departures from this simple law are met with. Marconi was the first to find these differences in his investigations on the Atlantic Ocean in 1902. Chief of these were, first, that during the day reception was not possible at distances greater than about 800 miles from the transmitting station, while signals were easily readable at nearly 2,000 miles during the night ; secondly, that signals were not of constant intensity either during the day or during the night.

Next in importance were the first systematic experiments of Dr. L. W. Austin and Dr. Louis Cohen on behalf of the American Navy during the five years, 1910 to 1915. The maximum distance covered during these experiments were 3,800 km. or 2,400 miles. As a result of their labours, these investigators evolved the well-known absorption formula, now generally called after them.

Let h_T be the effective height of the transmitting aerial,
λ, the wavelength,
d, the distance between the transmitting and receiving stations,
I_T, the current in the transmitting aerial,
h_R, the effective height of the receiving aerial,
and R, the resistance of the receiving aerial,

then the formula for the current in the receiving aerial is

$$I_R = \frac{120\pi h_R h_T I_T}{d\lambda R}.$$

This formula is based on the assumptions that (*a*) the surface of the earth is plane ; (*b*) the ground is a perfect conductor, and (*c*) the atmosphere round the earth is a perfect di-electric. The formula itself is quite accurate for short distances and the assumptions are justified in such cases.

The absorption factor is of the form $e^{-kd\lambda^{-m}}$, e being the base of the natural logarithms. The experiments of Austin and Cohen gave for k and m the values 0.0015 and 0.5 respectively. This coefficient could not and did not fit into every value ; it was a broad application to fit into average results for transmission over the sea, particularly for long waves.

Later, in 1914–15,* Fuller carried out measurements over longer ranges than Austin did. Between San Francisco and Honolulu, the distance is 3,800 km. ; and the distance between Tuckerton and Honolulu is 8,000 km. For these distances, Fuller's coefficient—also of general application—was $e^{-0.0045d\lambda^{-1.5}}$.

These coefficients for absorption during transmission are not comprehensive. It would be well-nigh impossible to frame a formula which would take into account the time of the day, the season of the year, the nature of the medium between any two stations, clouds, thunderstorms and numerous other factors that may affect radio wave transmission. The formula should also include terms involving wavelength and distance. Even if such a formula could be framed, it would be so complicated and unwieldy that in arithmetical computation, for practical cases, its utility would really be small.

4. *Later Experiments.*—In England, Duddell and Taylor conducted the first accurate measurements of field strength by the direct measurement of the current in the receiving aerial with a sensitive galvanometer. The lower the value of the field strength, the more sensitive the galvanometer had to be. A limit was soon reached for the use of this method at about 60 miles from the transmitting station.

Following the direct method of Duddell and Taylor, came the famous experiments Drs. L. W. Austin and Louis Cohen carried on during the years 1909-1913. Fig. 1 shows the arrangement used.

At short distances from the transmitting station, the thermo-galvanometer was introduced direct in the aerial lead. At longer distances, the crystal and shunted telephone shown on the right-hand side had to be used. For still longer distances, the crystal and galvanometer circuit on the left hand, loosely coupled to the aerial circuit was necessary. The three methods were also used for checking against each other.

* Fuller, *Trans. A.I.E.E.*, Vol. 34, Part 1, p. 809.

With these arrangements, Austin and Cohen determined the field strength of the spark station, Brant Rock, over a distance of 1,000 miles on the sea, giving as the result

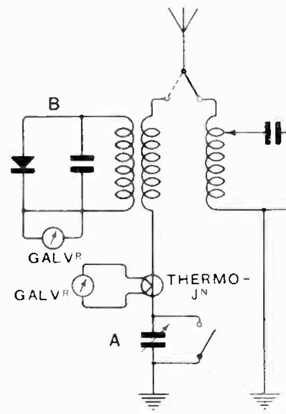


Fig. 1.—*Circuit used by Dr. L. W. Austin and L. Cohen,* 1909-1913. *The transmission was from Brant Rock and reception on two vessels at sea. The circuits A and B were for short and long ranges respectively.*

of their work the well-known daylight formula which forms the basis of all later formulæ.

5. Meanwhile, the extremely valuable properties of the thermionic vacuum tube were gradually better understood and its value was in proportion appreciated. The flexibility in the use of this remarkable piece of apparatus as an oscillation generator of almost all the desired ranges of frequency, a detector of spark or continuous waves, and an amplifier, rapidly made it indispensable in all radio frequency measurements, and specially so in field strength determinations. The old method of direct measurement came to be chiefly used for the determination of the effective height of aerials; and the modern "substitution" method, first suggested and used by Eccles, came to be exclusively used.

The principle underlying this method consists in equalising the E.M.F. induced by the incoming signal in the receiving aerial by a local easily regulatable E.M.F. The equalising or comparison is effected either by a telephone or a galvanometer.

Generally, the aerial used is either an antenna or a suitable closed aerial, the choice depending more or less upon circumstances. The E.M.F. induced is then magnified by one or other of the three well-known types of amplifier, the number of stages depending upon the strength of the signal. With the transformer or tuned circuit amplifier, elaborate and systematic shielding arrangements have to be undertaken.

After amplification and detection, and if necessary further low frequency amplification, the signal passes through a pair of telephones or a sensitive indicating instrument of the electrostatic or the electromagnetic type.

Next the deflections of the indicating instrument or the sound in the telephones are simulated by a locally controlled calibrated oscillation generator, generating at the correct frequency.

Due to personal equation in the telephonic method, the indicating instrument, *i.e.*, the galvanometric method is increasingly substituted in all modern accurate measurements. The galvanometer of the Einthoven type or the single string electrometer responds to the high speed signals of up-to-date stations; their deflections can be photographed continuously throughout the 24 hours to be kept as permanent records of almost minute to minute variations of signal strength.

There is one drawback in any signal measuring apparatus which may be safely put down as its weak spot; it is the single or multi-stage amplifier. If only it would work perfectly steadily with its characteristics unvaried for a reasonably long period, the amplifier would have extended usefulness as an instrument of great value. As it is, reproduction and repetition of results are impossible in the same manner as with the well-known types of measuring instruments. Its calibration in one form or other has become a necessity for every reading that is made.

The substitution method has rendered possible the measurement of extremely low values of field strength. Dr. L. W. Austin has measured the electric intensity of the high-power station Cavité to be 2μv/metre. Intensities of distant high-power stations can be anywhere between 10μv and 100μv per metre. Stations a few hundred miles away give intensities of the order of a few millivolts per metre.

Section B.

Vallauri's Method.—Almost the first to use the substitution method in the measurement of field strength is Prof. Vallauri. In the early part of 1919, when the radio station at Annapolis (Maryland, U.S.A.) carried on experimental transmission, Vallauri measured the strength of the incoming signals on behalf of the Italian Navy at his laboratory at Leghorn. His method is one of aural comparison, and accuracy to within 50 per cent. is claimed. Fig. 2 shows the diagram of connections used in these experiments.*

There are two large identical triangular loops at right angles to each other, one pointing towards the transmitting station, so that the other receives no signals at all. By throwing the switch L_1 L_2 to one side or the other, either of the loops can be connected to the antenna circuit, which is tuned to the particular wavelength required by a fixed condenser and a variometer V. This circuit is coupled inductively over a mutual inductance M_1 to a secondary circuit tuned by a fixed condenser and a variable air condenser. Across the latter is a six-stage resistance-coupled amplifier with the telephones at the output end. For beat reception the heterodyne oscillator G_1 is coupled to the secondary circuit over the mutual inductance M_3. The measuring circuit consists of a local oscillator G_2 coupled to the antenna circuit by the calibrated mutual inductance M_2.

The actual signal is received on the loop L_1 pointing to the transmitting station by throwing the switch to the side L_1. Generator G_1 is started and the signal is tuned by the variometer V; M_1 and M_3 are adjusted for the best and most convenient reception. G_2 is not in operation.

Next, the switch is thrown to L_2 on to the loop L_2; G_2 is started while all other adjustments are kept undisturbed and unaltered. The frequency of G_2 and the mutual inductance M_2 are so adjusted that the sound in the telephones due to this artificial signal is identical with that due to the actual signal. Rapid transfers of the switch from one loop to another ensure identity of the sound in the telephones. Knowing the dimensions of the loops, the current in the primary of the mutual inductance M_2, and the value of M_2, the field strength of the received signal is calculated.

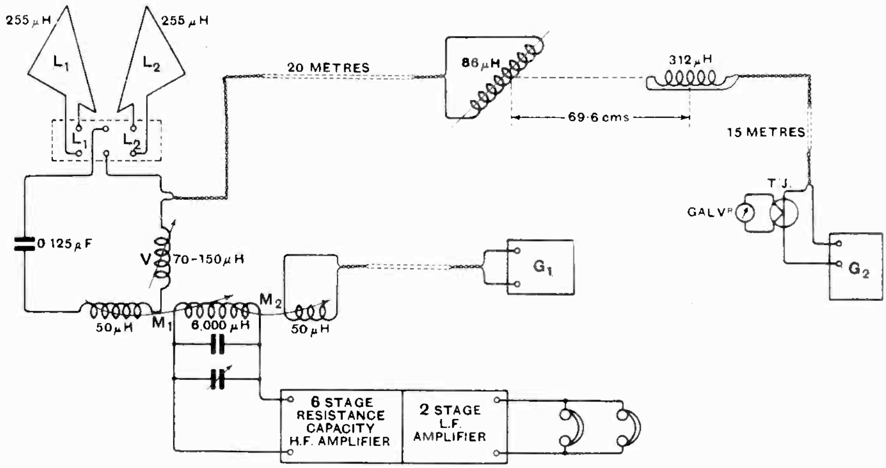


Fig. 2.—*Circuit arrangement employed by G. Vallauri in 1919. Observations were made at Leghorn, Italy, on the transmissions from Annapolis.*

In order to secure the highest possible accuracy the number of people listening in various telephones was six, and thus an average could be struck amongst the six observations.

2. *The "Aldebaran" Tests.* — Lieut. Guierre conducted, in 1919–1920, a series of tests on behalf of the French Navy on the sloop *S.S. Aldebaran*. The two main objects were to establish, if possible, the laws of wave propagation over an almost continental path and to investigate the field strength at

* *Proc. Inst. Radio Engs.*, Vol. 8, 1920, p. 286.

Tahiti,† the waves travelling almost completely over sea. The measurements were all relative to an arbitrary but invariable scale.‡

The arrangement of apparatus is shown in Fig. 3. The receiving aerial is loosely coupled to a two-stage amplifier with tuned grid coupling, followed by a detector with a telephone transformer and a pair of telephones shunted across by adjustable resistances R'' and R'''. A heterodyne, not shown in the figure, completes the arrangement for the reception of continuous waves. The whole of the receiving arrangement is well screened and earthed.

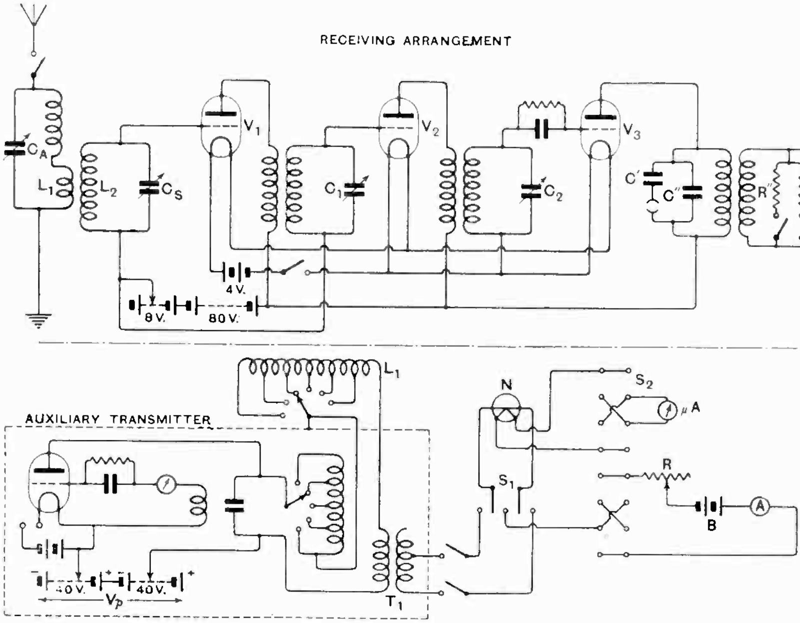


Fig. 3.—*Circuits used in the measurements undertaken by Lieut. Guierre, of the French Navy, on the S.S. "Aldebaran," 1919-1920. The signals measured were those from Bordeaux.*

The auxiliary transmitter consists of an oscillating triode, the anode voltage of which can be varied within wide limits. The transmitter is also screened thoroughly with the exception of coil L_1, which forms the radiating part of the transmitter.

The two transmitters—the local and the distant—transmit alternately continuous dashes of 10 seconds' duration on exactly identical wavelengths, the alternation being controlled by chronographs. The method consists in equalising, both in pitch and in intensity, the signals due to the two transmitters by suitable adjustments of the shunt resistances across the telephones and the voltage of the auxiliary transmitter. This is claimed to be more accurate than measurement by extinction of sound. Lieut. Guierre says that personal errors due to the observer do not exceed 15 per cent.

The chief objection to this method is the elaborate organisation needed for an extended investigation into radio wave phenomena. Special signals mean for a commercial station, money, larger staff, more equipment and interference with the ordinary traffic. But the inestimable advantage of this method, specially in these days, lies in the fact that the synchronising arrangement removes the great problem of interference by the large number of high power stations not far from each other.

3. *The Western Electric Coy.'s Method.*§—To measure the strength of European radio

† Toulon and Tahiti form antipodes to each other.
‡ *Radio Review*, Vol. II, Dec. 1921, pp. 619-635.

§ 1. *Proc. Inst. Radio Engs.*, Vol. XI, No. 1, p. 26.
2. *Proc. Inst. Radio Engs.*, Vol. XI, No. 2, p. 115.

stations, Messrs. Englund, Bown & Friis developed measuring apparatus suitable either for aural or galvanometric reception.

The apparatus consists of a 6 ft. square loop aerial with 46 turns spaced $\frac{1}{4}$ in., a filter suited to the wavelength in question, followed by a complete amplification system the spaces of the incoming signal, so that the two signals are heard alternately and give the same tone pitch, if of the same frequency.

The local signal is then adjusted by the artificial line to have the same loudness as the signal ; the current in the line and its

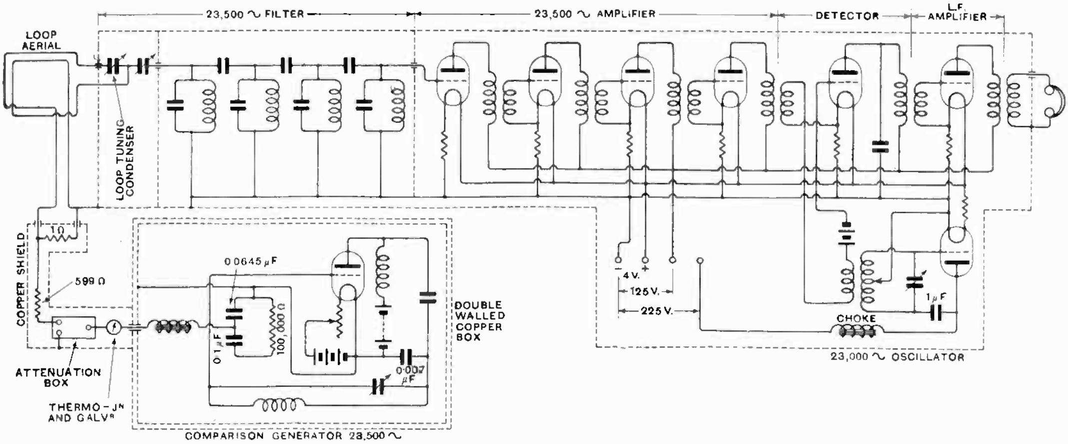


Fig. 4.—*Circuit used by Englund, Bown and Friis, of the Western Electric Coy., for measuring signal strength at Nauen, Marion, and New Brunswick,* 1922-1923.

with a telephone or continuous current galvanometer at the end. Calibration and comparison is effected by a local oscillator generating at the signal frequency, the output current of which passes through a specially designed attenuation box and feeds a one-ohm shunt across the coil aerial. Fig. 4 shows the arrangement. Thorough screening of the whole apparatus, by using copper lined boxes to house the various elements of the set, avoids mutual interference as well as the disturbances due to atmospherics, power and lighting lines, telephone circuits, etc.

Method of Operation.—The loop aerial is turned on to the maximum position of the signals ; these are tuned, and pass through the filter and the amplification system. Statics permitting, a micro-ammeter is used. Otherwise, one has to use the telephones. Next, the local oscillator is turned on and its frequency adjusted to equality with the incoming signal. By means of a key the local oscillator is turned on and off during setting are noted. The field strength is given by

$$D = \frac{3I_l F R_s \times 10^{18}}{2\pi f A N}$$

where

I_l = current in the line.
F = attenuation factor.
R_s = resistance of shunt across loop (one ohm).
f = frequency of signal.
A = area of loop in sq. cms.
N = number of turns in the loop.

The noteworthy points in this apparatus are :—

(*a*) The high degree of selectivity obtained by a rather elaborate filter.

(*b*) The method of getting small known radio frequency voltages by the artificial line or attenuation box.

(*c*) Injection of the small voltage into the aerial by a shunt resistance across its terminals.

(*To be concluded.*)

Dimensionality in Wireless Equations.

By W. A. Barclay, M.A.

THE subject of Dimensionality is one of the most interesting and important in modern physics, and one which is receiving much attention to-day. The various concepts dealt with, particularly in the sphere of electricity, are widely different in their nature, and their general co-ordination and interpretation is rapidly becoming a science in itself. It cannot yet be said, however, that any final body of doctrine exists in a realm where much is still left to conjecture. For example, the nature of the constants μ and k which relate the dimensions of electromagnetic and electrostatic quantities to the fundamental dimensions of length, time and mass is so far unknown, although the interpretation of the relation between the two is now classical. Closely allied to the subject of dimensionality is that of the units by means of which numerical magnitudes in the several dimensions are expressed. Electrical science in general has been peculiarly unfortunate in the different systems of units which have from time to time been proposed for practical working, and the new science of radio has had to extend the list still further with, *e.g.*, microamperes and picofarads. Such units are rendered necessary by reason of the extreme smallness of the H.F. currents dealt with. The clumsy system of wavelengths which was for so long in general use is now, happily, being superseded by that more convenient measure of frequency, the kilocycle.

It is not proposed to deal here with the absolute dimensions of the quantities which occur in wireless work. The most complete discussion of the subject known to the writer is that by Dr. N. R. Campbell in his monumental treatise *Physics, The Elements*, and to this work readers who may be interested are referred. The aim of the following note is the strictly utilitarian one of pointing out how the recognition of this concept of dimensionality may be of great service to the student and experimenter—as it has been to the writer—in checking the accuracy of equations to which they may be led in the course of theoretical work.

A physical equation is, of course, something more than a mere statement of numerical equality. The symbolism employed is designed to show the nature of the quantities whose equivalence is asserted, and in quantitative work the units in which the several magnitudes are expressed are, or should be, stated. In ordinary theory, however, it is usual to employ symbols which express a definite qualitative, in addition to a quantitative content, without any reference to units at all. Thus we speak of a resistance R, a capacity C, a reactance ωL or an impedance $\sqrt{R^2+\omega^2L^2}$, it being understood that the equations in which these symbols occur will be valid for any consistent system of units which may be selected for their numerical interpretation. The units must, of course, be self-consistent. In dealing with valve filament current, for example, we may use volts, amperes and ohms for our units; with grid currents, volts, microamps and megohms would be more appropriate. In both cases the equation $e=iR$ remains valid; that is to say, on substituting numerical values correct results would be obtained in either system. On the other hand, volts, microamps and ohms do not form a consistent system.

From the above considerations it is obvious that equations such as $e=iR$, represent a qualitative as well as a quantitative identity, a fact which may be otherwise expressed by saying that the dimensions of both sides of the equation must be similar. If, then, the left-hand side of an equation consists of the algebraical sum of quantities all of the same dimension, the R.H.S. must equally consist of a term or sum of terms each of that dimension. It is to be noted that if equations occur in which each side contains terms of different dimensions it can only mean that the sum total of all terms of any dimension on one side of the equation must equal the sum for that dimension on the other. In other words, we must equate separately to each other the individual dimensions from both sides of the equation, forming as many separate equations as there were different dimensions in the original equation. In a somewhat similar way the equations which express variation of current due to alternating E.M.F.s in a circuit when written in vector form are really the equivalent of two simple equations, in which the resistance and reactance components of the vector quantities are separately equated. The special meaning attaching to such equations should always be emphasised as a special technique is required to deal with them.

Apart from the vector equations referred to, the ordinary equations of wireless theory are generally uni-dimensional, and express the equivalence in dimension and magnitude between various physical quantities of the same kind. Thus, applying Kirchhoff's Laws to a current network, we are enabled to equate the sum of the P.D.s around the branches to the P.D. across the circuit. Here we have an equation between voltages, and every term in it is of the dimensions of a voltage. For any link in the circuit we have Ohm's Law, $i=e/R$. Here, both sides of the equation are of the dimensions of a current. We might also write it $e=iR$, where both sides are of voltage dimensions, or again $R=e/i$, which is an equation between resistances.

By thus multiplying the terms of an equation by suitable factors we may alter its dimensionality (having regard always to the laws of algebraical multiplication). It is thus possible to choose at will the particular dimensions with which we wish the equation to deal. This principle of selecting dimensions can be carried out within the equation itself. For instance, if the fraction A/B have the same dimensions as the term C in the equation

$$\frac{A}{B}=C$$

it is obvious that the intrinsic dimensions of A and B do not matter, and that we may alter the dimensionality of all the terms comprising the numerator A by suitable multiplication provided the same is done to all terms of the denominator B.

The general circuit equations of wireless are, of course, more complicated, but the same considerations hold throughout. We deal in fact with elaborate algebraical fractions and radicals which those unskilled in mathematics are apt to regard with distrustful aversion, while even a good algebraist must scan his working closely lest error should have crept in. The principle of dimensionality provides a certain test of error in such cases, though, unfortunately, it is no guarantee of correctness.

In these equations we deal with the absolute or numerical values of the impedances encountered, to the exclusion of their vectorial aspect. Such impedances may be expressed in ohms, equally with the resistances and reactances into which they may be resolved. Thus, the symbols R, ωL, $1/\omega C$ and Z may all be considered to have the same dimensions, viz., those of a resistance, and may be treated as resistances in the type of equations with which we are here dealing. For example, we may write the impedance of a resistive inductance to voltage impulses of frequency $\omega/2\pi$ as

$$Z=\sqrt{\omega^2L^2+R^2}$$

in which the dimensions of the R.H.S. are evidently those of the left. Again, for capacity, inductance and resistance in series, we may write the well-known formula

$$Z=\sqrt{\left(\omega L-\frac{1}{\omega C}\right)^2+R^2} \quad \ldots \quad (1)$$

This, of course, might be rewritten

$$Z^2=\left(\omega L-\frac{1}{\omega C}\right)^2+R^2 \quad \ldots \quad (2)$$

It will be observed that the terms comprising this equation have different dimensions from those of the preceding. Since, however, each of the terms of (2) has the same dimensions, those, namely, of a resistance squared, the equation is dimensionally correct. Had one of the terms differed in dimensions from the others, the inference would be that an error in working had occurred.

It is convenient in circuital equations to regard every term as the dimensional equivalent of a resistance, or of some power of a resistance (which need not necessarily be integral). In so doing, we need not concern ourselves at all with the physical interpretation of the various terms which occur in our working, such, for example, as the powers of resistances referred to. All that matters from the practical standpoint is that after the process of algebraical manipulation is completed, the final result shall be intelligible. Though any discussion of the philosophical considerations on which the procedure is based would take us too far afield for our present purpose, it is not to be thought that the process is in any way unscientific. Like the imaginary unit in algebra, "it works."

The ratio of two terms having the same dimensions is a pure number, and as such has no dimensions. For instance, such a quantity as $\omega L/R$ is a pure number. So also is $\omega^2 LC$, which is the ratio of an inductive to a capacitative reactance. For this reason, the oft-recurring expression $1-\omega^2 LC$ is in order; should we at any time meet the expression $R-\omega^2 LC$ in a similar context, we should at once suspect an error in working. Again, powers and roots of pure numbers cannot be other than pure numbers themselves, and thus the juxtaposition of such quantities as occur in the equation

$$\frac{Z^2}{R^2} = \frac{1}{\omega^2 C^2 R^2} \cdot (1-\omega^2 LC)^2 + 1$$

which is another form of (2) is seen to be dimensionally correct. The factor $1/\omega^2 C^2 R^2$ is the square of a ratio of resistances. It,

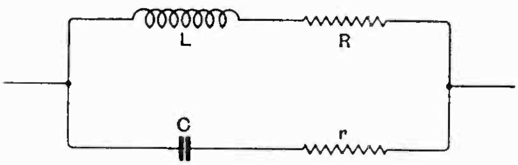


Fig. 1.

therefore, as well as the bracket term, is a pure number, and the equation is one in zero dimensions throughout. After a very little practice in looking at equations from this point of view it becomes possible to visualise at a glance the dimensionality of each term or component, and thus to "spot" a dimensional error at sight.

As another example, let us suppose that we have been led to the following value of L_0, the equivalent inductance of the circuit of Fig. 1 at the frequency $\omega/2\pi$,

$$L_0 = \frac{L(1-\omega^2 LC)-\omega C(R^2-r^2\omega^2 LC)}{(1-\omega^2 LC)^2+\omega^2 C^2 (R+r)^2} \quad (3)$$

As mentioned above, it is usually convenient to work as far as possible with quantities of the dimensions of some power of a resistance. We therefore multiply both sides by ω, thus,

$$\omega L_0 = \frac{\omega L(1-\omega^2 LC)-\omega^2 C(R^2-r^2\omega^2 LC)}{(1-\omega^2 LC)^2+\omega^2 C^2 (R+r)^2} \quad (4)$$

$$= \frac{\alpha-\beta}{\gamma+\delta} \text{ (say).}$$

The L.H.S. is then of the dimensions of a resistance. Now, the quantities γ and δ of the denominator are both of zero dimensions. From this it follows that both the terms α and β of the numerator must be of the nature of resistances in order that the equation may be dimensionally satisfied. The first term, α, is the product of a dimensional resistance, ωL, with a pure number, and so passes the test. The second term, β, consists of the expression $\omega^2 C(R^2-r^2\omega^2 LC)$. Now we have seen the combination $\omega^2 LC$ to be of zero dimensions. The bracket factor is thus of the dimensions R^2. Multiplied by ωC, the reciprocal of a resistance, it would be reduced to the single power of resistance necessary for dimensional equality. There occurs, however, an extra factor ω, the presence of which destroys the necessary qualitative similarity, and indicates the presence of an error in the previous working. As a matter of fact, of course, the ω is superfluous, and equation (3) should be written

$$L_0 = \frac{L(1-\omega^2 LC)-C(R^2-r^2\omega^2 LC)}{(1-\omega^2 LC)^2+\omega^2 C^2 (R+r)^2}$$

Although the selection of a resistance for the fundamental unit in the above exposition is entirely arbitrary, its use, nevertheless, will be found a matter of practical expediency. Once the significance of the various combinations of symbols in relation to the resistance unit is appreciated, the principle affords a useful means of checking equations by mere inspection. It is well, however, to repeat the warning that although *necessary*, it is not in itself a *sufficient* test of correctness.

The Frenotron Valve—A Vienna Novelty*

THE ordinary back-coupled detecting valve has two disadvantages: first, to obtain the greatest sensitiveness the back-coupling has to be increased until the oscillation point is nearly reached, and secondly, the rectified current is not proportional to the voltage applied to the grid, but to its square, causing insensitiveness to weak signals and distortion of loud ones. To obtain stable adjustment in the neighbourhood of the oscillation point, Dr.

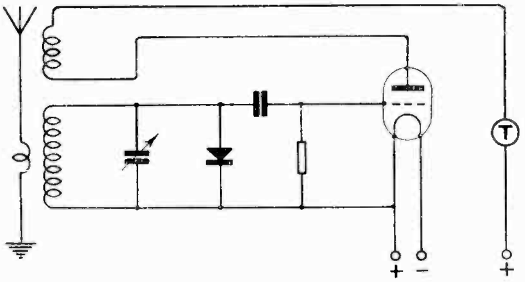


Fig. 1.—*The shunt shown as a crystal detector.*

Pollak-Rudin connects a variable shunt resistance across the condenser of the tuned grid circuit. This shunt should have a high resistance when the signals are weak and a decreasing resistance as the signals increase in strength or as the voltage across the condenser terminals increases. In Fig. 1 this shunt is shown as a crystal detector, and in Fig. 2 as a diode, the action of which can be adjusted by means of the potential

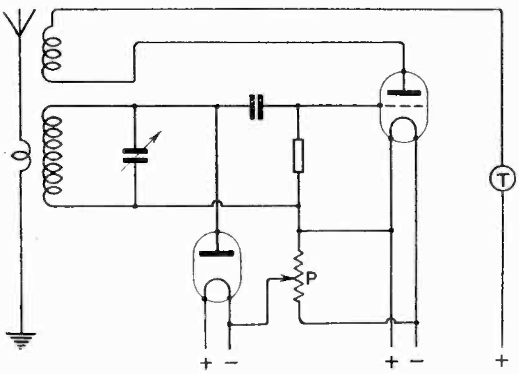


Fig. 2.—*The shunt as a 2-electrode valve.*

divider *P*. To avoid the necessity of adjustment which would make these methods somewhat troublesome, the shunt diode has been incorporated in the valve as shown in Fig. 3, when the filament is seen to extend beyond the normal grid and anode and act as a cathode to the special anode *H*. The connections for the valve are shown in Fig. 4.

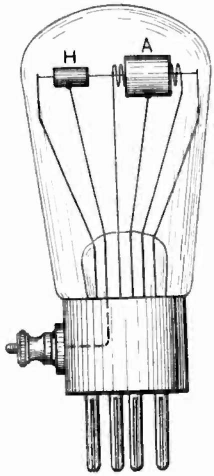


Fig. 3.

Although devised primarily as a stabilising device, the new valve has great advantages from the fact that the rectified current is no longer proportional to the square

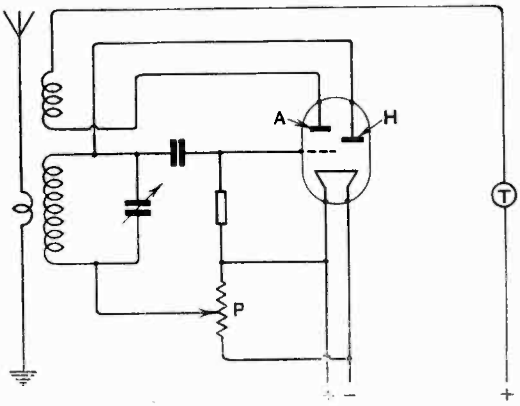


Fig. 4.—*Connections for the Frenotron valve.*

of the electromotive force induced in the grid circuit, but is approximately directly proportional to it. This proportionality leads to a decrease in distortion. This is discussed mathematically in the original article.

G. W. O. H.

---

* From an article in "Elektrotechnik and Maschinenbau," Vienna, 13th November, 1927.

Some Practical Applications of Quartz Resonators.

Paper read by Messrs. G. W. A. Cobbold, M.A., and A. E. Underdown, before the Wireless Section, Institution of Electrical Engineers, on 7th March, 1928.

ABSTRACT.

THE paper deals with different applications of the quartz crystal, the latter half of the paper more especially dealing with certain applications developed by the authors at the Signals Experimental Establishment, Woolwich.

INTRODUCTION.

In a lengthy introductory section, the authors refer to early work on the subject by Cady, G. W. Pierce, E. Giebe, D. W. Dye, and others. The use of the crystal as a frequency standard and frequency stabiliser is discussed, these being the applications dealt with in the paper.

When a valve and a crystal resonator are associated in such a way as to maintain oscillation, the frequency of which is controlled by the resonator, the complete circuit is generally referred to as a quartz "oscillator." Although other circuits using the quartz crystal have proved valuable, it appears to the authors that for practical applications the quartz oscillator is likely to dominate the field of usefulness.

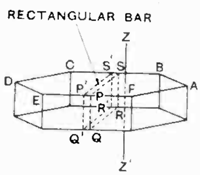


Fig. 1.

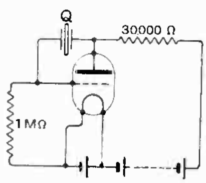


Fig. 4.

Fig. 1* is given as illustrating the manner in which a rectangular bar is normally cut from a block of natural quartz. The surface *ABCDEF* is at right angles to the optical axis ZZ^1. The three electrical axes are *AD*, *BE* and *CF*, and in the case illustrated the length of the bar, *PS*, is at right angles to the electrical axis *AD*. This perpendicularity to one of the electrical axes is not essential, however.

Notes are also given in the paper on cutting, grinding and mounting the crystals, reference being made to Hinderlich's paper on this subject.† When the crystal is used as an interference resonator a very appreciable air gap between crystal and electrode is generally provided in practice, but in the case of crystals used for oscillators the air gap is usually either extremely small or entirely absent.

* The author's original figure numbers are adhered to throughout this abstract.

† *E.W. & W.E.*, 1927, Vol. 4, p. 29.

A brief discussion is also given of the relationship between dimensions and fundamental frequencies, and of the equivalent electrical network of a crystal system.

In drawing a comparison between the quartz oscillator and other frequency standards, the usual standard method of an elinvar fork and multivibrator is considered to be preferable as national or international standards of the very highest

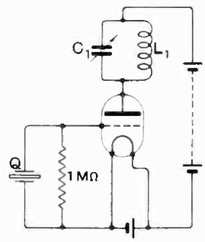


Fig. 5.

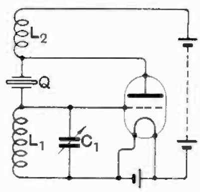


Fig. 6.

order, but the authors consider that there is a great use for quartz resonators as secondary standards, especially for short waves.

Practical applications already described in the technical press are then reviewed.

EXPERIMENTAL WORK.

In this section the authors deal with various experiments carried out by them since 1925. These have chiefly been in the development of quartz oscillators.

In the experiments crystals of the "bar" type

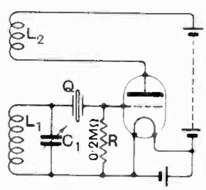


Fig. 7.

were employed, measuring approximately 18.5 mm. long, 5 mm. wide, and 1.5 mm. thick, the width being parallel to the optical axis and the length and thickness respectively perpendicular and parallel to one of the electrical axes. Army pattern valves A.R.3 (L.T. 2v., H.T. 48v.), proved quite satisfactory in use.

The circuits of Figs. 4, 5 and 6 were first tested, the last giving best results. The reaction circuit of Fig. 7 led to the final circuit of Fig. 8, the values shown being for a crystal of natural frequency 144.5 kc. (2,075 m.), the natural frequencies of all

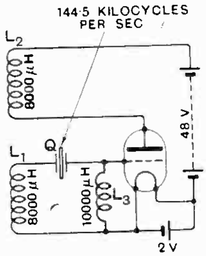


Fig. 8.

three coils being appreciably above that of the crystal.

In order to obtain measurements of very small changes in the air gap, a crystal holder with a micrometer adjustment of gap was made, as shown in Fig. 9.

A series of tests was carried out to ascertain how the controlled frequency varied in accordance with known changes in the constants of the circuits, changes of air gap, temperature, etc.

The following results may be summarised:

(1) The results of measurement of the air-gap show the relative importance of the frequency change due to slight changes in a small gap of about 0.05 mm. in comparison with the effect of similar changes in a wide gap of about 1 mm.

(2) An increase of capacity of 54 $\mu\mu$F across the coils produced a decrease in frequency of 7 cycles in 144.5 kc., approximately 1 part in 20,000.

(3) For a 37 per cent. increase in inductance of $L1$ or $L2$ or a 33 per cent. increase in $L3$, a change of only 1 cycle in 144.5 kc. was observed.

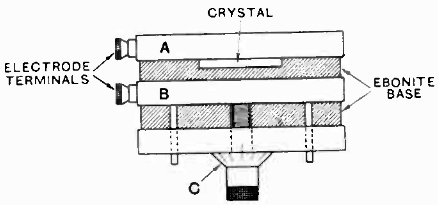


Fig. 9.

(4) 40 per cent. change of H.T. changed the frequency 1 part in 50,000; 10 per cent. decrease of L.T. caused a decrease of 1 cycle in 144.5 kc.

(5) Between temperatures of 55° and 125° F., results showed a temperature coefficient of − 4 per million per degree F.

(6) Change of valve for another of the same type, but of different make, never gave more than 2 cycles change in 144.5 kc.

(7) A variable condenser across $L1$ gave a range of circuit tuning—in the absence of the crystal—of from 190 to 100 kc. Controlled oscillations of approximately 144.5 kc. were obtained for all values of the circuit frequency from 190 down to 145 kc. At this point they ceased and were not obtainable at any frequency below that value.

Experiments are also described using six crystals between two common electrodes, the crystals having wavelengths of 300, 320, 340, 360, 380 and 400 m., and being each brought into operation by appropriate inductance tappings.

Circuits for the frequency control for a small transmitter are also shown.

The frequency measurements in these experiments were made against a multivibrator wavemeter (N.P.L. design) with a valve-driven elinvar fork of 1,000 cycles. The apparatus includes a multivibrator of 1 kc., and a high-frequency multivibrator which can be set to 19, 20 or 21 kc. From this can be obtained oscillations at any frequency between 100 and 1,200 kc., which is a multiple of either 19, 20 or 21 kc.

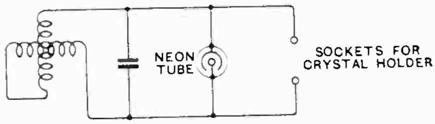


Fig. 15.

Use of Quartz Crystals with a Neon-tube Wavemeter.

The authors then turn to applications of the quartz crystal on which they have been engaged. These are chiefly in connection with wavemeters.

The first case is the use of a crystal as resonance indicator using the circuit of Fig. 15. With a powerful source of oscillations a resonance curve such as that of Fig. 16 is obtained. The neon lamp glows over the region *AEPRD*, but the insertion of the crystal causes the crevasse *PQR* due to

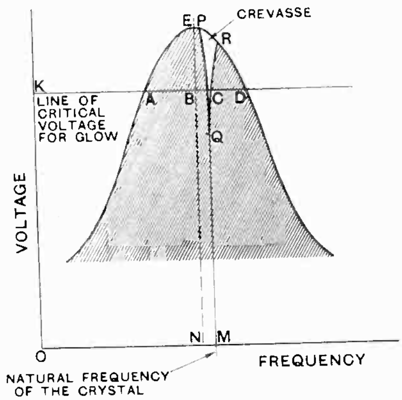


Fig. 16.

the absorption of energy by the crystal. In practice *BC* represents a very minute change of frequency, about 1 in 10,000. *ON* and *OM* need not be equal, although they should not differ by a great amount and the intersection of the crevasse with the line KAD should not occur too close to either A or D.

This arrangement may be used to check the calibration of a wavemeter at as many points as there are crystals provided, and the authors illustrate a holder in which four crystals are permanently enclosed, to provide such points.

Practical notes are also given on the use of this method.

USE OF QUARTZ CRYSTALS AS REFERENCE STANDARDS IN CONJUNCTION WITH A SUB-STANDARD WAVEMETER.

Fig. 18 illustrates a quartz oscillator using seven quartz bars in a common mounting, to be used in conjunction with a sub-standard wavemeter covering the range of 100 to 4,800 m. The wavemeter is an oscillating valve circuit with telephones so that its oscillations may be heard beating with those of the quartz oscillator. The seven crystals have the following wavelengths corresponding to their longitudinal modes of vibration: A 1,800 m., B 1,600 m., C 1,400 m., D 1,300 m., E 1,200 m., F 1,100 m., G 1,000 m. The wavelengths have been accurately measured, and a calibration chart is provided with the instrument, giving the fundamental wavelengths and all the harmonic derivatives between 100 and 4,800 m. The quartz oscillator unit is normally connected up to the wavemeter with which it is used, the working voltages being supplied to the three terminals by means of connecting straps from the wavemeter. The instrument may, however, be used separately, when batteries should be directly connected to the terminals.

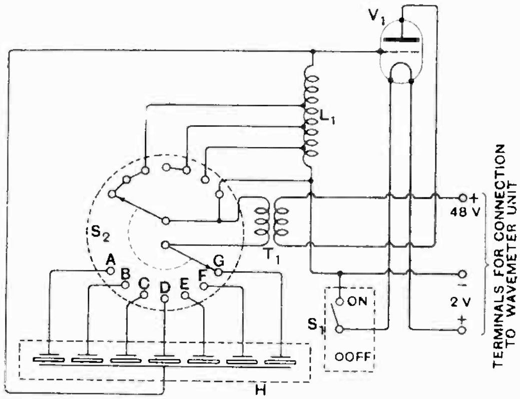


Fig. 18.

USE OF A QUARTZ OSCILLATOR IN A WAVEMETER GIVING A SERIES OF WAVELENGTHS THAT ARE ALL MULTIPLES OF 100 METRES.

This apparatus, which is shown in Fig. 19, has been designed to facilitate the calibration of wavemeters and wireless receivers. It is intended to work in conjunction with a "power oscillator" of about 10 watts, and as the use of harmonics is involved it is essential that this oscillator should be roughly calibrated.

A single crystal is used having a wavelength (corresponding to its frequency of longitudinal vibrations) of 400 m., and tuned circuits of 400 m., 200 m. and 100 m. can be brought into circuit by means of the switches S_1 and S_2. The third harmonic of 133.3 m. is not used as it gives groups which are not multiples of 100 m. The presence of this undesirable harmonic is reduced to about 25 per cent. of its value by the absorption circuit C_7 L_7.

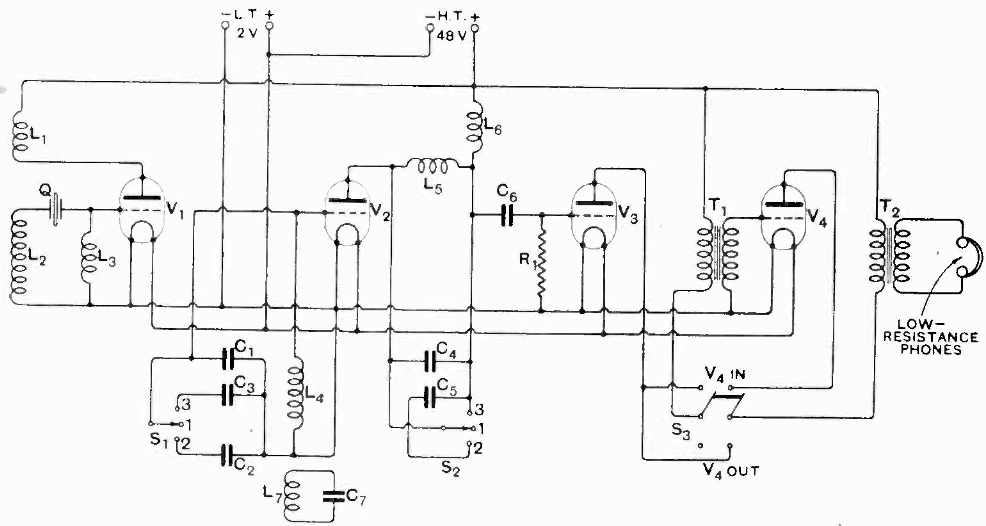


Fig. 19.

The power oscillator can be accurately set to the following wavelengths: Any multiple of 100 m.

up to 1,200 m., when the 4th harmonic is selected; any multiple of 200 m. up to 2,400 m. when the 2nd harmonic is used; any multiple of 400 m. up to 4,800 m. when the fundamental is employed. Other multiples of 100 or 200 m. up to 4,800 m. may also be obtained if the oscillator is sufficiently powerful.

The common batteries provide the necessary coupling between the quartz oscillator and the H.F. valve V_2.

USE OF A QUARTZ CRYSTAL IN AN INSTRUMENT GIVING A SERIES OF FREQUENCIES THAT ARE ALL MULTIPLES OF 1,000 KC.

This instrument, which is called a "crystal multivibrator," is a reference standard of frequencies from 2,000 to 15,000 kc., *i.e.*, 150 to 20 m. Its circuits are shown in Fig. 20. With the exception of the 2-volt accumulator the whole apparatus is contained in a single wooden case.

The instrument consists of three parts:—

(a) *Crystal controlled oscillator.*—Oscillations of V_1 are controlled at 1,000 kc. by the crystal. The circuit is adjusted so that in the absence of the crystal uncontrolled oscillations of about 3 to 5 per cent. higher are generated. In these conditions the crystal takes control immediately the valve is switched on. Final control of this condition is afforded by C_1, which is a manufacturing adjustment. The crystal is 3 mm. square and 1.5 mm. thick, and vibrates longitudinally at its fundamental frequency.

(b) *Selector circuit.*—This is divided into three sections, brought into operation by the switch S_2 and giving the frequency ranges:—

Range I. 2 to 5 megacycles (2nd to 5th harmonic).

Range II. 5 to 12 megacycles (5th to 12th harmonic).

Range III. 11 to 15 megacycles (11th to 15th harmonic).

The variometer in Range III was found to be a good arrangement for increasing the strength of the high order harmonics.

(c) *Detector Amplifier*, consisting of V_2 and V_3.

CONCLUSION.

In this concluding section, the authors review some of the advantages, etc., of the quartz crystal. As standards, in comparison with forks, they have the advantage that their natural frequencies are well within the spectrum of wireless frequencies, while in comparison with standard electrical circuits they are more compact and constant, and of lower temperature coefficient.

To obtain greatest possible accuracy, it seems probable that the crystal should be *in vacuo*, while blocks of fused quartz should be used as distance pieces between the electrodes or the air-gap altogether dispensed with by pressing one of the electrodes on to the crystal by means of a light spring.

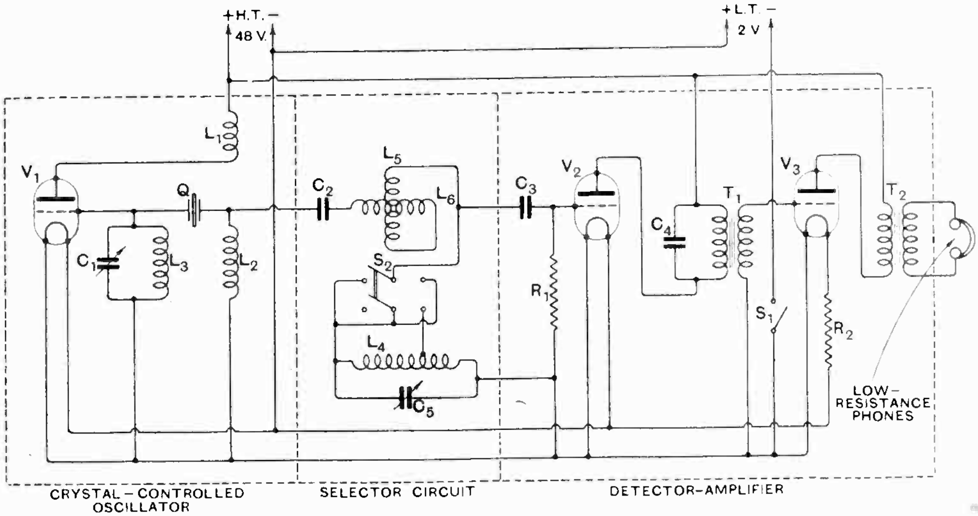


Fig. 20.

DISCUSSION.

In opening the discussion, Lt.-Col. A. S. Angwin expressed particular interest in the practical applications of the quartz crystal. Referring to the matter of air-gap, he said that no gap was certainly best for the maximum power, but considerable power could be obtained with a small gap. The Post Office used a metal-to-metal system with micrometer adjustment. He thought the authors were conservative in their estimate of the quartz crystal as a standard of frequency. An oscillator had been described (in proceedings of the I.R.E.) which gave constancy of 1 in one million over a period of 10 days. He queried the authors' use of the name "multivibrator," and suggested "quartz crystal harmonic generator." The use of the term "longitudinal vibrations" was ambiguous as compared with Prof. Cady's original nomenclature.

Col. Aston suggested some uses arising out of the paper. One was in connection with the very small variations of frequency described in the tests carried out by the authors. One important use was the adjustment of several transmitters to exactly the same wavelength. Makers' supplies of crystals were not usually better than 1 in 1,000 accuracy, and he suggested that temperature control might be utilised to get such closer accuracy as suggested by the authors. Thermostatic control could finally maintain constancy of temperature and of frequency. The use of quartz crystals as selective couplings and rejectors was also important. Tests at the I.E.E. indicated a decrement so small as to make the overall circuit too narrow for speech. The use of the crystal as a band-pan filter was thus suggested.

Mr. Lucas referred to the authors' use of longitudinal vibrations. Transverse vibrations were more usual. The fundamental on the longitudinal mode was very marked, but the transverse was more liable to have other frequencies. Early experiments had shown inconstancy as regards frequency and decrement. Tapping of movement altered the constants. Nodal support methods of mounting *in vacuo* gave a great improvement in accuracy, and he showed curves illustrating the improvement in decrement, etc., effected by such mounting.

Capt. Hopkinson also referred briefly to transverse vibrations and to methods of mounting for harmonics.

Lt.-Col. H. Lefroy asked if anything had been done as regards low-frequency applications. He had read of one crystal being caused to oscillate at two (radio) frequencies to produce a beat note.

Mr. Underhill referred to the need for definitions of longitudinal and transverse vibrations. Care in mounting was very necessary. Had the authors noticed that the odd harmonics appeared to be stronger than the even? With reference to the production of low frequency, singing was sometimes caused by two different frequencies being present due to flaws.

Prof. J. T. MacGregor Morris queried the authors' suggestion that there was no frequency change when there was no air-gap. In insulation tests, both D.C. and A.C., there was great difficulty in getting good contact. In permittivity tests, Dye had found it better to have a definite air-gap. A.C. measurements showed definite capacity and resistance at nominal contacts.

Mr. E. B. Moullin asked for further information as to the effect of the dimensions of the crystals.

Mr. B. Williams referred to early experiments made with crystals on and after Prof. Cady's visit to England in 1923. A crystal controller wavemeter had been in use at the Air Ministry station at Kidbrooke for some years. In the circuit of Fig. 6, minute changes could be got for final frequency adjustment on the tuning condenser. Used as a high-frequency coupling at 3,000 metres, he had found a crystal circuit extremely sharp and capable of operating a relay on a change of a few cycles.

Mr. M. J. Scroggie asked if the authors had observed any effect due to supersonic airwaves in the airgap. Such effects had been known to exist.

Capt. P. P. Eckersley said it was interesting to know that such high constancy was now so easily obtainable. The *source de control* for broadcasting wavelengths had preferred the fork method. As regards the use of the crystal for transmitter control, he said that with a good drive oscillator and care in operation there was no difficulty in obtaining a constancy of 200 in one million, which was enough for present purposes.

Mr. Cobbold briefly replied to the discussion, more especially to points raised by Col. Angwin and Prof. MacGregor Morris.

On the motion of the Chairman (Lt.-Col. A. G. Lee, O.B.E., M.C.), the authors were cordially thanked for their paper.

A demonstration of the "crystal multivibrator" was given after the reading of the paper, various harmonic frequencies being selected. The very different effects of hand capacity on the controlled and the uncontrolled oscillators were very clearly demonstrated.

Correspondence.

Letters of interest to experimenters are always welcome. In publishing such communications the Editors do not necessarily endorse any technical or general statements which they may contain.

The Performance of Valves in Parallel.

To the Editor, E.W. & W.E.

SIR,—In my letter on the above subject which appeared in the January number of *E.W. & W.E.*, I assumed that the fallacy in Mr. Denman's article was so obvious that it would be immediately admitted when once pointed out. As this is not the case, I have carefully reconsidered the position.

I now find that Mr. Denman's treatment is quite correct provided that the flow of current in the valves is continuous. It is then quite possible for the alternating component to be 180° out of phase in individual valves in particular cases. The assumed condition applies to amplifiers under normal conditions of operation.

In the case of transmitting circuits on the other hand it is usual to operate the valves so that the anode current flows during one half of the cycle only, the valves being rendered non-conducting during the other half of the cycle. When valves are operated in parallel on a circuit of this type it is obvious that the pulses of current must occur in all valves simultaneously, and to talk of the currents in individual valves being 180° out of phase would be absurd. It was circuits of this type which I had in mind when I wrote my previous letter.

I must apologise for failing to give the matter more careful consideration in the first instance, but the heading of the article led me to suppose that the results were of universal application and I naturally applied them to the particular case in which I happened to be interested at the moment.

K. E. EDGEWORTH.

Khartoum, Sudan.

Design of Choke Coils and Transformers.

To the Editor, E.W. & W.E.

SIR,—Your article in the issue of February on air gaps in transformers carrying a D.C. component is very interesting, but one must not infer from it that any existing intervalve transformer would of necessity be improved by the introduction of air gaps, for so far as I am aware there is not one on the market which does not contain them.

Considering a favourite form of magnetic circuit which comprises a T on the double width leg of which the windings are placed and a U which completes the circuit, it will be seen that there is one air gap between the leg of the T and the U, and one on each side between the tops of the U and the arms of the T, and the edges are generally so rough that the magnetic resistance is quite considerable.

In the next layer the stampings are reversed so that these joints get covered, but here one has the scale and insulation on the steel to prevent contact.

It will be found that at low frequencies there is a much more scattered field as a result of these air gaps in a transformer made from such stampings than from the same winding placed upon ring punchings of equal volume and cross sectional area, and the effect is very noticeable at 500 cycles, even if there is no secondary winding or load.

No doubt it would be very difficult to construct the counterpart of an ordinary intervalve transformer upon a ring core, but it would be very useful to compare its performance with the latter and see what the air gaps amount to, as it appears impossible to calculate or predict them with any degree of certainty.

Wireless instruments are becoming more and more instruments of precision in the search for quality of reproduction, and possibly an investigation of the kind suggested might help to remove an element of guesswork in design.

WM. A. RICHARDSON.

Ashford, Kent.

Good Quality in H.F. Amplifiers.

To the Editor, E.W. & W.E.

SIR,—With reference to my article in the March issue, I note that you consider 5 per cent. too stringent for the possible reduction in amplification. I think you will agree that if a low-frequency amplifier reduced the higher frequencies by much more than 10 per cent. it would not be considered as first class.

In Carrier Telephony work, where square topped filters are used, the width of the curve is measured six transmission units down, which is equivalent to, roughly, 50 per cent. of the height.

Here, however, intelligibility and not quality is the primary factor, and good intelligibility can be obtained with a band of only 2,000 cycles.

In the case of the ordinary resonance curve, which is not square topped, perhaps 10 per cent. is a fairer figure than 5 per cent., in which case "n" becomes 1.11. Combining the low and high frequency amplifiers, the overall reduction would then amount to about 19 per cent., which is near the limit for really good quality.

C. C. INGLIS.

BOOK RECEIVED.

LEFAX RADIO HANDBOOK. Compiled by Dr. J. H. Dellinger, of the Radio Laboratory, U.S. Bureau of Standards, comprising Introductory Notes, Fundamental Principles, Elements of Receiving and Transmitting Apparatus, Operation of Receiving Sets, Aerials, Tables, and Useful Data and Index; neatly bound in loose-leaf folder so that supplementary sheets may be readily inserted. Published by Lefax, Inc., Philadelphia, Pa. Price $3.50 or with one year's supplements, $7.50.

Abstracts and References.

Compiled by the Radio Research Board and reproduced by arrangement with the Department of Scientific and Industrial Research.

PROPAGATION OF WAVES.

ON A METHOD OF DETERMINING THE STATE OF POLARISATION OF DOWN-COMING WIRELESS WAVES.—E. V. Appleton and J. A. Ratcliffe. (*Proc. Roy. Soc.*, 117A, pp. 576–588, February, 1928.)

The paper is summarised as follows :

1. An experimental method of determining the polarisation constants of ellipticity of down-coming wireless waves is described.

2. The use of the method in a series of measurements in England with 400-metre waves has shown that the down-coming waves are in general elliptically polarised and that the polarisation is approximately circular. The sense of rotation is found to be left-handed.

3. It is shown that, according to the magneto-ionic theory of atmospheric deflection of wireless waves, in which the influence of the earth's magnetic field is recognised, such left-handed elliptical polarisation might be expected if the electrical carriers in the ionised layer are of electronic mass, but that similar measurements made in the Southern Hemisphere would yield evidence which would very materially confirm or disprove such an interpretation.

THE SCATTERING OF WIRELESS WAVES.—T. L. Eckersley. (*Nature*, 18th February, 1928, p. 245.)

Description of the evidence for a very pronounced scattering of wireless waves from the upper regions of the atmosphere which plays a considerable part in short-wave transmission. The writer states that, whatever other conclusions may be drawn from the evidence, it seems certain that the Heaviside layer is by no means a uniformly ionised region. but is very patchy, and there is some evidence of the existence of clouds which are small in dimensions compared with a wavelength of 14 metres.

ON THE INFLUENCE OF SOLAR ACTIVITY ON RADIO TRANSMISSION.—L. Austin and I. Wymore. (*Proc. Inst. Radio Engineers*, 16, pp. 166–173, February, 1928.)

Description of further examination of the daylight long wave signal measurements of the Bureau of Standards for evidence of correlation with solar activity. It has been shown previously that a probable correlation exists between signals and sunspots when the observations are continued for several years and averaged in periods of a month or more. The present paper deals especially with observations averaged in shorter (five-day) periods. While the relationship is generally evident here, it is sometimes obscured by an apparent relative phase shift between the signal and sunspot curves.

THE EFFECT OF WEATHER CONDITIONS ON LONG-DISTANCE RECEPTION.—S. K. Lewer. (*E.W. & W.E.*, 5, pp. 152–161, March, 1928.)

CO-OPERATIVE MEASUREMENTS OF RADIO FADING IN 1925.—J. Dellinger, C. Jolliffe, and T. Parkinson. (*Scientific Papers of the Bureau of Standards*, No. 561, 1927).

Among the results obtained is that fading is at its worst from 60 to 125 miles from a broadcasting station, and has successive maxima and minima at varying distances in excess of the range previously stated. Two readily distinguishable types of fading are recognised, a fairly slow and a relatively rapid fluctuation. The work led to the discovery of a highly regular type of fading, sometimes occurring during the 45 minutes just following sunset, which is evidently due to an interference phenomenon, its period being correlated with the distance between transmitter and receiver.

VARIATIONS OF ATMOSPHERIC PRESSURE AS A POSSIBLE CONTRIBUTING CAUSE OF STATIC, OF EARTH CURRENTS AND THEIR VARIATIONS, AND OF VARIATIONS ON THE EARTH'S MAGNETIC FIELD.—R. Hamer. (*Physical Review*, 31, p. 156, January, 1928.)

Abstract of a paper presented at the Chicago meeting of the American Physical Society, November, 1927.

A vertical glass tube filled with moist earth formed part of a closed circuit including a sensitive galvanometer. Sudden changes of air pressure caused variations to occur in the current which flowed due to electrolytic action in the soil acids at the electrodes. To eliminate effects due to pressure changes causing variations of soil resistance, the electrodes were insulated by glass dishes, one end earthed and the tube shielded. The insulated top electrode was connected to a quadrant electrometer. Similar pressure changes cause the electrometer to indicate the presence of a temporary charge at the electrodes. Apparently a temporary disturbance takes place in the distribution of the electrons or ions in the earth when sudden changes of air pressure occur. It is suggested that earth current measurements may be influenced by these two effects. The experiments also seem to afford obvious explanations of the many various known facts peculiar to the propagation of radio waves, especially in the case of reception. Possibly barometric changes cause variations in earth currents directly, and also indirectly by varying surface soil resistance. If these are large enough to produce observable magnetic effects, they may explain why magnetic variations seem to parallel those of earth currents.

IONISATION IN THE UPPER ATMOSPHERE.—E. O. Hulburt. (*Proc. Inst. Radio Engineers*, 16, pp. 174–176, February, 1928.)

Abstract of a paper read at the open meeting of the U.R.S.I., Washington, October, 1927.

The author re-examines the causes of ionisation in the upper atmosphere in the light of recent radio data and theory, and concludes that the sun's ultra-violet light is a necessary and sufficient cause of the Kennelly-Heaviside layer. The experiments are found to show that the electron density increases with the height above the earth, reaching a maximum value of about 4×10^5 at a height in the daytime of 150 to 200 km., above which the value of the electron density is not known, except that it does not go on increasing. The author emphasises the view that he can see no possibility of the existence of electron banks above the main one having its maximum electronic density at a height around 150–200 km. and therefore that inferences from radio data which suggest the presence of such outlying layers must be examined with care before they can be accepted.

Cf. Nature, 6th August, 1927, p. 187 (these Abstracts, October, 1927, p. 634).

EXPERIMENTS AND OBSERVATIONS CONCERNING THE IONISED REGIONS OF THE ATMOSPHERE.—R. A. Heising. (*Proc. Inst. Radio Engineers*, 16, pp. 75-99, January, 1928.)

Experiments are described in which a virtual height of the reflecting ionised region was measured using time lag between impulses arriving over a direct, and the reflected path. The measurements were made on 57 and 111 metres. The height was ascertained only at night and the daylight hour before sunset. Movements of the reflecting region are plotted showing slow rises and rapid drops. The rising rate approximates 6 miles a minute, and the falling rate 20 miles a minute. Multiple reflections were observed. Transmission measurement curves are given showing dependence of 16-7/8 metre signals on the night ionisation, and the assistance that sunlight ionisation can give. Experiments and curves are mentioned that show absorption to be one of the important factors causing poor daylight transmission in the wavelength region contiguous to 214 metres. It is pointed out that the absorbing region is below the refracting region and that the sky wave must make two passages through the absorbing region. It is shown that both electromagnetic waves from the sun, and β particles, must be assumed as producers of ionisation to explain phenomena observed. On this theory the electromagnetic waves from the sun produce the ionisation in the absorbing region, and part of the day ionisation in the refracting region. This ionisation is pictured as beginning at an altitude of about 16 miles and extending upward, and as experiencing diurnal and seasonal variations. The β particles produce, at an altitude higher than the absorbing region, further ionisation which is the principal ionisation at night due to the absence of the electromagnetic ionisation. This ionisation is pictured as occupying part of the same region as the electromagnetic ionisation and being very irregular in intensity and position.

THE PROPAGATION OF RADIO WAVES ALONG THE SURFACE OF THE EARTH AND IN THE ATMOSPHERE, BY PROFESSOR P. O. PEDERSEN.—J. C. Rybner. (*Proc. Inst. Radio Engineers*, 16, pp. 219-223, February, 1928.)

A comprehensive review of this book, dealing with the various chapters in detail, and outlining the connected physical theory of wave propagation there given.

SUR L'INTERPRÉTATION DE RÉSULTATS EXPÉRIMENTAUX RELATIFS AUX PROPRIÉTÉS DIÉLECTRIQUES DES GAZ IONISÉS. (On the interpretation of some experimental results concerning the dielectric properties of ionised gases.)—H. Gutton. (*L'Onde Electrique*, 7, pp. 1-4, January, 1928.)

In *L'Onde Electrique* for April, 1927, p. 137 (these Abstracts, September, 1927, p. 572), the author described experiments which led him to conclude that, when the ionisation of a gas is great, it is no longer possible, as in Eccles' theory, to assume that the mutual action of the ions does not come in, and the apparent diminution of the dielectric constant of the gas does not remain proportional to the number of ions per c.c.

In a memoir by P. O. Pedersen, entitled "The propagation of radio waves along the surface of the earth and in the atmosphere," several pages are devoted to these experiments, and they are explained without modifying Eccles' theory.

This explanation does not appear to the author to agree with the experimental results, which he outlines again here, and which he still maintains show that Eccles' theory is only valid for weak ionisation, the weaker the longer the wavelength, and that mutual action between the ions is necessary to explain the experimental phenomena described.

A THEORY OF THE UPPER ATMOSPHERE AND METEORS.—H. B. Maris. (*Proc. Inst. Radio Engineers*, 16, pp. 177-180, February, 1928.)

A calculation of the rate of separation of gases of different density in the earth's atmosphere leads us to expect a uniform mixture of all gases below 100 km., and for greater heights, densities of hydrogen and helium roughly a hundred thousandth of those previously calculated. Known absorption and radiation coefficients for gases of the upper atmosphere indicate that we should expect a daily temperature variation of about 140° during the summer and 30° during the winter for all heights greater than 80 km.

A RADIO FIELD STRENGTH SURVEY OF PHILADELPHIA.—K. McIlwain and W. Thompson. (*Proc. Inst. Radio Engineers*, 16, pp. 181-192, February, 1928.)

The method and apparatus are described and the results discussed, the field strength contour map of Philadelphia obtained being reproduced.

RADIO COMMUNICATION.—G. Marconi. (*Proc. Inst. Radio Engineers*, 16, pp. 40-69, January, 1928.)

An address delivered before the American Institute of Electrical Engineers and Institute of Radio Engineers, New York City, 17th October, 1927. A brief historical sketch of the investigations carried out by the author and his assistants on short waves, describing some of the strides that have already been made in their application to radio communications over long distances.

ATMOSPHERICS AND ATMOSPHERIC ELECTRICITY.

CHANGES IN THE ELECTRIC FIELD DUE TO LIGHTNING DISCHARGES.—J. Jensen. (*Physical Review*, 31, p. 312, February, 1928.)

Abstract of a paper presented at the Nashville meeting of the American Physical Society, December, 1927.

Further investigations confirm previous results and are in agreement with the conclusions of Wilson and of Schonland and Craib, that the lower pole of thunderclouds usually carries a negative charge. It is stated that photographs of individual flashes in some cases show a branching towards the earth, which is in contradiction to Simpson's theory ; the thin and rambling branches suggesting the electronic darts mentioned by Dorsey as feeding into the main discharge path.

LA SISMICITÉ DU SOLEIL ET LA PÉRIODICITÉ DES ORAGES MAGNÉTIQUES (The sun's "seismicity" and the periodicity of magnetic storms).—E. Belot. (*Comptes Rendus*, 185, pp. 1259–1261.)

In a recent series of articles, M. Deslandres has enunciated the law of periodicity of magnetic storms due to the emission of ions and electrons by layers deep within the sun, where volcanoes spaced by 60° are found along the equatorial zone. Besides these six most intense storm centres, there are secondary periodicities coming from emissions at 30° and 15° to them, marking less important magnetic storms. This paper investigates the causes for these periodicities.

PROPERTIES OF CIRCUITS.

GRID CURRENT MODULATION.—E. Peterson and C. R. Keith. (*Bell System Technical Journal*, 7, pp. 106–139.)

A paper discussing some of the properties of a type of modulator utilising the non-linear relation existing between grid voltage and grid current, and the advantages recent laboratory investigation indicates that it may possess.

The term grid current modulator is used to describe those valve circuits in which modulation is initially produced in the grid circuit of a three-electrode valve due to the non-linear grid current-grid voltage relation. Comparison with a representative plate current modulator using the same valves and the same plate potential shows that by modulating at maximum efficiency in the grid circuit and using the plate circuit solely for amplification, the maximum power output is increased about eight times, the power efficiency about five times, and the ratio of side-band output to signal input approximately three times. Under these conditions more carrier input power is needed for the grid than for the plate modulator.

Normally modulation is also produced in the plate circuit, which is shown to be out of phase with that produced in the grid circuit. By inserting high impedances to the input frequencies in the plate circuit, plate circuit modulation is prevented, and the reduction of grid circuit side-band is likewise avoided. By including in the grid circuit an impedance which is high to the desired side-band frequencies, the maximum grid side-band voltage is obtained. In this way the power and modulating efficiencies of the valve circuit are made a maximum.

Where modulation occurs only in the plate circuit of a valve, the side-band amplitude is proportional to the product of the amplitudes of the input frequencies when these amplitudes are small. In the present type of grid current modulator the side-band amplitude is proportional to the smaller of the two input amplitudes provided the ratio between these is greater than about 3/2. This feature makes the modulator particularly valuable in communication systems.

LES CIRCUITS À DEUX ONDES ET LEURS APPLICATIONS (Two-wave circuits and their applications).—L. Brillouin and E. Fromy. (*L'Onde Electrique*, 6 and 7, pp. 561–579 and 33–39, respectively.)

In a previous paper (*O.E.*, 5, pp. 371 and 419), the authors investigated the general problem of poly-wave circuits and showed that in the particular case of two-wave resonance, a large number of circuits could be produced, reducible to eleven characteristic types, themselves grouped into three classes.

In the present paper, these three classes are more especially studied, and are given a form able to furnish a practical means of realising two-wave circuits. Investigation is first made of the modes of vibration of these two-wave circuits, utilising a graphical method. The conclusion drawn from this first part is that it is always possible to arrange the circuits so that the oscillations on each of the two waves are localised in certain parts peculiar to them, the adjustments of the complex circuit on the two waves being thus mutually independent. In practice, with two simple types of circuit supplementing one another, resonance can be effected on any two waves, whether near one another or very far apart. By means of electric or magnetic coupling with one or two coils, one can very easily couple a complex circuit to any other circuit, arranging so that the coupling is strictly nil for one of the waves and normal for the other, from which there results the possibility of effecting complete selection of the two waves and considerable flexibility in the adjustments.

These general considerations lead to the statement of principles for constructing two-wave antennæ, capable of being connected to receivers or transmitting valves and providing simple means of producing simultaneously on the same antenna, either two independent transmissions or receptions or one reception and one transmission.

WEITERER BEITRAG ZUR NEGADYNSCHALTUNG (Further contribution on the negadyne circuit-arrangement).—E. Mittelmann. (*Zeitschr. f. Hochfrequenz.*, 30, pp. 157–160, November, 1927.)

By taking the lead of the space charge grid to the oscillatory circuit in the negadyne arrangement, the back-coupling can be suppressed to the extent that the unstable state previous to the starting to oscillate is only attained with pretty high heating values. A high anode direct current is thus rendered possible. By inserting a choke of sufficiently high inductance in the anode circuit, the tendency of the valve to oscillate becomes still further checked.

A STUDY OF THE RECTIFICATION EFFICIENCY OF THERMIONIC VALVES AT MODERATELY HIGH FREQUENCIES.—W. E. Benham. (*Philosophical Magazine*, 5, pp. 323-334, February, 1928.)

Description of experiments with a diode which show that:

(*a*) For a given input voltage amplitude, the rectified current is in general different at different frequencies, the frequencies employed in the experiments lying between 4.1 and 16.8 megacycles (λ73-λ17.8 metres).

(*b*) The value of input voltage amplitude at which departure from square law rectification takes place decreases as the frequency is increased.

The form of the frequency variation is investigated in detail in the case where the input voltage amplitude is small enough for rectification to take place according to a square law. In this case the rectified current falls off as the frequency is increased, the rate of variation being markedly affected by the filament temperature.

Experiments with a helium-filled valve used as a triode show a variation of similar form and magnitude for plate voltages below the critical potential, the variation corresponding, however, to an increase with frequency as distinct from the decrease with a two-electrode valve. For plate voltages above the critical potential, the variation with frequency is much more rapid, doubtless due to the presence of slowly-moving ions; at a certain frequency, depending on the potential, the rectified current is zero, the rectified current due to the space-charge being neutralised by a similar current due to the helium ions. At a higher frequency (about N = 14 megacycles) the rectified current is the same as it would be in the absence of helium ions; in other words, there is no rectification due to helium ions in the neighbourhood of this frequency.

PARASITIC OSCILLATIONS IN THE CASE OF A TUNED-ANODE OSCILLATOR.—M. Reed. (*E.W. & W.E.*, 5, pp. 135–147, March, 1928.)

SOME EXTENSIONS OF THEORY AND MEASUREMENTS OF SHOT-EFFECT IN PERIODIC CIRCUITS.—H. B. Vincent. (*Proc. Nat. Acad. Sciences*, 13, pp. 774–785.)

TRANSMISSION.

ÜBER DIE VON EINEM ABREISSENDEN MODULIERTEN UNGEDÄMPFTEN SENDER GELIEFERTE SCHWINGUNGSFORM (On the form of oscillation yielded by an interrupted modulated continuous wave transmitter).—F. A. Fischer. (*Zeitschr. f. Hochfrequenz.*, 30, p. 188, December, 1927.)

While a modulated high-frequency oscillation is in general an aperiodic phenomenon, the oscillation afforded by an interrupted modulated continuous wave transmitter is always periodic. In general, however, the "carrier frequency" does not occur below the partial oscillations. The two phenomena are identical only in the particular case when the modulation frequency is a whole multiple of the carrier frequency.

GENERALISED THEORY OF ANTENNÆ.—R. M. Wilmotte. (*E.W. & W.E.*, 5, pp. 119–131, March, 1928.)

BERMERKUNGEN ZU DER ARBEIT VON HORST WINKLER "ZIEHERSCHEINUNGEN BEIM LICHTBOGENSENDER" (Remarks on Horst Winkler's paper, "Oscillation hysteresis phenomena in the case of arc transmitters").—W. Burstyn. (*Zeitschr. f. Hochfrequenz.*, 30, p. 167, November, 1927.)

Winkler observes in his paper (this *Zeitschr.*, July, 1927; these Abs., November, 1927, p. 695) that all investigation of oscillation hysteresis phenomena hitherto has been confined to the special case of the valve transmitter. Burstyn here states it must have escaped Winkler's notice, that in *E.T.Z.* of 2nd December, 1920, there was a paper by him, "Coupling Phenomena with Continuous Oscillations," in which oscillation hysteresis phenomena in arc transmitters are fully discussed. Moreover, Burstyn claims to have discovered the phenomena, quoting a passage from *E.T.Z.* of 26th June, 1913, to that effect.

NOTE SUR LE CHOIX PRÉLIMINAIRE DES CONSTANTES ELECTRIQUES D'UNE ANTENNE PSEUDO-SYMÉTRIQUE (Note on the preliminary choice of the electric constants of a pseudo-symmetrical antenna.—M. Waserman (*L'Onde Electrique*, 7, pp. 40–44, January, 1928.)

RECEPTION.

A HIGH-EFFICIENCY RECEIVER FOR A HORN-TYPE LOUD-SPEAKER OF LARGE POWER CAPACITY.—E. C. Wente and A. L. Thuras. (*Bell System Technical Journal*, 7, pp. 140–153.)

Description of a telephone receiver of the moving coil variety, which is particularly adaptable to the horn type of loud-speaker, and whose design is such as to permit of a continuous electrical input of 30 watts as contrasted with the largest capacity previously available of about 5 watts. Further, the receiver has a conversion efficiency from electrical to sound energy varying between 10 and 50 per cent. in the frequency range of 60 to 7,500 cycles. Throughout most of this range, its efficiency is 50 per cent. or better, which is contrasted with an average efficiency of about 1 per cent. for other loud-speakers either of the horn or cone type.

A RADIO-RECEIVING OSCILLATOR FOR RECEIVER INVESTIGATIONS.—G. Rodwin and T. Smith. (*Proc. Inst. Radio Engineers*, 16, pp. 155–165, February, 1928.)

Description of a modulated radio-frequency oscillator. The apparatus incorporates a means for obtaining radio-frequency outputs of widely varying range, a metering system, a means for changing the generated frequency in small steps to either side of a given frequency, and a modulation and indicating system.

GOOD QUALITY IN H.F. AMPLIFIERS.—C. Inglis. (*E.W. & W.E.*, 5, pp. 132–134, March, 1928.)

WHAT IS THE CORRECT CHARACTERISTIC FOR A VARIABLE CONDENSER ?—K. E. Edgeworth. (*E.W. & W.E.*, 5, pp. 148–150, March, 1928.)

ANODE BEND OR GRID RECTIFICATION ?—A. P. Castellain. (*Wireless World*, 22, pp. 188–190, 22nd February, 1928.)

Some practical data on their relative merits.

UN 4 VALVOLE DI USO GENERALE (A 4-valve general purpose receiver).—U. Guerra. (*Radio Tecnica*, 1, pp. 28–36, February, 1928.)

Description of this instrument employing a screened valve.

ZUSAMMENFASSENDER BERICHT: DER KRISTALLDETEKTOR (The crystal detector: survey of the subject).—A. Schleede and H. Buggish. *Zeitschr. f. Hochfrequenz.*, 30, pp. 190–193, December, 1927.)

Recent investigation of the detector problem leads to an explanation of certain contradictions previously existing in the literature of the subject. In the case of galena and partly also with pyrites, it is shown that:

1. Sensitive crystals are differentiated from insensitive ones by their chemical composition. While insensitive galena approximately corresponds to the theoretical composition, sensitive galena exhibits a relative excess of sulphur and deficiency in lead by about 1 to 2 per cent.

2. The existence of places of varying sensitivity in a piece of naturally occurring galena is to be attributed to the fact that even pieces which look homogeneous from the outside are really made up of separate crystals of varying sensitivity.

It is stated, however, that the observations do not render possible a definite decision between the different explanations of the rectifier effect that have been advanced, although the excess of sulphur discovered in sensitive galena points distinctly to the electronic theory.

SUR UNE ANOMALIE DANS LE FONCTIONNEMENT DES DÉTECTEURS À CONTACT ET SUR SES CONSÉQUENCES (On an anomaly in the operation of contact detectors and its consequences).—J. Groszkowski. (*L'Onde Electrique*, 6, pp. 554-558, November, 1927.)

Investigation of the existence of an anomaly in the working of the contact detector, due to the particular shape of its static characteristic. The irregularity is indicated by the variable behaviour of the dynamic characteristic, it being possible to obtain a certain value for the rectified current for different values of the tension being rectified. The author considers the conditions under which this anomaly can occur and its consequences.

VALVES AND THERMIONICS.

NEW VALVE RECTIFIER.—A. Gehrts. (*Siemens Zeitschrift*, August, 1927.)

The new valve has a cathode made from thorium-coated molybdenum placed between two tantalum anodes and represents therefore a two-way valve. The chief claims for the new cathode material are that it is insensitive to temperature changes of several hundred degrees and is not affected by the bombardment of positive ions.

DIE ENTWICKLUNG IM ELEKTRONENRÖHRENBAU (Development in valve construction).—H. Simon. (*Zeitschr. f. techn. Physik.*, 11, pp. 434–445, November, 1927.)

A paper presented at the meeting of German physicists at Bad Kissingen, September, 1927.

An account of the progress in valve construction made in the last year, referring particularly to the work done in the laboratories of the Telefunken Company. Study is made of the material for filament, grid and anode; of automatic mounting and exhausting; the construction of valves for specific purposes; and noise in transmitting valves and its elimination.

Cf. also *Telefunken-Zeitung*, 47, pp. 38–50.

DIE TECHNISCHE HERSTELLUNG VON OXYDKATHODEN (Industrial production of oxide cathodes).—W. Statz. (*Zeitschr. f. techn. Physik.*, 8, pp. 451–456.)

Discussion of different methods of producing oxide cathodes with their advantages and drawbacks.

KLEINGLEICHRICHTER FÜR RUNDFUNKZWECKE (Small rectifiers for broadcast purposes).—M. Bareiss. (*Zeitschr. f. techn. Physik*, 8 pp. 449–451.)

Physical and technical particulars are given of the construction of different kinds of small-power rectifying valves.

THE OVERSHOOTING OF THE TEMPERATURE OF A TUNGSTEN FILAMENT.—L. Bockstahler. (*Physical Review*, 31, p. 303, February, 1928.)

Using a double strip oscillograph, simultaneous photographic records were made of the heating current in a straight filament tungsten lamp and the thermionic current emitted by the central portion of the filament. The records showed that, on closing the circuit, the expected momentary overshooting of the heating current was followed by a marked overshooting of the thermionic current. Since the thermionic current indicated the temperature of the filament, there was an overshooting of the power consumption when the current was turned on the cold filament. The magnitude and duration of the surge depends on the final temperature and size of the filament.

ON ELECTRICAL FIELDS NEAR METALLIC SURFACES.—J. Becker and D. Mueller. (*Physical Review*, 31, p. 308, February, 1928.)

If an electron must pass through surface fields in order to escape from the surface, a properly directed applied field, F, should partially neutralise the surface fields and hence increase the thermionic current i. A simple analysis shows that $d(\log_{10} i)/dF = (11{,}600/2.3T) \times S$, where T = surface temperature and S = distance from the surface at which the surface field equals F. For clean surfaces the observed current-voltage relation can be accounted for if the only force acting on the escaping electron is due to its image field. For composite surfaces such as thorium on tungsten, another field due to the adsorbed ions is superposed on the image field. Close to the surface this "adsorption field is very intense and helps electrons escape, thus decreasing the work function; farther from the surface this field reverses sign, grows to a maximum value and then steadily decreases. This reverse field has appreciable values at surprisingly large values of S. Hence the logi – F curve for composite surfaces is steeper than that for clean surfaces.

THE PHOTO-ELECTRIC AND THERMIONIC WORK FUNCTIONS OF OUTGASSED PLATINUM.—L. Du Bridge. (*Physical Review*, 31, pp. 236-243, February, 1928.)

Description of an investigation which establishes agreement between the photo-electric and thermionic work functions for outgassed platinum and finds the thermionic constant A for cleaned platinum very considerably greater than that required by Dushman's theory.

A COMPARISON OF THE THERMIONIC AND PHOTO-ELECTRIC WORK FUNCTIONS FOR CLEAN TUNGSTEN.—A. H. Warner. (*Proc. Nat. Acad. Sciences*, 13, pp. 56-60.)

THERMIONIC EMISSION AND THE "UNIVERSAL CONSTANT" A.—E. H. Hall. (*Proc. Nat. Acad. Sciences*, 13, pp. 315-326.)

THE RESTORED ELECTRON THEORY OF METALS AND THERMIONIC FORMULÆ.—R. H. Fowler. (*Proc. Roy. Soc.*, 117A, pp. 549-552, February, 1928.)

PHOTO-ELECTRIC EMISSION, THERMIONIC EMISSION AND PELTIER EFFECT.—E. H. Hall. (*Proc. Nat. Acad. Sciences*, 13, pp. 43-46.)

RITICAL PRIMARY VELOCITIES IN THE SECONDARY ELECTRON EMISSION OF TUNGSTEN.—H. Krefft. (*Physical Review*, 31, pp. 199-214, February, 1928.)

DIRECTIONAL WIRELESS.

ROTATING-BEACON RADIO TRANSMITTERS.—(*E.W. & W.E.*, 5, pp. 85-93, February, 1928.)

Abstracts of three papers read before the Wireless Section of the Institution of Electrical Engineers, January, 1928.

UNTERSUCHUNGEN ÜBER DIE PEILBARKEIT KURZER WELLEN BEI TAG UND NACHT. (Experiments on the possibility of taking bearings on short waves by day and night.—F. Michelssen. (*Zeitschr. f. Hochfrequenz.*, 30, pp. 183-187, December, 1927.)

Account of an investigation on the usefulness of waves shorter than 100 metres for taking bearings, which was carried out by the Telefunken Company in conjunction with the Marine Service during the summer of 1926.

The experiments were described in *Telefunken-Zeitung*, 44 and 45-46, and the results summarised in these Abstracts, *E.W. & W.E.*, November, 1927, pp. 698 and 699. The conclusion reached was that the use of short waves for taking bearings is not at present practicable.

DIE VERGRÖSSERUNG DES EMPFANGSBEREICHES BEI DOPPELRAHMEN UND DOPPELCARDIOIDEN-ANORDNUNGEN DURCH GONIOMETER. (Increasing the range of reception with double frames and cardiode-arrangements by means of goniometers.)—A. Esau. (*Zeitschr. f. Hochfrequenz.*, 30, pp. 141-151, November, 1927.)

Description of receiving arrangements consisting either of frames or cardiode systems, with which, by employing goniometers in the subsidiary and principal systems, reception is rendered possible from all directions and not only from that given by the base-line of the antennæ, as previously, without prejudicing the freedom from disturbance. The necessary condition for this is that the ratio

$$\frac{\text{spacing of the antennæ}}{\text{wavelength}}$$

is chosen small.

Cf. "Directional characteristics of antenna combinations, Esau, *Zeitschr. f. Hochfrequenz*, 27, p. 142; 28, pp. 1 and 147 (these Abstracts, September, 1926, p. 570; and March, 1927, p. 179).

KURZWELLENPEILVERSUCHE MIT RAHMEN UND HILFSANTENNE AUF GRÖSSERE ENTFERNUNGEN ÜBER SEE. (Experiments on short-wave direction-finding, with frame and auxiliary antenna, over greater distances, over sea.—F. A. Fischer. (*Zeitschr. f. Hochfrequenz.*, 30, pp. 188-189, December, 1927.)

Supplementing the investigation of 1926, referred to above, in June of 1927, the experiments were carried out over greater distances. This time the direction-finder was on land near the coast, while a 150-watt transmitter was erected on a ship. Since the experiments in the previous year had shown that as wide a frequency band as possible considerably lightened the work with short waves, the transmitter was again run with alternating anode tension. The direction-finding apparatus was that developed by Telefunken for the previous experiments: a frame with auxiliary antenna, forming the grid circuit coil of a push-pull receiver. The wavelengths investigated were 49, 39, 28.5 and 19 metres, and the distance ranged between 30 and 570 sea miles. The results are comprehensively tabulated.

These show that at a distance of 30 miles, bearings could be taken on waves as short as 19 metres. At 85 miles, the vanishing of the surface wave and appearance of the space wave were distinctly observable. The surface wave, of course, first disappears for the smallest wave and the effect of the space wave first appears with the longer waves. At 130-230 miles, the longer waves became successively unemployable, while silent zones occurred with the smaller waves. From 230 miles onwards, it was clearly only a question of pure space radiation with all waves. Either direction-finding was entirely impossible, or the minimum was very broad and wandered slowly through large angles. This wandering first begins with distances over 200 miles, which accounts for its not being observed in the summer of 1926. The waves of 28.5 and 19 metres were received over these greater distances only by day, but then sometimes with exceptional strength.

MEASUREMENTS AND STANDARDS.

Precision Determination of Frequency.—J. Horton and W. Marrison. (*Proc. Inst. Radio Engineers*, 16, pp. 137-154, February, 1928.)

Paper read at a meeting of the U.R.S.I., Washington, October, 1927, summarised as follows:

The relations between frequency and time are such that it is desirable to refer them to a common standard. Reference standards, both of time and of frequency, are characterised by the requirement that their rates shall be so constant that the total number of variations executed in a time of known duration may be taken as a measure of the rate over shorter intervals of time. Frequency standards have the further requirement that the form of their variations and the order of magnitude of their rates shall be suitable for comparison with the waves used in electrical communication.

Two different types of standard meeting these requirements are described; one consisting of a regenerative valve circuit, the frequency of which is determined by the mechanical properties of a tuning fork, and the other a regenerative circuit controlled by a piezo-active crystal.

Data taken over a period of several years with a fork-controlled circuit show that, under normal conditions, its rate may be relied on to two parts in one million. Data taken over a much shorter time with crystal-controlled oscillators indicate that they are about ten times as stable.

A Precision Method for the Measurement of High Frequencies.—C. B. Aiken. (*Proc. Inst. Radio Engineers*, 16, pp. 125–136, February, 1928.)

Consideration of a precision method for measuring the frequency of an oscillatory circuit. The theory of the method is discussed and an equation developed relating the frequency of the beat note between two oscillators to the natural frequency of a circuit which is loosely coupled to one of them. This equation is considered in some detail and certain of its properties are deduced. Curves are drawn for three typical cases. The causes and avoidance of certain errors are considered. The method is extended to the case of a non-oscillating circuit. Lastly, a method is suggested for the measurement of small values of mutual inductance.

Condenser Shunt for Measurement of High-frequency Currents of Large Magnitude.—A. Nyman. (*Proc. Inst. Radio Engineers*, 16, pp. 208–217, February, 1928.)

Description of a new precision device, consisting of a large condenser in parallel with a small one, the latter carrying the current to a small thermocouple ammeter. The construction of the device includes provisions for reducing and restricting the electrostatic and electromagnetic field, due to large current; the reduction of distributed inductance and capacity; the prevention of the resonance effect of high harmonics in the operating current; and the location of the measuring instrument at a distance from the circuit. Large ratings are possible by connecting a number of condenser units in parallel.

A Triode Amplifier for Small Direct Currents.—A. Marcus. (*Physical Review*, 31, p. 302, February, 1928.)

Abstract of a paper presented at the Nashville meeting of the American Physical Society, December, 1927, describing a type of "thermionic galvanometer" which is being employed to measure ionisation currents, photo-electric currents, and piezo-electric currents of magnitudes considerably below the range of the galvanometer when used without the triode.

Electrical Measurement of Communication Apparatus.—W. J. Shackelton and J. G. Ferguson. (*Bell System Technical Journal*, 7, pp. 70–89, January, 1928.)

A paper presented at the A.I.E.E. meeting at Pittsfield, May, 1927, describing precision high-frequency measurements of a fundamental type. Standards of frequency, resistance, capacitance and inductance are briefly discussed and bridge methods of measuring frequency, inductance, effective resistance, capacitance, dielectric loss, etc., described.

How Broadcasting Wavelengths are Checked.—R. Braillard and E. Divoire. (*Wireless World*, 22, pp. 219–222, 29th February, 1928.)

Description of the international listening station at Brussels.

On the Determination of the Piezo-electric Constant of a Quartz Resonator at High Frequency.—T. Fujimoto. (*Physical Review*, 31, p. 312, February, 1928.)

Abstract of a paper presented at the Nashville meeting of the American Physical Society, December, 1927.

The Use of the Cathode-ray Oscillograph in the Study of Resonance Phenomena in Piezo-electric Crystals.—K. S. Van Dyke. (*Physical Review*, 31, p. 303, February, 1928.)

Abstract of a paper presented at the Nashville meeting of the American Physical Society, December, 1927.

The piezo-electric resonator in series with a known resistance A forms one side of a bridge, while the other side consists of a known impedance in series with a second known resistance B. The deflecting systems of the cathode-ray oscillograph are connected so that one indicates the potential across A and the other that across B. When a source of alternating potential whose frequency is independent of any reaction from the resonator is applied to the bridge, the oscillograph indicates by a Lissajous figure the relative magnitudes and phases of the currents in the two arms. The impedance of the resonator at frequencies near resonance may be computed from measurements on the figure for those frequencies, and the constants of the electric network equivalent of the resonator obtained therefrom.

THE POWER-FACTOR AND CAPACITY OF THE ELECTRODES AND BASE OF TRIODE VALVES WITH SPECIAL REFERENCE TO THEIR USE IN THERMIONIC VOLTMETERS.—G. W. Sutton. (*Proc. Phys. Soc.*, 40, pp. 14-22, December, 1927.)

Discussion of the conditions under which a three-electrode valve-voltmeter should be operated to ensure a minimum power consumption, and at the same time give indications closely proportional to the square of the input voltage. A simple method of adjusting the operating voltages to fulfil the necessary conditions is described.

THE USE OF THE GRID-GLOW TUBE AS AN ELECTROSTATIC VOLTMETER.—T. Wilkins and F. Friend. (*Physical Review*, 31, p. 301, February, 1928.)

Abstract of a paper presented at the Nashville meeting of the American Physical Society, December, 1927.

DIE BERECHNUNG DER AKUSTISCHEN EIGENSCHAFTEN DES KONDENSATORMIKROPHONS (Calculating the acoustic properties of the condenser microphone.—A. J. Jakowleff. *Zeitschr. f. Hochfrequenz.*, 30, pp. 151-157, November, 1927.)

The theory of the condenser microphone is given and a method for its calculation. The theory shows that the condenser microphone permits reproduction of speech without amplitude distortion if

1. The membrane has as high a natural frequency as possible and, at least, is two or three times higher than the highest frequency to be reproduced by the microphone;
2. The damping factor equals 1.35 times the natural frequency.

It is seen, however, from the calculation, that only the first requirement is capable of fulfilment, the second one not being so.

Lastly, a theoretical curve for the condenser microphone is shown and compared with the curves obtained experimentally by F. Trendelenburg and E. C. Wente.

DISPERSIONSMESSUNGEN IM GEBIETE KURZER ELEKTRISCHER WELLEN (Dispersion measurements in the region of short electric waves). —W. Hein. (*Zeitschr. f. Hochfrequenz.*, 30, pp. 160-167 and 176-183, November and December, 1927.)

The method of Barkhausen and Kurz is applied to the production of short undamped electric waves for dispersion measurements according to the first and a modified second Drude method. In the first part of the paper the theory of these two methods is developed after a process borrowed from cable theory. In the second part the experimental arrangement is described. The external circuits of the valve generator are in the form of parallel wire systems and, with moving bridges permit the production of waves from $\lambda/_2 = 18$ cm. up to $\lambda/_2 = 160$ cm. The oscillations are transferred to the measuring arrangement by means of a tuned parallel wire system. The third part gives the results. The dielectric constant of water was determined at various frequencies in the given wave range, but no anomalous dispersion was found, while glycerine gave the dispersion drop calculated by Debye.

NOUVELLE MÉTHODE POUR LA MESURE ABSOLUE, EN HAUTE FRÉQUENCE, DES CONSTANTES DIÉLECTRIQUES DES LIQUIDES (A new method for the absolute measurement of the dielectric constant of liquids, at high frequency).—R. Darbord. (*Comptes Rendus*, 185, pp. 1193-1195.)

ELECTRICAL RESISTANCE AND MAGNETIC PERMEABILITY OF IRON WIRE AT RADIO FREQUENCIES.—G. Wait, F. Brickwedde, and E. HALL. (*Physical Review*, 31, p. 303, February, 1928.)

While Mitiæv observed that the high-frequency resistance of iron wire undergoes a critical change at about 100 metres wavelength, and Wwedensky and Theodortschik a critical change in permeability of iron, the authors have repeated the experiments and find no critical variation.

SUBSIDIARY APPARATUS AND MATERIALS.

AN IMPROVED FORM OF CATHODE RAY OSCILLOGRAPH.—R. H. George. (*Physical Review*, 31, p. 303, February, 1928.)

Abstract of a paper presented at the Nashville meeting of the American Physical Society, December, 1927, describing an oscillograph designed for maximum flexibility. It is constructed almost entirely of metal, and arranged for inserting photographic plates and films in the vacuum to obtain permanent records of transient phenomena. By employing interchangeable cathode parts the accelerating potential of the beam can be varied from less than 100 volts to thousands of volts, depending on the deflectional and photographic sensitivity required. The deflecting plates are adjustable, and as many as three pairs can be used at one time, making possible three simultaneous deflections by electrostatic fields. Magnetic deflecting coils may also be employed when desirable.

A TWO-RANGE VACUUM TUBE VOLTMETER.—C. Jansky, Jr., and C. Feldman. (*Journal Amer. Inst. Elect. Eng.*, 47, pp. 126–132, February, 1928.)

Discussion of the design, uses and limitations of a new circuit employing the three-element vacuum tube as a voltmeter. The unique features are two overlapping ranges of voltage and a single operating battery. The effect of waveform and its elimination are considered.

THE UNIVERSAL H.T. BATTERY ELIMINATOR.—N. P. Vincer-Minter. (*Wireless World*, 22, pp. 184 and 226, February, 1928.)

THIN-FILM RECTIFIERS.—J. Slepian. (*Electrical World*, 90, p. 1003.)

Abstract of paper presented before the American Electrochemical Society, September, 1927.

The principles underlying the operation of thermionic rectifiers are reviewed and applied to a theory of thin-film rectifiers. The phenomena exhibited by the following rectifiers are described and discussed in terms of this theory: crystal detectors, tantalum and ferro-silicon electrolytic rectifiers, electrolytic rectifiers with metallic conduction, the copper-hemi-sulphide rectifier of Pawlowki and the copper-oxide rectifier of Grondahl. The author contends that the many types of devices recently placed upon the market for rectifying 110-volt alternating current, etc., can be largely explained as due to the properties of thin-films separating two electrically conducting substances.

STEUERUNG VON ELEKTRONENSTRÖMEN IN QUECKSILBERDAMPFENTLADUNGEN (Control of electron currents in mercury vapour discharges.—E. Lübcke.) (*Zeitschr. f. techn. Physik*, 8, pp. 445–449, November, 1927.)

A paper presented at the meeting of German physicists at Bad Kissingen, September, 1927.

Description of the separation of the wall currents of a mercury vapour discharge into ions and electrons, leading to the construction of a new valve, by means of which anode currents up to 5 amps. can be obtained with anode tensions as low as 200 volts.

SUR LE DÉMULTIPLICATEUR DE FRÉQUENCE FERROMAGNÉTIQUE (The ferromagnetic frequency sub-multiplier.)—M. Rouelle. (*Comptes Rendus*, 185, pp. 1450–1452.)

THE MEASUREMENT OF ACOUSTIC IMPEDANCE AND THE ABSORPTION COEFFICIENT OF POROUS MATERIALS.—E. C. Wente and E. H. Bedell. (*Bell System Technical Journal*, 7, pp. 1–10, January, 1928.)

Various ways of determining the acoustic impedance and the absorption coefficient of porous materials from measurements on the standing waves in tubes are discussed, and values obtained for some commonly-used damping materials at different frequencies are given. The values for the absorption coefficients of a number of types of built-up structures are also tabulated, which show that relatively high absorption may be obtained at low as well as at high frequencies. The use of such combinations of absorbing materials has the advantage that more uniform damping at all frequencies can be obtained, and the degree of damping can be readily controlled by covering the proper area of surface. These two factors have become increasingly important in studio and auditorium design, with improved technique in recording and reproducing speech and music.

STATIONS: DESIGN AND OPERATION.

WORLD BROADCASTING: 1,116 STATIONS.—(*Electrical Review*, 6th January, 1928, p. 22.)

It is pointed out, in the *Telegraph and Telephone Age*, that radio telephone broadcasting services are now provided by 431 stations in 57 countries, in addition to the 685 operating in the United States and its non-contiguous territories. Outside the United States the most powerful broadcasting stations are those at Motala (Sweden) and Moscow (Russia), having 40,000 watts each; Russia also has a 20,000-watt station at Moscow, and one of 10,000 watts at Leningrad. Daventry operates on 16,000 watts. A station of power ranking above 40,000 watts is reported to be under construction in the Netherlands, while the Rosenhügel station, in Austria, is being transformed to a working capacity of 60 kW. and a nominal capacity of 200 kW.

THE DUTCH SHORT-WAVE STATION.—(*Wireless World*, 22, pp. 210–212, 29th February, 1928.)

Brief account of PCJJ, recently transferred from Eindhoven to Hilversum, with photographs of the equipment.

STATO ATTUALE DELLE STAZIONI TRASMITTENTI A ONDE LUNGHE (Present condition of long-wave transmitting stations.)—R. Hirsch. (*Radio-Tecnica*, 1, pp. 6–9, February, 1928.)

Although the attention of radio technical men, recently, has been mostly concerned with short-wave stations and broadcasting, the large companies still occupy themselves with perfecting the construction of ultra high-power long-wave stations. This article sets out the requirements of these stations, which ever become more exacting, and illustrates the extent to which they are being met by reference to the new high-power long-wave station of Torre Nuova, at Rome.

I MODERNI TRASMETTITORI AD ONDE CORTE PER SERVIZI COMMERCIALI (Up-to-date short-wave transmitters for commercial services).—M. Cabrini. (*Radio-Tecnica*, 1, pp. 21–27, February, 1928.)

An illustrated description of the Nauen station.

SIMULTANEOUS BROADCASTING IN CZECHO-SLOVAKIA.—E. K. Sandeman. (*Electrical Communication*, 6, pp. 171–177, January, 1928.)

Description of a typical example of the arrangements necessary for satisfactorily radiating a programme, originating at any one place, simultaneously from a number of transmitting stations.

GENERAL PHYSICAL ARTICLES.

THE RIGOROUS AND APPROXIMATE THEORIES OF ELECTRICAL TRANSMISSION ALONG WIRES).—J. R. Carson. (*Bell System Technical Journal*, 7, pp. 11–25, January, 1928.)

POTENTIAL DIFFERENCE AND CAPACITY IN A.C. PROBLEMS.—G. W. O. Howe. (*E.W. & W.E.*, 5, pp. 113-118, March, 1928.)

AN ELECTRICAL METHOD OF HARMONIC ANALYSIS.—S. Brown. (*Physical Review*, 31, p. 302, February, 1928.)

Abstract of a paper presented at the Nashville meeting of the American Physical Society, December, 1927.

MAGNETIC REFLECTION.—R. Abbott. (*Physical Review*, 31, p. 313, February, 1928.)

Description of an experiment proving the reflection of the magnetic field from a large electro-magnet by a zinc plate, which acted like a mirror due to eddy currents.

SIFFLEMENT CONTINU PRODUIT PAR UN QUARTZ PIÉZO-ÉLECTRIQUE ÉMETTANT SIMULTANÉMENT DEUX OSCILLATIONS DE HAUTE FRÉQUENCE (The continuous whistling produced by piezo-electric quartz simultaneously emitting two high-frequency oscillations). —F. Bedeau and J. de Mare. (*Comptes Rendus*, 185, pp. 1591-1593.)

THE HIGHLY PENETRATING COSMIC RAYS.—A. Corlin. (*Nature*, 3rd March, 1928, p. 322.)

A letter referring to the fact that Millikan and Cameron failed to detect variations in the intensity of cosmic rays (Supp. to *Nature* of 7th January), as found by Kolhörster, von Salis, Büttner and Steinke (after correcting his measurements for sidereal time) and giving reasons for suggesting the possibility that the variations are caused mainly by somewhat softer cosmic rays (coming from the "heated vacuum" of the Mira stars ?) than those found by Millikan and Cameron when their apparatus was sunk deep below the levels of the lakes used by them.

HIGH ALTITUDE TESTS ON THE GEOGRAPHICAL, DIRECTIONAL AND SPECTRAL DISTRIBUTION OF COSMIC RAYS.—R. Millikan and G. Cameron. (*Physical Review*, 31, pp. 163–173, February, 1928.)

THE DIFFRACTION OF ELECTRONS BY A CRYSTAL OF NICKEL.—C. J. Davisson. (*Bell System Technical Journal*, 7, pp. 90–105.)

Until the experiments described here were performed, it could be said that all experimental facts about the electron could be explained by regarding it as a particle of negative electricity; but now it appears that in some way a "wave-length" is connected with the electron's behaviour. The work thus shows an interesting contrast with the discovery of A. H. Compton that a ray of light (a light pulse) suffers a change of wavelength upon impact with an electron, a change corresponding exactly to the momentum gained by the electron.

Physics is thus faced with a double duality. Compton showed that light is in some sense *both* a wave motion and a stream of particles. The author now shows that a beam of electrons is in some sense *both* a stream of particles and a wave motion.

ON THE EXTRACTION OF ELECTRONS FROM COLD CONDUCTORS IN INTENSE ELECTRIC FIELDS. —O. W. Richardson. (*Proc. Roy. Soc.*, 117A, pp. 719–730, February, 1928.)

ON THE MECHANISM OF PHOTO-ELECTRIC EMISSION. —J. H. Hsu. (*Physical Review*, 31, p. 311, February, 1928.)

Abstract of a paper presented at the Nashville meeting of the American Physical Society, December, 1927, describing a simple theory of the mechanism of photo-electric emission, according to which the work function should in general be equal to the lowest resonance potential of the substance under investigation.

EVAPORATION OF TUNGSTEN UNDER VARIOUS PRESSURES OF ARGON.—G. Fonda. (*Physical Review*, 31, pp. 260-266, February, 1928.)

NOTE ON THE RÔLE OF POSITIVE IONS IN THE DISRUPTIVE DISCHARGE.—J. Townsend. (*Physical Review*, 31, p. 220, February, 1928.)

A UNIFIED THEORY OF GRAVITATION AND ELECTRICITY.—C. Snow. (*Physical Review*, 31, p. 150, January, 1928.)

Abstract of a paper presented at the Chicago meeting of the American Physical Society, November, 1927.

The theory gives the same advance of perihelion and bending of starlight by sun as Einstein's, but is mathematically distinct from his. Electric and magnetic (gravitational) charges are relative (like velocity) and physically indeterminate. They appear as projections of a charge-vector upon the time-like electrical axis and the space-like imaginary magnetic axis, which we may (and do) choose arbitrarily. Rotation of these axes in their plane would enable us to give an electron zero electric or zero magnetic charge, thus altering the form but not the content of our description of nature.

GRAVITATION AND ELECTRICITY AS MANIFESTATIONS OF A SIX-DIMENSIONAL WORLD.—C. Snow. (*Physical Review*, 31, p. 160, January, 1928.)

Abstract of a paper presented at the Chicago meeting of the American Physical Society, November, 1927.

SOME EXPERIMENTAL DIFFICULTIES WITH THE ELECTROMAGNETIC THEORY OF RADIATION. —A. H. Compton. (*Jour. Franklin Institute*, 205, pp. 155-178, February, 1928.)

NOTE ON THE LAW THAT LIGHT-RAYS ARE THE NULL GEODESICS OF A GRAVITATIONAL FIELD.—E. T. Whittaker. (*Proc. Cam. Phil. Soc.*, 24, pp. 32-34, January, 1928.)

MISCELLANEOUS.

TALKING AND SYNCHRONIZED MOTION PICTURES. —W. H. Bristol. (*Jour. Franklin Institute*, 205, pp. 179-196.)

A condensed presentation of the author's method of making and reproducing synchronized motion pictures.

PICTURES BY WIRELESS.—A. J. Smith. (*Electrician*, 13th January, 1928, pp. 27–28.)

Brief account of the development of the Telefunken-Karolus method in Germany.

WEIGHING BY RADIO.—(*Journ. Amer. Inst. E.E.*, 47, p. 16, January, 1928.)

A machine for automatically weighing material such as paper, rubber, has been developed in the laboratory of a New England producer of pulp and paper, the principles underlying the device being those of the tuned radio circuit. The web of material passes between two parallel metal plates which act as a condenser in the receiving circuit: variations in the weight of the web change the capacity of the condenser and affect the response of the circuit to a wave of controlled frequency. These variations are shown on a meter connected in the circuit and may be used to operate machine controls by suitable relays. The machine is of great service in maintaining uniformity in the weighing of paper and an adaptation of the device may be used to register the moisture content of the paper.

ÜBER VERSTÄRKUNG IN DER BILDTELEGRAPHIE (On amplification in picture telegraphy).—O. Schriever. (*Telefunken-Zeitung*, 47, pp. 78–84.)

IL FONOGRAFO E LA RIPRODUZIONE ELETTRICA (The phonograph and electric reproduction).—U. Guerra. (*Radio-Tecnica*, 1, pp. 10-16, February, 1928.)

THE NEW RADIO-TELEGRAPH CONVENTION.—Lieut.-Col. Chetwode Crawley. (*Electrical Review*, 24th February, 1928, pp. 322-323.)

Notes on the Convention drawn up by the International Conference held in the United States.

LABORATORIEN UND FORSCHUNGSARBEITEN DER FUNKABTEILUNG DER DEUTSCHEN VERSUCHSANSTALT FÜR LUFTFAHRT IN BERLIN-ADLERSHOF (Laboratories and research work of the radio department of the German experimental establishment for aviation at Adlershof, Berlin).—H. Fassbender. (*Zeitschr. f. Hochfrequenz.*, 30, pp. 173-176, December, 1927.)

A brief description of the equipment and investigations carried out in the various sections, with illustrations.

D. E. H.

Esperanto Section.

Abstracts of the Technical Articles in Our Last Issue.

Esperanto-Sekcio.

Resumoj de la Teknikaj Artikoloj en Nia Lasta Numero.

PROPAGADO DE ONDOJ.

LA EFEKTO DE VETERAJ KONDIĈOJ ĈE LONG-DISTANCA RICEVADO.—S. K. Lewer.

En ĉi tiu artikolo la aŭtoro skizas pluajn esploradojn pri la ĉi-supra temo (vidu *E.W. & W.E.*, Dec. 1925a kaj Julio 1926a). La mezuro de kondiĉoj por longdistanca, ekzemple, transatlantika, ricevado estas priskribita kiel C, kaj oni montras, per komparo de rezultoj, por 1924a, 1925a, kaj 1926a, ke ŝanĝoj ĉe C spertas specon de ĉiujara ripetado. Eblaj kaŭzoj por ĉi tiuj variadoj estas tiam diskutitaj, kaj diversaj fizikaj elementoj, kiuj kredeble havas tian influon, estas revuitaj. La aŭtoro poste diskutas variadojn de atmosfera premado kaj skizas konturajn mapojn de premado por unuj el la sendadaj vojoj. Kelkaj kondiĉoj, kiujn oni trovis bonaj kaj malbonaj respektive por sendado, estas montritaj, kaj rilato estas starigita inter prema distribuo kaj C.

La efekto de premaj ŝanĝoj je tera aŭ mara nivelo ĉe la premado kaj ionigado de la Tavolo Heaviside estas poste konsiderita, kaj la efekto de iu rezultanta kurbeco de la tavolo ĉe la refrakto aŭ reflekto de senfadenaj ondoj estas diskutita kaj ilustrita.

La aŭtoro konkludas, ke estas atestaĵo, ke la kondiĉoj por ricevado kaj la prema distribuado trans la Atlantika Oceano estas ripetitaj ĉiujare laŭ kompleksa sed difinita maniero, kaj ke estas rilato inter ili.

PROPRECOJ DE CIRKVITOJ.

POTENCIALA DIFERENCO KAJ KAPACITO ĈE ALTERNKURENTAJ PROBLEMOJ.

Redakcia artikolo de Prof. Howe kun gravaj aplikadoj al la teorio de antenoj.

La fundamentaj difinoj de potencialo kaj kapacito estas diskutitaj, kiel aplikita unue al kontinua kurento aŭ al elektrostatikaj problemoj. La malfacileco de ekzakta difino de potencialo en A.K. praktikado estas tiam pritraktita, kaj kelkaj aplikadoj estas ilustritaj kaj diskutitaj, notinde la mezurado de la potenciala diferenco inter diversaj partoj de a.k. senda linio. Per ĉi tio, modifo de la difino de potencialo kiel aplikita al a.k. estas derivita.

La argumento pri senda linio estas poste etendita al la ekzemplo de senda anteno. Oni konkludas, ke estas konsilinde ne provi ian a.k. difinon de la kapacito por unuo-longo de la anteno en la aplikado de la senda linia formularo, sed kalkuli la elektrostatikan kapaciton laŭ la supozo de distribuo de ŝarĝado, kiel ilustrita de l'aŭtoro. La induktanco por unuolongo estas poste konsiderita, kaj la aŭtoro konkludas, ke la metodo donas utilan proksimiĝon, uzante simplajn rimedojn por solvi tre kompleksan problemon.

Generaligita Teorio pri Antenoj.—R. M. Wilmotte.

La aŭtoro unue aludas al antaŭaj artikoloj de Colebrook kaj de Moullin, kaj al la malfacileco pri difinoj de la terminoj uzitaj je antenaj mezuradoj. Kapacito kaj induktanco por la unuo-longeco estas diskutitaj kaj la distribuo de la konstantoj en simpla vertikala anteno estas konsideritaj kaj ilustritaj. La efektivaj konstantoj de ricevaj kaj sendaj antenoj estas poste pritraktitaj, inkluzive la diferencoj, kiuj ekzistas en la du okazoj, la efektiva alteco, k.t.p. Oni priskribas eksperimentojn por kontroli la konkludojn atingitajn teorie, la ekzperimentoj ampleksantaj kaj ricevadon kaj sendadon. Utila metodo por trovi la naturan frekvencon de anteno estas ankaŭ donita, la metodo uzanta neniajn instrumentojn, kiuj eble, pro sia reaktanco, tuŝas la rezultojn.

Du matematikaj aldonaĵoj estas donitaj, la unua traktanta pri l'apartigo de reaktanco en ĝiajn kapacitan kaj induktancan konsistaĵojn, kaj la dua traktanta pri l'efektivaj konstantoj de l'antenoj dum sendado kaj ricevado.

Parazitaj Osciladoj en la Okazo de Agorditanoda Oscilatoro.—M. Reed.

La nuna artikolo estas daŭrigo de unu en *E.W. & W.E.* de Dec. 1927a, kiam la temo de parazitaj osciladoj estis pritraktita ĝenerale.

La okazo diskutita estas koncerne aŭdeblafrekvenca oscilatoro de 965 cikloj, kiam oni trovis diferencojn je la konduto laŭ la inversigo de kaj krada kaj anoda bobenoj kaj alĝustigo de la anoda konekta pinto.

La komuna induktanco uzita estas ilustrita, kaj eksperimentoj estas priskribitaj koncerne (1) La efekto de l'aŭdebla oscila cirkvito ĉe la parazita oscilado, (2) La forteco kaj frekvenco de la parazitaj osciladoj, (3) La efekto de kondensatoro konektita trans la anodo kaj krado, (4) Determino de la natura frekvenco de la konsisteroj de l'oscilatoro.

Eksperimentaj rezultoj estas donitaj por ĉi tiuj diversaj okazoj, el kiuj la parazitaj oscilaj cirkvitoj estas konsideritaj. La efektiva komuna induktanco inter la krada kaj anoda bobenoj, kun ambaŭ direktoj de konekto kaj por diversaj valoroj de anoda konekta pinto, estas konsideritaj, kaj klarigoj estas donitaj por la rezultoj obtenitaj en ĉi tiuj okazoj. La rilato inter la parazita oscilado, kaj la pozicio de la konekta pinto estas ankaŭ konsiderita.

Finiga resumo mallonge revuas la rezultojn, dum aldonaĵo traktas pri la determino de l'efektiva komuna indukto inter la anoda kaj krada bobenoj.

Bona Kvalito Ĉe Altfrekvencaj Amplifikatoroj.—C. C. Inglis.

La prelego traktas pri la larĝeco de strio necesa por esti pasigita de la altfrekvenca (ekz., agorditanoda) ŝtupo por bona kvalito.

Oni donas analizon de agordita cirkvito de L, R & C (Induktanco, Rezistanco, kaj Kapacito, respektive), kaj derivas esprimon por la larĝeco de strio (en cikloj ĉiusekunde) de la resonanca kurvo je $1/n^{ono}$ de ĝia alteco. Ĉe bona bobeno, oni montras ke por 5-procenta malaltigo el de la maksimumo, la stria larĝeco donita estus tro mallarĝa. La efekto de valva amortizo estas poste diskutita. Ĉe valvo de 20,000 omoj, oni montras, ke la efekto estus doni strion de bezonita larĝeco, sed valvo de 100,000 omoj (ekz., skrenita valvo) donus tro mallarĝan strion. Oni tial konkludas, ke valvo de tro alta impedanco devus ne esti uzita se bona kvalito estas konservota.

Du matematikaj aldonaĵoj estas donitaj.

HELPA APARATO.

Kio Estas la Korekta Karakterizo por Variebla Kondensatoro ?—Leŭt.-Kol. K. E. Edgworth.

La aŭtoro revuas la respektivajn meritojn de kondensatoroj laŭ la leĝoj (A) Rektlinia Kapacito, (B) Rektlinia Ondlongo, (C) Rektlinia Frekvenco. La argumentoj estas laŭ la duala vidpunkto de la bezonita interspaco inter stacioj kaj la facileco de korekta alĝustigo. Oni konkludas, ke la rektlinia ondlonga tipo estas feliĉa kompromiso posedanta la avantaĝojn (1) eviti amasigon de stacioj je mallongaj ondolongoj, kiel ĉe Rektliniaj Kapacitaj Kondensatoroj, (2) eviti tre krizan alĝustigon je longaj ondolongaj, kiel ĉe Rektliniaj Frekvencaj Kondensatoroj, (3) faciligi la konstruon de instrumentoj montrantaj ciferojn laŭ metroj.

DIVERSAĴOJ.

Resumoj kaj Aludoj.

Kompilita de la *Radio Research Board* (Radio-Esplorada Komitato) kaj publikigita laŭ aranĝo kun la Brita Registara Fako de Scienca kaj Industria Esplorado.

Libro-Recenzoj.

Recenzoj estas donitaj pri la jenaj verkoj :

The Propagation of Radio Waves along the Surface of the Earth and in the Atmosphere. (La Propagado de Radio-Ondoj laŭlonge de la Surfaco de la Tero kaj en la Atmosfero) de P.O. Pedersen.

The Interaction of Pure Scientific Research and Electrical Engineering Practice. (La Interago de Pura Scienca Esplorado kaj Elektra Inĝeniera Praktikado) de Prof. J. A. Fleming.

A Study of Radio Direction Finding. Special Report No. 5 of the Radio Research Board. (Studo pri Radio-Direkto-Trovado. Speciala Raporto No. 5 de la Radio-Esplorada Komitato) de D-ro. R. L. Smith-Rose.

The Thermionic Valve. (La Termiona Valvo) de F. Goddard.

Les Filtres Electriques : L'Alimentation de Postes Recepteurs. (Elektraj Filtriloj : Provizado de Kurento por Riceviloj.) de M. Veaux.

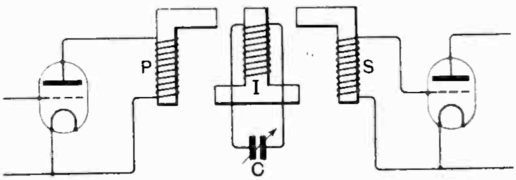
Some Recent Patents.

The following abstracts are prepared, with the permission of the Controller of H.M. Stationery Office, from Specifications obtainable at the Patent Office, 25, Southampton Buildings, London, W.C.2, price 1/- each.

SELECTIVE COUPLINGS.

(*Application date, 10th September,* 1926. *No.* 282136.)

A selective intervalve coupling comprises a primary winding *P* in the output circuit from the first valve, a secondary winding *S* connected to the grid of the second valve, and an intermediate winding *I*, tuned by means of a shunt condenser *C* to the desired signal frequency. Each coil is



wound on separate cores built up of thin laminæ of high-grade annealed silicon steel, of a thickness of .002 to .003 inches and having high ohmic resistance and a very low hysteresis.

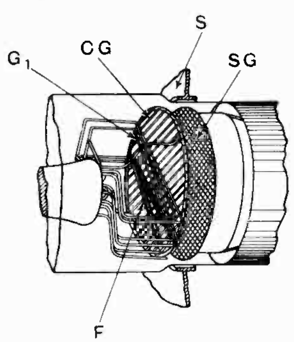
Frequencies other than that to which the intermediate coil is tuned are absorbed or dissipated in the metal-cored windings, though the desired signals are transferred through the coupling without appreciable loss.

Patent issued to the Dubilier Condenser Co., Ltd.

SHIELDED GRID VALVES.

(*Application date, 14th September,* 1926. *No.* 282150.)

The introduction of a positively-charged auxiliary grid between the control grid and the filament, although it serves the desired purpose of neutralising the space charge, has the disadvantage that it tends to absorb considerable quantities of current. In order to obviate this drawback the inventor



proposes to use a space-charge grid constructed of a very fine single wire running parallel to the filament and located between the latter and the control grid.

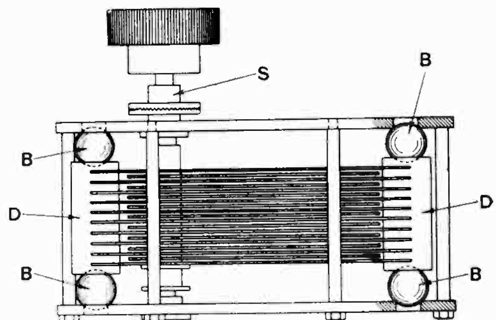
The invention is illustrated as applied to a shielded-grid valve of the Round type, comprising a *W*-shaped filament *F*, a control grid *CG*, and a shielding grid *SG* co-operating with an external screen *S*. The additional space-charge grid G_1 is shown mounted parallel with and just above the filament *F*. It is preferably made of the same gauge wire as the filament.

Patent issued to H. J. Round.

TUNING CONDENSERS.

(*Convention date* (*Austria*), *25th January,* 1927. *No.* 282580.)

In order to facilitate the assembly of variable condensers, loose glass balls *B* are used as shown so that the parts can be centred rapidly and automatically. The moving plates are secured to a control spindle *S* as usual. The fixed plates are



first mounted in blocks *D* which are then clamped by means of screw bolts against the insulator balls *B*, seated in suitable slots or depressions, as shown.

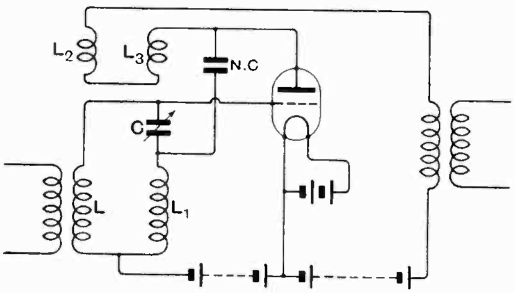
Patent issued to F. Horny.

PARASITIC OSCILLATIONS.

(*Convention date* (*U.S.A.*), *17th July,* 1926. *No.* 274472.)

It is pointed out that when attempts are made to neutralise interelectrode capacity effects by the well-known method of using a small feed-back condenser between the plate and a central tapping on the input coil, parasitic or ultra high-frequency oscillations are liable to be set up, particularly where several stages of balanced high-frequency amplification are connected in series. A remedy is found by introducing a definite inductive coupling between the plate and grid, the sense in which the coupling coil is wound being such as to oppose regeneration at the parasitic frequency.

For instance the coils L, L_1 are equivalent to the centrally-tapped input coil used in the original Rice circuit, the neutralising condenser being shown at NC, and the tuning condenser at C. The extra stabilising coils are shown at L_2 and L_3,



and are coupled respectively to the coils L and L_1. In practice the windings L, L_1 are combined into one coil, whilst the coils L_2, L_3 are similarly united, so that the resultant or overall back-coupling effect is substantially zero and does not diminish the signal strength.

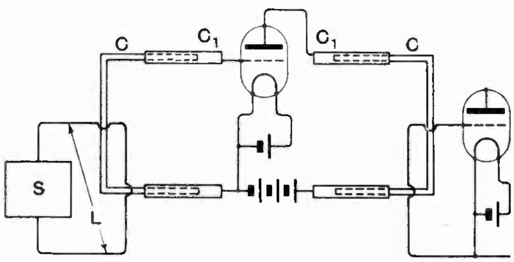
Patent issued to The Westinghouse Electric Co.

HANDLING ULTRA HIGH FREQUENCIES.

(*Application date*, 15*th October*, 1926. *No.* 283651.)

In order to avoid undesirable capacity leakage, and to keep circuit induction within the necessary limits in generating and amplifying very short wavelengths, the input and output leads of the generating or amplifying valves are constructed in the form of telescopic " wave " circuits as shown. A wave circuit is defined to be one in which the conductors are of a length comparable with that of the waves being handled.

In the case of the amplifier shown, the input voltage from a source S is applied to the system by magnetic coupling between the leads C and L. A corresponding electro-magnetic wave is set up in the space between the upper and lower pair of conductors, C, C_1, and travels with approximately the speed of light towards the grid of the amplifier,



where it is reflected back again, and so on. The optimum disposition of the voltage loops and nodes of the stationary-wave system to set up is secured by adjusting the overall length of the telescopic lead C, C_1.

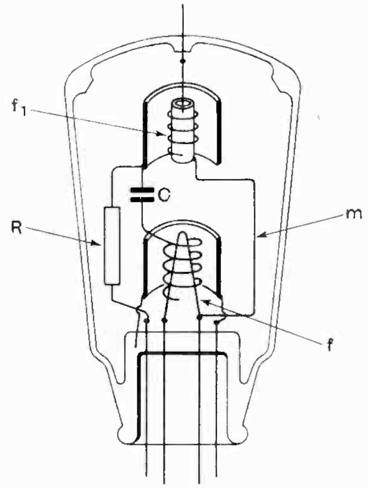
Patent issued to Standard Telephones & Cables.

A PHOTO-ELECTRIC VALVE AMPLIFIER.

(*Convention date* (*Germany*), 12*th November*, 1925. *No.* 261391.)

The electron-emission required in the first valve stages of a multi-valve receiver is only a small fraction of that expended in the last or power-amplifying valve, where a considerable current must be made available in order to drive the loud-speaker. Dr. Loewe utilises this fact to secure a welcome reduction in expenditure of filament current by depending upon the light and heat energy radiated from the incandescent filament of the power stage to liberate a sufficient supply of electrons to run one or more of the earlier valves.

Fig. 1 shows a multiple-unit valve containing two separate sets of electrodes. The lower or power-amplifying set comprises a filament f heated by a battery as usual, a spiral grid, and cylindrical plate. The upper set consists of a " cold " cathode f_1, preferably a cylinder coated with photo-electric substance such as sulphite of thallium, or a hydride



of selenium or rubidium, which liberates electrons under the influence of the light and heat radiated from the incandescent filament f. The electron emission from the upper cathode may also be supplemented by a direct metallic connection m. The intervalve coupling consists of a special high-resistance element R and a condenser C.

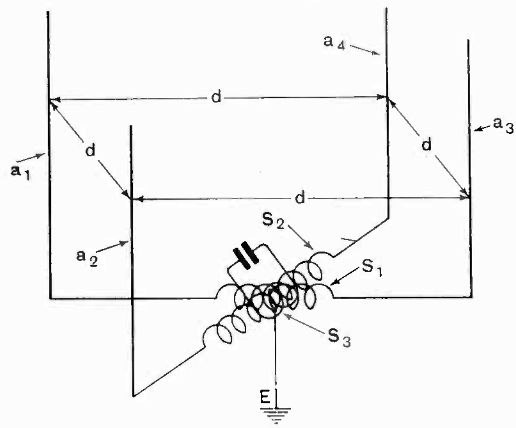
Patent issued to Dr. Siegmund Loewe.

DIRECTION-FINDING.

(*Convention date* (*Germany*), 29*th October*, 1926. *No.* 279794.)

It is found that the accuracy of the readings given by the standard DF equipment, particularly in the case of aircraft flying at a considerable height above the ground, largely depends upon the elevation at the moment of taking the bearings, and also upon the polarisation of the incident ray. A vertically-polarised ray will, for instance, give a very different result to one that is horizontally polarised.

Variable readings due to such changes of polarisation are avoided by using a receiving aerial of the form shown in the Figure, and comprising four vertical wires a_1, a_2, a_3, a_4, each individually non-directional and connected diagonally in pairs through coils S_1, S_2, the centres of which are earthed at E. The coils S_1, S_2 are in turn coupled



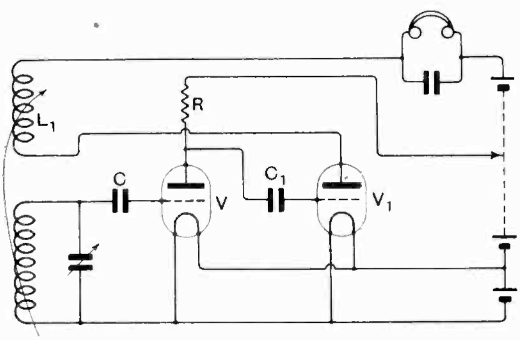
to the pick-up or search coil S_3 leading to the bearing dial. The distance d between the wires must be not greater than one-tenth that of the working wave-length for satisfactory results. The derivation of this distance factor is set out mathematically in the specification.

Patent issued to Dr. A. Esau.

REGENERATIVE RESISTANCE COUPLINGS.

(*Application date*, 19*th October*, 1926. *No.* 284002.)

When an anode-bend rectifier V is resistance-coupled to a following valve V_1, it is well known that the best results can be obtained by using a high



value of coupling resistance, but it is then difficult to introduce reaction. The drawing illustrates a circuit whereby this difficulty can be overcome.

A condenser C of 0.001 mfds is inserted in the grid lead of the first valve. This ensures that the grid potential is automatically adjusted to the strength of the incoming signals, thus avoiding the necessity for using a potentiometer. A condenser C_1 of 0.002 mfds is also inserted in the grid circuit of the valve V_1. No leak resistance is used in either case. The absence of a grid leak across C_1 is stated to reduce the internal impedance of the valve V_1, thereby facilitating the introduction of reaction, through the medium of a coil L_1.

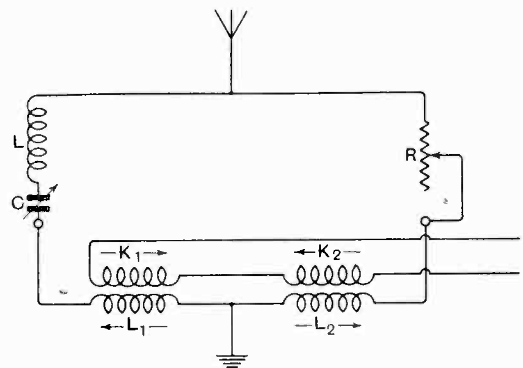
On the longer wavelengths the sense of reaction usually reverses, and for this work it is preferred to use capacity reaction in the form of a small condenser of 0.002 mfds inserted between the plate of valve V_1 and the grid of valve V, a high-frequency choke being placed on the plate circuit of the second valve.

Patent issued to C. E. Prince and W. S. Percival.

INTERFERENCE-ELIMINATORS.

(*Convention date* (*Germany*), 3*rd February*, 1926. *No.* 271911.)

In order to cut out interference due to a particular undesired frequency, the receiving aerial is branched into two circuits, each containing a similar loading coil L_1, L_2 to which the pick-up coils K_1, K_2 feeding the receiver are coupled. The left-hand branch circuit comprises an additional



inductance L and capacity C tuned to the interfering wave-length, so that it forms an acceptor circuit for that particular signal.

Under these circumstances the circuit LC presents zero impedance to the undesired signals, so that the corresponding induced currents can be perfectly balanced by means of a resistance R inserted in the right-hand branch of the aerial, no phase compensating means being required. The direction of the primary and secondary currents due to the undesired signals are indicated by the arrows, from which it will be seen that they are balanced out so far as the receiver circuit is concerned.

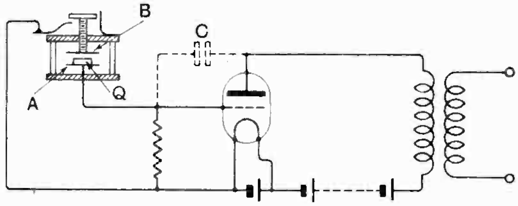
Incoming signals of any other frequency will not however be eliminated, but will pass through to the receiver, though at slightly reduced strength. The arrangement is stated to be particularly useful for combined receiving and transmitting sets, the receiver being completely shielded from the effects of the local transmitter. The method can also be adapted for eliminating several disturbing wave-lengths by adding other aerial branches containing suitable acceptor circuits.

Patent issued to the C. Lorenz Co.

PIEZO-ELECTRIC CONTROL.

(*Application date, 2nd November,* 1926. *No.* 284761.)

The generation frequency of an oscillating valve is controlled by adjusting the thickness of the air-



gap between a piezo-electric crystal and one of its plate electrodes. The Figure shows a valve sustained in continuous oscillation through inter-electrode capacity, indicated by the condenser *C* shown in dotted lines. The grid of the valve is connected to the lower support or electrode *A* of a quartz crystal *Q*, whilst the filament is connected through a terminal to an adjustable screw carrying the upper crystal electrode *B*.

As the air-gap between the plate *B* and crystal *Q* is increased, the oscillation frequency of the valve rises until a point is reached when the crystal ceases to vibrate. Conversely as the air gap is diminished the valve frequency decreases.

The crystal may be considered to act as a capacity reactance at all frequencies except at a resonant frequency, when its reactance may be either capacitative or inductive. In order to sustain the valve in oscillation, when the back-coupling between plate and grid is capacitative, as shown, the effective reactance both in the plate and grid circuits must be inductive. Accordingly by varying the reactance in the output circuit of the valve, the latter may be set so as to oscillate at any one of the fundamental or resonance frequencies peculiar to the crystal *Q*.

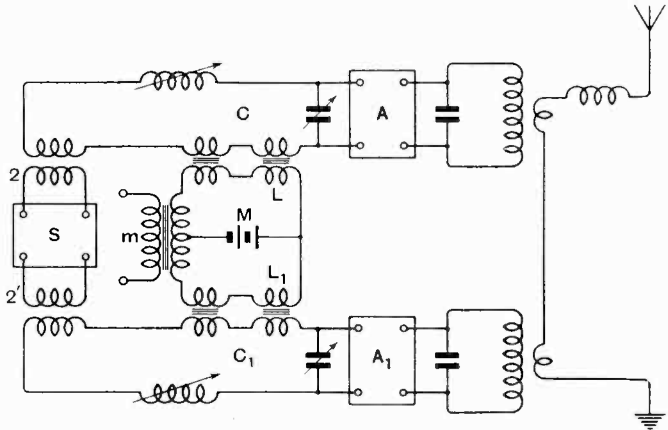
Patent issued to Standard Telephones & Cables, Ltd.

MODULATION BY PHASE-DISPLACEMENT.

(*Convention date* (*France*), 10*th May,* 1926. *No.* 270749.)

Signalling is effected by altering the relative phases of two carrier-waves of the same frequency, the arrangement being such that for ordinary Morsing the difference in phase varies directly with the amplitude of the signals, and at signal frequency, whilst in speech or other modulated signalling the phase-difference varies directly with the amplitudes of the acoustic currents. In this way sufficient modulation is secured with a comparatively low power-expenditure, the modulated high-frequency currents being subsequently amplified. There need be no amplitude change, but only a phase variation, at the receiving end, and in this form the system provides an effective method of secret signalling, since the ordinary type of receiver will not detect the modulation.

The simplest type of circuit, in which the phase variations create changes of amplitude in the received wave, is shown in Fig. 1. High-frequency



oscillations from a source *S* are fed through windings 2, 2^1, arranged to have a phase-displacement of say 150 degrees, to two circuits C, C_1. The latter are coupled to a magnetic modulator *M* in which the signal currents from a source *m* tend to increase the saturating current say in the coils *L* and reduce it in coils L_1, thus setting up the required phase-variation in the currents flowing in the circuits C, C_1. These are subsequently passed through separate amplifiers A, A_1 and combine vectorially in the transmitting aerial.

Patent issued to Soc. Française Radio-Electrique.