EXPERIMENTAL WIRELESS & The WIRELESS ENGINEER

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Editorials.

Who Discovered the Long Range of Short Waves?

A DISCUSSION on this subject has been going on lately in the correspondence columns of the *Electrician* between Mr. L. B. Turner and Mr. Marconi. In the issue of 8th January, Mr. Turner stated that " within the last two or three years it has been discovered that with much shorter waves the Austin-Cohen formula overstates the attenuation enormously. It is largely *this discovery, made by wireless amateurs transmitting with the pitifully useless wavelengths (as all thought)* allotted to them by the authorities which has stimulated renewed efforts to elucidate the behaviour of the upper atmosphere." The italics are ours in order to indicate the words to which Mr. Marconi took exception in a letter in the issue of 22nd January, in which he drew attention to papers read by Mr. C. S. Franklin and himself in 1922 dealing with experiments down to wavelengths of 2 metres carried out since 1916, and to a paper read by himself in July, 1924, in which he specifically mentions the inapplicability of the Austin-Cohen formula to short wave phenomena. In the issue of 29th January Mr. Turner points out that the 1922 papers deal entirely with short range directive work, and that the 1924 paper was published on 25th July, when the work of amateurs and others had already proved the astonishing ranges obtained with short waves. Mr. Turner gives a number of references to *The Wireless World* between April and July to prove the activities of amateurs in this sphere before Mr. Marconi's lecture. On 5th February Mr. Marconi returns to the charge, pointing out that these amateur transmissions were all with wavelengths of 100 metres or more, and could not be differentiated from the freak transmissions frequently observed at night-time. He can find no anticipation of his discovery that the daylight range increased as the wavelength was reduced from 100 metres down to 32 metres. In the current number Mr. Turner makes a brief reply, but adds nothing further of note to the discussion.

Another Question of Nomenclature.

UNDER this title we publish in this issue an interesting letter from Lieut.-Col. Edgeworth, who, while agreeing with our protest against the misapplication of the term " impedance " to what we called the " differential resistance " of a valve, makes further suggestions with which we do not entirely agree. The main points of his letter are : (1) That the impedance is the real quantity obtained by dividing the terminal P.D. by the current ; (2) that in the method involving imaginary quantities, reactance is regarded as an imaginary resistance ; and (3) that the quantity $R+jX$ should be called a complex resistance.

Now with regard to the first point, we do not agree that one is entitled to give this narrow interpretation to the term "impedance." Unless two alternating quantities, such as P.D. and current, are in phase, one can only define their quotient by adopting some convention, and Col. Edgeworth adopts the usual convention of taking their R.M.S. or maximum values irrespective of their phase, but when one remembers that the current and P.D. may be in the same direction at one moment and in the opposite direction at another moment, and that one of them may be zero when the other is a maximum, it will be obvious that their quotient, although a real number, is anything but a real physical quantity. When one writes $V=I\times Z$ there is no reason why Z should be limited to giving the mere numerical relation between the voltmeter and ammeter readings when it can be made to give also the phase relations between V and I, nor why it should cease to be called the impedance when so used.

Turning to the second point of Colonel Edgeworth's letter, we doubt whether it is strictly correct to say that reactance is regarded as an imaginary resistance. In the method referred to, resistance is treated as a real quantity and reactance as an imaginary quantity, or, to be even more correct, reactance is multiplied by $j=\sqrt{-1}$ to make the combination imaginary, but that is something very different to regarding it as an imaginary resistance.

We have several reasons for disagreeing with the third suggestion. $R+jX$ is one way, and a very informative way, of stating the impedance, and therefore "impedance" it should be called. The second term jX has nothing to do with resistance, real or imaginary, and therefore the name "resistance," however qualified, should not be applied to it. We prefer to keep the term "resistance" strictly for that component of the impedance which causes a dissipation of energy, whilst the term "reactance" is applied to the other component which is associated with the storing and restoring of energy in the magnetic and electric fields. The expression $R+jX$ cannot be called a vector, but when it is multiplied by a vector, such as the current I, the product $IR+jIX$ is another vector made up of two components, one IR in phase with the current, and the other IX 90° ahead of I, for this is the meaning of the j placed before the I. Hence $R+jX$, whilst not a vector itself, performs an operation on a vector, producing another vector $\sqrt{R^2+X^2}$ as big as the first one and ahead of it by an angle ϕ where $\tan\phi=X/R$.

Hence, of the names mentioned in Colonel Edgeworth's letter, "generalised or complex resistance" should be ruled out because of the misapplication of the word "resistance." "Operator" by itself is too vague, but "operator impedance" or "impedance operator" are both correct and self-explanatory. Although "impedance vector" would be incorrect, in that it is not a vector, "vector impedance" would be a good term, the word "vector" being used as an adjective to indicate that the impedance was given in a form suitable for application to vectors. But whether written $\sqrt{R^2+X^2}$ or $R+jX$ or $Z\underline{/\theta}$ the quantity is an impedance and should be so called.

Early Work of Professor A. S. Popoff.

An interesting letter relating to the early work of Professor A. S. Popoff appears under Correspondence in the issue of *The Wireless World* for 24th February.

Readers are probably aware that there has been some controversy respecting the date when Professor Popoff first demonstrated the practical application of wireless to communication by means of the morse code. The statement had been published that Professor Popoff at a meeting of the Russian Physico-Chemical Society demonstrated the principle by transmitting by means of wireless the morse letters spelling the words "Heinrich Hertz," on the 7th May, 1895. A careful investigation has produced from Russia the correction, supported by first-hand evidence, that this particular experiment did not take place at the meeting of the Society on 7th May, 1895, but nearly a year later before the same Society at a meeting held on 24th March, 1896.

In view of the fact that a good deal of propaganda has been put out claiming for the late Professor Popoff priority in the practical demonstration of wireless telegraphy, and, since this report has been widely published, we think the matter of sufficient importance to make this special reference to the letter appearing in *The Wireless World*.

Rejectors and Absorbers.

By Professor G. W. O. Howe, D.Sc.

[R432.1

REJECTORS and absorbers are generally regarded as two different devices for excluding from the receiving circuits unwanted oscillations of a given frequency. Such devices are often called wave-traps and are used to prevent a near-by transmitting station from interfering with the reception of a distant station. Not only is the receiving system tuned to the distant station, but a special device is introduced to discriminate very selectively against one definite interfering frequency. If there are several interfering stations of different frequencies, then several such devices may be employed, each tuned to exclude one of the interfering stations. In a draft list of definitions recently under discussion, the following descriptions were given:

Absorber.—An arrangement whereby energy received on an unwanted wave-length can be withdrawn from the receiving circuits otherwise than through the detector.

Rejector.—A combination of inductance and capacity joined in parallel, applied to a receiving circuit in such a way that it imposes the maximum possible impedance to currents of a specific frequency in the path in which the rejector is placed, its impedance to other frequencies being comparatively small.

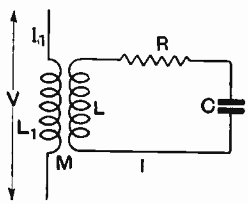


Fig. 1.

The impression given by these definitions is that in the first device the energy is side-tracked into the absorbing circuit where it is dissipated, whereas in the second device the impedance prevents the interfering induced E.M.F. from producing any appreciable current in the aerial.

We propose to show that the two devices are practically identical, not only in their results but also in their mode of operation.

In Fig. 1 an absorbing circuit is shown having inductance L, capacity C, and resistance R. This circuit is coupled to the receiving aerial by means of the two coils of self inductance L_1 and L and mutual inductance M. In vector notation we have in the aerial circuit

$$V = j\omega L_1 I_1 + j\omega MI \quad .. \quad (1)$$

and in the absorbing circuit

$$j\omega LI + IR + \frac{I}{j\omega C} + j\omega MI_1 = 0$$

$$\text{or } I\,[R + j\,(\omega L - 1/\omega C)] = -j\omega MI_1$$

$$\therefore\; I = -j\,\frac{\omega MI_1}{R + j\,(\omega L - 1/\omega C)} \quad .. \quad (2)$$

Substituting this value of I in equation (1) we have

$$V = \left[j\omega L_1 + \frac{\omega^2 M^2}{R + j(\omega L - 1/\omega C)}\right] I_1$$

$$= \left[j\omega L_1 + \frac{\omega^2 M^2 R - j\omega^2 M^2 (\omega L - 1/\omega C)}{R^2 + (\omega L - 1/\omega C)^2}\right] I_1$$

$$\therefore\; \frac{V}{I_1} = \left[\frac{\omega^2 M^2 R}{R^2 + (\omega L - 1/\omega C)^2} + j\omega\left\{L_1 - \frac{\omega M^2 (\omega L - 1/\omega C)}{R^2 + (\omega L - 1/\omega C)^2}\right\}\right] \quad ... \quad (3)$$

The first term represents the effective resistance introduced into the aerial by the presence of the absorbing circuit; any resistance in the coil L_1 would be added to it. The second term represents the effective reactance; whether the inductance L_1 is increased or decreased by the presence of the absorbing circuit will depend on the sign of $\omega L - 1/\omega C$, *i.e.*, on whether the resonant frequency of the circuit is above or below the frequency of the current under consideration. If the absorbing circuit is tuned to the resonant frequency $\omega/2\pi$ then $\omega L = 1/\omega C$ and equation (3) becomes

$$\frac{V}{I_1} = \frac{\omega^2 M^2}{R} + j\omega L_1 \quad .. \quad .. \quad (4)$$

In this case the presence of the absorbing circuit does not affect the apparent inductance of the primary or aerial circuit, but introduces an equivalent resistance ω^2M^2/R, *which increases as R is made smaller.* Hence the presence of a low resistance tuned absorbing circuit is equivalent to inserting a high resistance in the aerial circuit. This equivalent resistance is proportional to the square of the mutual inductance. If the two coils are similar and are very tightly coupled together, $L_1 = L = M$, and the equivalent resistance becomes ω^2L^2/R.

Equation (3) can be simplified by introducing two symbols, one to represent the frequency conditions and the other to represent the damping conditions. If ω_o is the resonant angular frequency $(2\pi f_o)$ of the absorbing circuit, then $\omega_o^2CL=1$; for any other angular frequency $\omega = 2\pi f$ we shall put $\omega^2CL = x$, so that $x = \omega^2/\omega_o^2 = f^2/f_o^2$. We shall also put $y = CR^2/L = R^2/\omega_o^2L^2$. It will be seen that $R^2/\omega^2L^2 = y/x$. If δ is the logarithmic decrement of the circuit, then $y = (\delta/\pi)^2$.

Equation (3) may now be written

$$\frac{V}{I_1} = j\omega L_1 + \omega^2M^2 \left[\frac{R - j\omega L\frac{x-1}{x}}{R^2\left[1 + \frac{\omega^2L^2}{R^2}\left(\frac{x-1}{x}\right)^2\right]} \right]$$

$$= j\omega L_1 + \omega^2M^2 \left[\frac{R + j\omega L\frac{1-x}{x}}{R^2\left[1 + \frac{x}{y}\left(\frac{1-x}{x}\right)^2\right]} \right]$$

Putting $k = \frac{M}{\sqrt{L_1L}}$ for the coupling co-efficient between the two coils, this may be written

$$\frac{V}{I_1} = j\omega L_1 + k^2\frac{L_1}{L}\left[\frac{R + j\omega L\frac{1-x}{x}}{\frac{xy + (1-x)^2}{x^2}} \right]$$

$$= j\omega L_1 + k^2\frac{L_1}{L}\left[R\frac{x^2}{(1-x)^2 + xy} + j\omega L\frac{x(1-x)}{(1-x)^2+xy} \right]$$

$$= k^2\frac{L_1}{L}R\left(\frac{x^2}{(1-x)^2+xy}\right) + j\omega L_1\left(1 + k^2\frac{x(1-x)}{(1-x)^2+xy}\right) \quad (5)$$

When tuned to resonance $x=1$ and this becomes

$$\frac{V}{I_1} = k^2\frac{L_1}{L}R\left(\frac{1}{y}\right) + j\omega L_1 = \frac{k^2\omega^2LL_1}{R} + j\omega L_1$$

$$= \frac{\omega^2M^2}{R} + j\omega L_1$$

as already found in equation (4).

The effective resistance thus introduced into the aerial circuit is proportional to the square of the coefficient of coupling between the two circuits and inversely proportional to the actual resistance of the absorbing circuit.

The power dissipated in the combination is equal to the current I_1 multiplied by the component of V in phase with it, or to I^2 multiplied by the effective resistance ω^2M^2/R. This power is all dissipated in the resistance of the absorbing circuit.

We now turn to a consideration of the so-called rejector circuit.

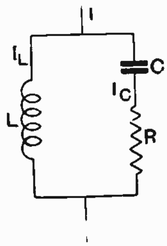


Fig. 2.

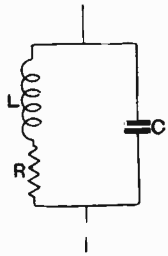


Fig. 3.

Fig. 2 shows a rejector circuit consisting of a condenser of capacity C in series with a resistance R, shunted by an inductance L.

If V is the P.D. across the combination, we have

$$V = I_c\left(R + \frac{1}{j\omega C}\right) = I_L\, j\omega L$$

$$\therefore\ I = I_c + I_L = V\left(\frac{1}{R + 1/j\omega C} + \frac{1}{j\omega L}\right)$$

$$\therefore\ \frac{I}{V} = \frac{j\omega C}{j\omega CR+1} + \frac{1}{j\omega L} = \frac{j\omega CR + 1 - \omega^2CL}{j\omega L(j\omega CR+1)}$$

$$\therefore\ \frac{V}{I} = \frac{j\omega L - \omega^2CLR}{1 - \omega^2CL + j\omega CR}$$

$$= \frac{\omega^4C^2L^2R + j\omega\left[L - \omega^2(CL^2 - C^2R^2L)\right]}{(1-\omega^2CL)^2 + \omega^2C^2R^2}$$

$$= \frac{(\omega^2CL)^2R}{(1-\omega^2CL)^2 + \omega^2C^2R^2} + j\omega\left\{\frac{L - \omega^2CL(L - CR^2)}{(1-\omega^2CL)^2 + \omega^2C^2R^2}\right\}$$

putting $\omega^2 CL = x$ and $\frac{CR^2}{L} = y$, this may be written

$$\frac{V}{I} = R\left(\frac{x^2}{(1-x)^2 + xy}\right) + j\omega L\left(\frac{(1-x) + xy}{(1-x)^2 + xy}\right) \quad .. \quad (6)$$

If $x = 1$, *i.e.*, for resonance,

$$\frac{V}{I} = \frac{R}{y} + j\omega L = \frac{L}{CR} + j\omega L = \frac{\omega^2 L^2}{R} + j\omega L$$

Very similar equations are obtained with the arrangement shown in Fig. 3, where the resistance R is in series with the inductance; the final equation for V/I when adjusted to resonance is exactly the same.

It is evident from the foregoing that both devices operate in exactly the same way by introducing a high effective resistance into the aerial circuit at a given frequency; other things being equal the energy absorbed by the circuit is the same in both cases. An absorber could just as correctly be called a coupled rejector, and a rejector could be regarded as a directly connected absorber. By making the two coils of the coupled absorber identical and coupling them very tightly together, one obtains a 1/1 transformer which can just as well be replaced by a single winding, and the absorber thus becomes a rejector.

NOTE.—Equation (5) can be written

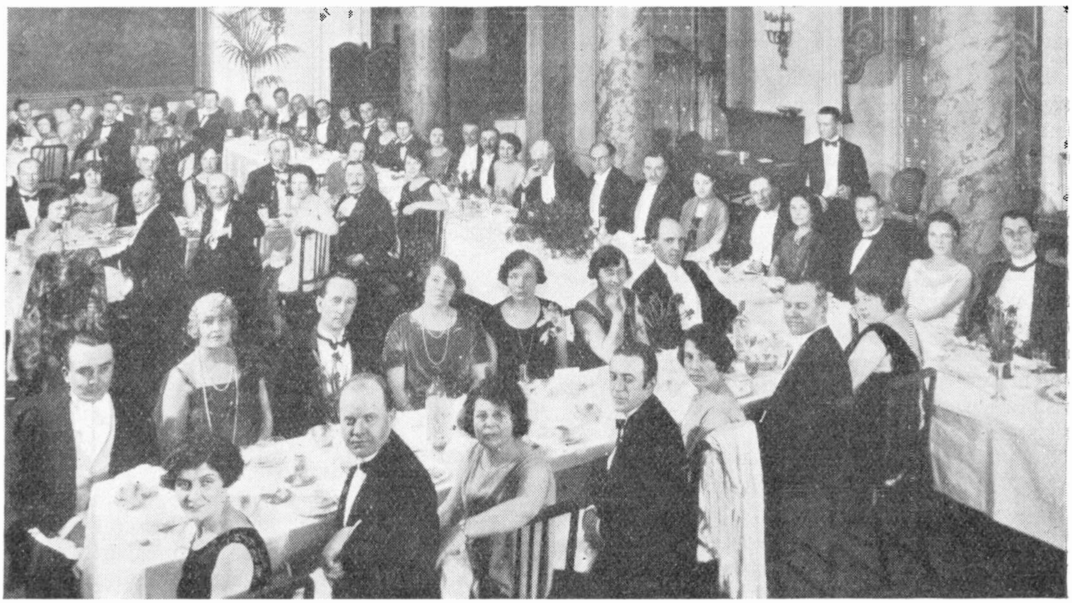
$$\frac{V}{I_1} = j\omega L_1 + \omega L_1 k^2 \cdot \frac{\sqrt{x^3 y} + jx(1-x)}{(1-x)^2 + xy}$$

This is a very useful form from which to plot curves; it contains only the reactance of the primary coil and the three variables, k, x, and y. If the coupled circuit is removed, $k = O$ and we are left with the first term.

Radio Society's Annual Dinner.

Dr. W. H. Eccles presided at the Sixth Annual Dinner of the Radio Society of Great Britain held again this year at the Waldorf Hotel, where the dining hall was filled to its maximum capacity.

The speakers included Mr. Reith, Earl Russell and Commander Carter, of the B.B.C., who, in responding to the toasts of the guests, referred to the co-operation given by members of the Society in the service of broadcasting.



Some of the company assembled at the Dinner. On the right of Dr. Eccles is Mr. Reith, Earl Russell, Mr. Klein and Mr. Fogarty. On his left can be recognised Commander Carter, Mr. McMichael and Mr. Maurice Child. Captain S. R. Mullard is seated opposite to Mr. McMichael and Mr. Elwell can be seen in the foreground seated opposite to Capt. Mullard.

H.F. Resistance.

By P. K. Turner, A.M.I.E.E.

[R240

The following article has been specially written as an introduction to a series of articles by S. Butterworth which are shortly to appear.

THERE will shortly appear in E.W. & W.E. one of the most important articles it has yet published: a complete account of the methods to be used in designing low-loss coils, in which the (very difficult) mathematical work has already been done and tables and curves provided by which anyone who can do simple algebra can design the best possible coil to fulfil any given conditions. This article is by one who is among the two or three specialists in the world who really know the subject inside out, and who has spent many years on the work.

But it has been thought advisable to have a preliminary article giving a general survey of the subject, in order that there may be a closer appreciation of just what is involved, and I have therefore tried in the following notes to give a clear account of what is meant by "H.F. Resistance," particularly in connection with coils.

Firstly, why has there been so much mystery about it? For the simple reason that H.F. resistance is not so easy to measure as D.C. resistance, nor is it easy to calculate.

The simplest (though not the most accurate) method of measuring D.C. resistance is as shown in Fig. 1. We apply a voltage to an ammeter in series with the resistance, and put a voltmeter across it. Say the voltmeter shows 5.5 and the ammeter .1; and suppose that we know already that the voltmeter takes .01A at 5.5V. Then the resistance takes .09A at 5.5V, and its resistance is given by

$$R = \frac{V}{I} = \frac{5.5}{.09} = 61.1 \text{ ohms.}$$

Now suppose we try to do the same thing with a coil at radio frequency. We are at once confronted with the difficulty that the coil has reactance as well as resistance. The reactance is given by

$$X = \omega L = 2\pi f L,$$

where L is the inductance in henries
f is the frequency

$$\omega = 2\pi f.$$

Suppose that L is 100μH, and (for simplicity) we test at 377 metres, where $f = 795.8$kC, which gives $\omega = 5 \times 10^6$.

Then $X = 5 \times 10^6 \times 100 \times 10^{-6}$ (since L is in microhenries)
$= 500$ ohms.

Now such a coil would have actually a resistance of about 5 ohms, and the impedance, which is what we get by dividing volts by current, is given by

$$Z = \sqrt{R^2 + X^2} = \sqrt{25 + 250\,000} = 500.25.$$

Theoretically, if we measured Z and knew L (and hence X) we could find R. In practice, quite a large R makes so little difference in Z that the method is impracticable.

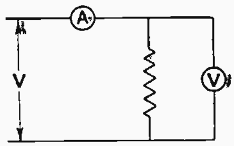


Fig. 1.

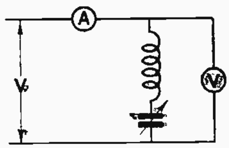


Fig. 2.

But we can avoid that difficulty. Suppose we put a condenser with the coil, as in Fig. 2, and then measure V and I when the circuit is exactly tuned. The definition of tuning is that the reactance of C is equal in amount to that of L, but *negative* in sign, so that the two cancel out and leave the resistance only. Then certainly, *if* we know what current the voltmeter takes, we can find R. But—and here comes the difficulty—we are measuring the resistance of coil plus condenser, not of the coil alone. There is also the point that in measuring this "resistance" we are actually measuring every source of power loss whatever in the coil. As will be shown later, there are several such sources of loss, and they all appear as additions to the resistance. This should be seen clearly, and perhaps one might digress for a moment into the general idea of power loss.

If we had a perfect coil, with no resistance or other losses, and we applied to it an alternating voltage as in Fig. 3*a*, we should get in it a current as in Fig. 3*b*. The current is apparently 90° behind the voltage. Now at any instant the power being delivered to the circuit is the product of volts and current. Thus during the time 1, power is delivered, but during the time 2, there is a *negative* voltage and a *positive* current at any instant, so that negative power is being delivered to the coil, or in other words the coil itself is delivering power back to the supply. It is fairly obvious from Fig. 3 (and can easily be proved) that during time 2 the coil gives back every bit of power it took during time 1. In fact, averaged over a number of cycles, no power at all is taken, although both voltage and current are there. If, however, there is any resistance, or leakage, or dielectric loss—in fact any source of power loss at all—there will be a component of current which is not exactly 90° out of phase with the voltage, and power will be absorbed. Thus, suppose that a piece of solid matter, such as dust, was placed between the plates of a condenser, and kept charged positively, then every time the upper plate was positive this object would move towards the lower one, and *vice versa*. It takes power to move an object in this way, and if we calculate the horse-power we can convert it into watts. Now if we have a given current I passing through a resistance R, it is known that the power W expended is

$$W = I^2R,$$

so that the power used in moving our dust (being known) can be used in the equation

$$R' = \frac{W}{I^2}$$

(the inverse of the previous one), and we can say that the "equivalent resistance" thrown into the circuit by that dust is R'. In fact, any source of power absorption can be represented by some resistance in series. This equivalent resistance may not be the same for all frequencies.

As will be shown later, it is not in fact at all difficult to measure the apparent H.F. resistance of a circuit containing a coil as its main item. But to make the corrections for other losses and give a figure actually representing the resistance of the coil itself is not so easy.

It is hardly necessary for me to state that the resistance is not the same as the D.C. resistance—all my readers have got thus far; but it might be as well to state that it is not the same even as the H.F. resistance (at the same frequency) of the same wire stretched out straight.

The next question is, as to whether it is possible to calculate the difference; and the answer is; Yes—at any rate to a very close approximation, and as regards certain forms of power loss.

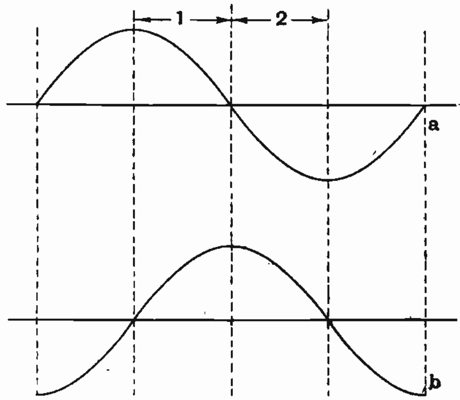


Fig. 3.

Let us try and sort out the various known losses: they are five in number, and we will deal with each of them in turn. They are :—

(A) The D.C. Resistance.
(B) The simple Skin Effect.
(C) The Proximity or Eddy Current Loss.
A, B and C together constitute the "Copper Losses."
(D) The Self-capacity Effect.
(E) The Dielectric Losses.
(These two are quite distinct.)

(A) The D.C. Resistance.

This is, as we all know, an inherent property of any wire. It is quite accurately known, may be calculated in advance by ordinary copper wire tables, and is easily measurable to high accuracy. It is independent of frequency.

(B) The simple Skin Effect.

This also is fairly well known by now. It may be looked at from two points of view. One is to say that alternating current in a wire is more or less forced to the surface, more and more so as the frequency goes up. Another, and in my own opinion a better way, is to say that the alternating field set up in the wire by the alternating current induces

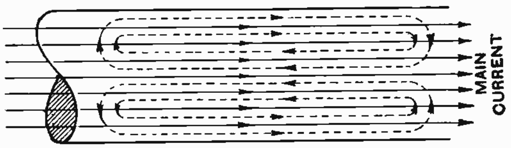


Fig. 4.

electromotive forces and sets up eddy currents in it. These are in the opposite direction to the main current in the centre of the wire, but return in the same direction at the surface, more or less as shown in Fig. 4. Hence the total current is increased at the surface and diminished at the centre. The power losses due to both currents can be added together and expressed as an increased resistance.

It will be obvious that this " Skin Effect " is itself an eddy current loss.

(C) The Proximity Effect.

If now we bunch several wires together, all carrying currents, then in the substance of each wire there will be, in addition to the eddy currents set up by its own field, another lot set up by the fields of the other wires. An attempt has been made in Fig. 5 to show the general sort of path followed

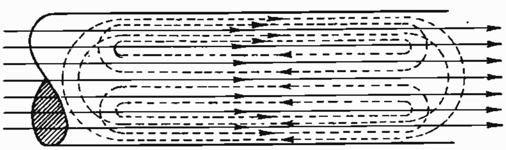


Fig. 5.

by these, and it will be seen that they are in the same direction as the main current and " skin effect " currents at one part of the surface of the wire, but in the other direction at the opposite part of the surface. In fact, when several wires carrying current act on one another, the currents flow, not only on the surface, but actually in one part of the surface only.

Again, it is found that the power losses due to these new eddy currents due to the proximity of other wires (hence " Proximity Effect ") can be calculated separately and added on.

(D) The Self-Capacity Effect.

As is well-known, every coil in practice has a certain capacity from turn to turn. In other words, some of the current going from one end of the coil to the other goes *via* the series of condensers formed by each turn and its neighbour. For most purposes it has been found permissible to represent this by saying that the coil behaves just as if it had a small condenser permanently connected across it as in Fig. 6. Obviously if such a coil is supplied with current from without, it is of the nature of a rejector circuit, and will offer an increased resistance on this account. What is not so clear is that this effect exists also if the coil itself is the source of voltage. The writer admits freely that he himself did not realise this till he went into the subject seriously.

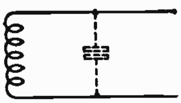


Fig. 6.

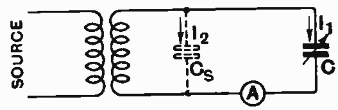


Fig. 7.

Suppose that the coil is coupled to a source, as in Fig. 7, and is tuned by C. Then the voltage set up in L sends current into C and C_s. But we can only get at and measure the current in C, so that for all practical purposes we must add to the actual resistance of L enough to bring the current down from $I_2 + I_1$ to I_1 only. Calculation shows that the correction is just the same for Figs. 6 and 7.

(E) The Dielectric Loss.

Further, the " condenser " C_s is not a perfect condenser. Instead of air dielectric it may have cotton or silk or enamel and wood or ebonite. Hence there are dielectric losses, and these also are shown as an addition to the resistance of the coil.

There might be added a sixth section, " Sundry Losses." But the losses in it are not really inherent in the coil, so we will only just mention them. They include such matters as eddy current loss in pieces of metal near the coil—screws, etc.—and possibly dielectric losses between the coil and other conductors in the neighbourhood. So long as one does not succumb to the temptation to mount variable condensers within cylindrical coils to save space, these losses are not as a rule serious.

Now, what do we know as to the relative importance of these various losses, and the way they depend on the design of the coil? Quite a lot, really; although until now, unfortunately, the work has only been published in the proceedings of learned societies, and has not been brought within the range of the amateur. How widespread is the ignorance of the work done, even amongst serious workers, was brought home to the writer a few weeks ago, when reading an article by a quite well-known technical journalist in a usually well-informed contemporary. This author thought that the skin effect was known to say 1 per cent. for straight wires; and that the proximity effect for single layers might be found to 10 per cent.; but, after all, we know very little about the actual H.F. resistance of coils.

What are the facts? The skin effect is certainly known to 1 part in 3 000, for I have a table giving it to this accuracy. It could certainly be worked out more accurately still if necessary. The proximity effect calculations are more difficult. I should estimate that the amount of the effect is known to within 1 or 2 parts in 1 000 for spaced single-layer coils, 1 in 300 to 500 for spaced multilayer, and 1 or 1½ in 100 for close-wound coils. Probably the errors are actually less than this estimate.

The other two losses, which we may call the "capacity losses," have not been worked out so accurately—or at any rate to my knowledge. They both depend on the actual self-capacity. If this is known, effect (D) —the capacity effect—is known at once with complete accuracy. Effect (E) depends on the actual material of the coil former and insulation of the wire. It could probably be estimated quite closely, but only by one used to judging the quality of material. Luckily, for most conditions (E) is not important; this may surprise some readers; but I will give just two examples:—

The first is a standard plug-in coil of well-known make. The resistance of a circuit containing coil, condenser and leads was measured at H.F. The copper losses were calculated and corrected for (D) (Capacity effect).

Result at 540 metres:—

Observed *total* loss 2.5.

Calculated copper loss 2.1, or 84 per cent. of total.

Thus the dielectric losses of the coil together with all other losses in the circuit (condenser, leads, etc.) amount to only 16 per cent. of the whole.

The second example is a "Daventry" coil of 2 400μH, wound with silk-covered wire on a wood and ebonite skeleton. Low self-capacity, but no extraordinary precautions.

Resistance measured, as in previous case, in probably the best-equipped laboratory in the country; 18 ohms for the whole circuit. Measured by the writer, after allowing for the rest of the circuit, 16 ohms. Calculated copper loss, corrected for capacity effect; 15 ohms. In this case the losses in condenser, etc., were twice the dielectric loss in the coil, which latter was only 6 per cent. of the total. As will be seen later, at shorter waves this becomes more important, but still the copper losses are the greatest except at ultra-short waves.

Now as to the effect of various points of design on these losses. The most important point is that, for constant spacing between turns, the D.C. and skin losses go down as larger wire is used, while the proximity losses rapidly go up. Hence there is one diameter of wire for each coil which gives minimum loss. But frequency is also important.

Roughly speaking, it may be said that the copper losses of a given coil go up with frequency, but more slowly than the frequency itself. But the dielectric losses go up faster than the frequency, and at very short waves may become quite important. But it is a curious point that most of the devices recently adopted to get low losses — spaced winding especially — have reduced the total loss chiefly because they have brought down the copper losses!

Taking the broadcast wave-lengths as a sort of intermediate band of frequencies, we are likely to find something like the following for a good modern coil with a condenser of .0002 or .0003 across it :—

		Per cent. of total losses.
D.C. Resistance	15	
Skin Effect	35	
Proximity Effect	40	
Total copper losses ..		90
Capacity Effect	5	
Dielectric Loss	5	
Total Capacity Losses ..		10
		100

Since the resistance of a coil varies with frequency, and also (as regards the Capacity effect) with the proportion between self-capacity and external tuning condenser, it is obvious that it is not a "constant" of the coil. In fact, the resistance *per se* is not a fair test, for the point that governs sharp tuning, etc., is the relation between the resistance and the reactance. For this reason it is best to judge a coil by its "power factor," which is approximately equal to the resistance divided by the reactance, in fact

$$\psi = \frac{R}{2\pi f L}$$

or if we like to put L in microhenries and substitute wave-length for frequency,

$$\psi = \frac{R\lambda}{1885 L_{(\mu H)}}.$$

However, even the power factor is not constant. As a rule there is one frequency at which the coil has a better power factor than at any other, and one might give its value at this. But, since coils for wireless work are nearly always designed to tune with a condenser, it is probably best to take, as a criterion of quality, the power factor measured at such a frequency that some definite tuning capacity is required. The writer's choice is a total capacity of .0003μF, including the coil's own self-capacity.

While we are on the subject of H.F. resistance, it may be of interest to describe the actual details of measuring the H.F. resistance of a coil. As is well known, there are several methods, and the one I propose to describe is selected simply because I have found it so convenient and accurate in practice that I prefer it to the others.

I propose to describe in detail the exact way in which a measurement is made by myself, saying little about alternative methods preferred by others.

The method used is the well-known one of "Resistance Variation," and is based on the following simple theory :—

Suppose a constant voltage V to be applied to the two resistances of Fig. 8, and the resulting current to be measured. Then

$$V = I_1 (R + R_1)$$

now suppose that R_1 is short circuited.

$$V = I_0 R.$$

I_0 being naturally larger than I_1. Obviously from these two formulæ,

$$I_0 R = I_1 (R + R_1) = I_1 R + I_1 R_1$$

or

$$\frac{R}{R_1} = \frac{I_1}{I_0 - I_1}.$$

In terms of H.F. work exactly the same applies. The coil L is exactly tuned by the condenser C to the H.F. voltage induced in it by an oscillator (Fig. 9). The current is measured. Then a fixed resistance R_1 is inserted into the circuit, and the current again measured. Application of the above formula will give the resistance of the circuit.

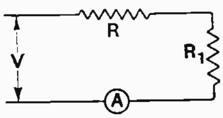


Fig. 8.

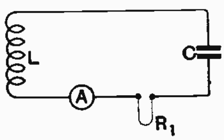


Fig. 9.

The author prefers to use a Moullin voltmeter (to measure H.F. volts across C) rather than the ammeter A. The reason is a simple one : A will actually be a thermo-junction connected to a D.C. meter. If the junction is a sensitive one, its resistance will be high : *e.g.*, a Cambridge vacuo-junction to give a visible deflection for 1mA has several ohms resistance. On the other hand, a Moullin voltmeter across C will give about ten times the sensitivity (for C = about .0003μF) and only throw in about .1 ohm of apparent series resistance. It is easy to show that for measuring small H.F. resistances the voltmeter gives much greater accuracy.

The same formula applies, as may be readily seen. Let E be the unknown E.M.F. actually set up in L, and V the volts across C. Then

$$I_1 = \frac{E}{R+R_1}$$

$$V_1 = \frac{I_1}{\omega C}$$

so $$E = \omega C(R+R_1)V_1$$

and with R_1 short-circuited

$$E = \omega CRV_0$$

so $$\frac{R}{R_1} = \frac{V_1}{V_0 - V_1}.$$

Now what are the conditions for accurate measurement? We will state them first, and then discuss them.

(A) R_1 must be known accurately.
(B) V_0 and V_1 must be measured accurately.
(C) C must not vary during the test.
(D) ω (*i.e.* f) must not vary during the test.
(E) E must not vary during the test.
(F) R must not vary during the test.

(A) This sounds simpler than it is; for, of course, it is the H.F. resistance of R_1 that is required. Luckily, the values of R_1 usually needed (from 1 to 30 ohms or so) can be obtained by a short straight piece of fine wire, such as 47 S.W.G. Eureka, for which the skin effect is negligible at all ordinary radio frequencies. It is, of course, necessary that the insertion of R_1 shall not change the tuning of the circuit. For this reason one always uses a link of equal length, making it part copper and part Eureka, so that the total inductance and capacity of the circuit is not changed. One takes for R_1 the difference between the all-copper link and the Eureka one. I have already described the type I use, and reproduce the sketch herewith (Fig. 10).

(B) This involves the whole matter of the Moullin voltmeter. There is not space in this article to go into a full description of my own specimen; but in essence it is a valve biased to -4.5 volts, with 22 volts on the anode. The normal anode current is 10 micro-amps, rising to about 50 μA for 2 volts (r.m.s.) of H.F. on the grid, and to about 200 μA for 5 volts. The D.C. meter in the plate circuit gives full deflection (unshunted) for 10 μA, and shunts of 5 to 1 and 20 to 1 are provided. For reading small voltages, one dry cell is used with a potentiometer and 10 000 ohms resistance to balance out the normal 10 μA and bring the meter to zero. It then gives full deflection for about a volt, and voltages down to .2 are quite accurately readable.

(C) This is easy, provided, of course, that the insertion of R_1 does not cause any change in the total capacity of the circuit. It is most important that the tuning shall be *dead* accurate as otherwise one is inserting reactance as well as resistance.

(D) and (E) This depends on constancy of the source as a first item. If, as usual, it is a valve oscillator, try the voltage of all batteries before and after the test, for if they have fallen at all the results are not dependable.

It is important also to remember that the source must be powerful enough to give the required voltage in the coil while very weakly coupled. It must be remembered that the current in the circuit being measured changes with R_1. This change actually affects the coil of the source, and changes both its inductance and resistance: this in turn may change both the strength and the frequency of E.

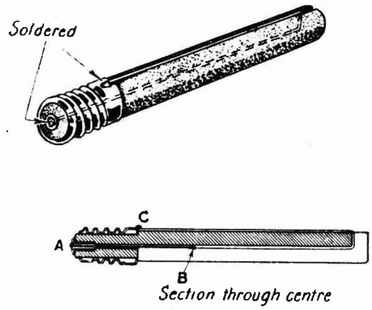


Fig. 10.

If the source coil and that being measured are never nearer than, say, three times the greatest dimension of either of them, this effect will be negligible.

(F) There are, of course, various ways in which R may change, but the most important are in the measuring instruments. If a thermo-junction is being used, its resistance will probably change as I varies. If the voltmeter is being used, its apparent resistance will change with E if the grid ever goes positive. As far as the writer's tests have gone, his own instrument, with 4½ volts bias, shows no change at all for less than 3 volts r.m.s. input.

Before I describe the actual routine of a test, there is one point which is very useful if much work is being done; that is the possibility of avoiding calculation by getting out a curve-sheet.

Looking at our formula for R, we have

$$R = R_1 \frac{V_1}{V_0 - V_1}$$

There are thus three variables, R_1 V_1, and Vo, which must be allowed for. But one has usually a set of fixed H.F. resistors, and for each one of these R_1 is fixed. So for each resistor there are two variables, V_1 and V_0.

But there is nothing to prevent one from starting off with a definite V_0 in every case (I use 3 volts). If we do this, then the only remaining variable is V_1, and for each resistor we can draw a curve of R against V_1. Actually, one can go farther, for every V_1 corresponds to some definite deflection of the instrument in the Moullin voltmeter, but since this might change as the valve ages, I prefer to have curves of R against V_1, which are not affected by changes in the voltmeter.

The condenser comes next—always see that there is nothing very near the coil or between it and the source, as that might set up a fictitious resistance. The condenser is a large one of good quality. The moving plates are earthed to the brass case, which is essential for any measurement work.

Close to the condenser is the valve panel of the Moullin voltmeter, the grid terminal being connected to the insulated condenser terminal by only a few inches of wire (16 S.W.G. bare wire is used). In the earthed side lead from coil to condenser is set the holder for the H.F. resistors.

The usual batteries are of course present, though not shown: the galvanometer actually in use is of the mirror type, and the scale is at the back of the bench.

The working routine is as follows: The galvanometer is shorted at the shunt box, and the voltmeter and oscillator valves switched on and left for half an hour to settle down—actually they change but little after ten minutes. Then the oscillator anode battery is disconnected while the Moullin voltmeter is "set," *i.e.*, the batteries adjusted till the deflection goes right across when unshunted. It is shunted down 20:1, and then the source is switched on and L_1

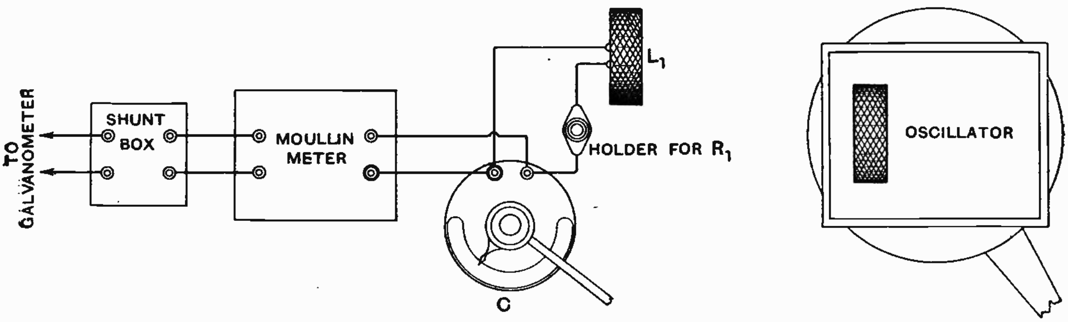


Fig. 11.

Here then in Fig. 11 is the layout used by the writer. On the right is the source, an ordinary valve wavemeter with about 60 volts on the anode. It is mounted on a wooden turntable, for reasons which will appear later.

Two or three feet from it is the coil to be tested, mounted in a single-coil holder if it is of the plug-in type. It is kept 4 to 5 inches above the bench by a block of wood or paraffin wax.

and C tuned. The value of E is adjusted till the Moullin voltmeter shows roughly 3 volts (with the copper link in at R_1). This is done by revolving the turntable: no attempt must be made to do it by adjusting the source batteries, as this would change the tuning.

Then the balancing potentiometer is adjusted till the deflection is just above zero. The galvanometer is unshunted, and C tuned very accurately. Care must be taken here. It must be remembered that the current of say $5\mu A$ through the unshunted galvanometer is the resultant of perhaps $100\mu A$ anode current and $-95\mu A$ from the balancing battery. If the condenser is handled carelessly and the circuit put considerably out of tune, the anode current will drop perhaps to 15 or $20\mu A$, leaving an unbalanced negative current of eight times the proper load on the galvanometer, which may have distressing results.

On first trying to tune in under these conditions, the experimenter will probably be surprised at the extraordinary sharpness of tuning. Full deflection on the unshunted instrument corresponds to only a few per cent. change of anode current, and since in a good circuit 1 per cent. change of capacity will halve the anode current, it will be appreciated that one may have to adjust the condenser to a tenth of a degree to get exact tuning.

When the tuning is correct, *first shunt the galvanometer* (this rule: **shunt the galvanometer before making any change in the circuit,** *must* be observed). Then take off the balancing voltage and adjust the oscillator until the galvanometer reads the exact V_o required. Short-circuit the galvanometer and insert an H.F. resistor instead of the copper link ; bring the shunt to normal value and read V_1. Repeat with other resistors, and note against each the values of V_1. Actually, of course, one will read deflections and get the values of V_1 from the calibration curves of the Moullin voltmeter.

Then we get for each value of V_1 and R_1 a value of R, and we average them. Strictly speaking, the average is not exactly correct, and one should use the Method of Least Squares to find the best possible result; but in practice this is hardly necessary.

There are one or two alternatives to calculating the values of R in each case. One obvious one is to plot $1/V_1$ against added resistance, as in Fig. 12. Here we have taken the case of observed volts and resistances given in the table below :—

R_1 ..	0	1.20	2.13	3.73
V_1 ..	3.0	1.8	1.4	1.0

From this table we find $1/V_1$ for each value of R_1, thus :—

R_1 ..	0	1.20	2.13	3.73
$1/V_1$	0.33̇	0.55̇	0.71	1.0

and the four points of Fig. 12 are plotted. They lie well on a straight line, which, produced to cut the R scale, does so at -1.85. From this it follows that $R_o = 1.85$.

A neater and in some ways better method, if a fair amount of work is being done, is that of Fig. 13, for the fundamental idea of which the writer is indebted to Mr. W. A. Barclay, who applied it, in E.W. & W.E. of Dec. 1925, to another purpose.

Fig. 13 should be got out permanently, on a large sheet of paper. The right-hand scale is marked in ohms, and should cover the largest R_1 in use and the largest R_0 likely to be found in the work being done. The left-hand scale is divided in reciprocals of V_1. To set it out, decide on a given number of inches or centimetres from the point ∞ to the point 1— say Z inches. Then the point marked 2 is $Z/2$ from ∞ ; the point 3 is $Z/3$, etc.

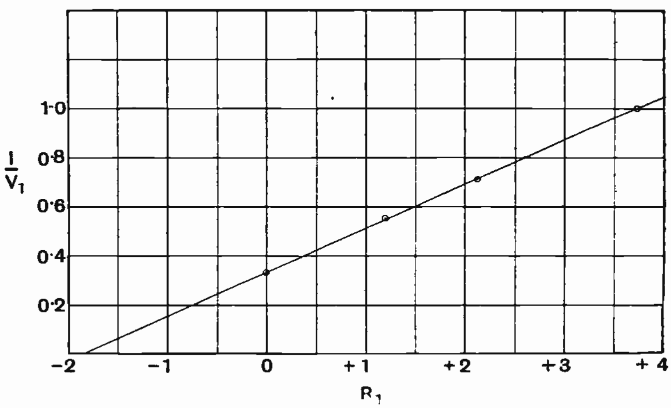


Fig. 12.

This being done, take corresponding values of R_1 and V from the test results, and join the corresponding points on the diagram by light pencil lines. All these lines should cut one another at the same point, but probably (owing to experimental error) they will enclose a small polygon. Draw a line from ∞ through the centre of this, and it will cut the scale of R_0 at the value of R_0. In this case we have repeated the results used for Fig. 12, with the same result; $R_0 = 1.85$.

If, however, a really large quantity of work is being done, it is probably best to get out a direct-reading curve for each resistor.

The following part-completed table shows how points on these curves are found: they are then plotted on the same sheet, each marked with some key-letter which is also marked on the corresponding resistor.

$$R = R_1 \frac{V_1}{V_0 - V_1}$$

$V_0 =$	3			
$V_1 =$	2.9	2.8	2.7	.. .5
$V_0 - V_1 =$	0.1	0.2	0.3	.. 2.5
$\frac{V_1}{V_1 - V_1} =$	29	14	9	.. 0.2
$(R_1 = 1.2)$ $R_0 =$	34.8	16.8	10.8	.. .24
$(R_1 = 1.78)$ $R_0 =$	50.8	24.9	16.0	...356
etc., etc.				

In this case, of course, one simply averages the results of testing a given R with several resistors. The most accurate measurements are made with a value of R_1 in the neighbourhood of half of R.

Finally, by one method or another, we get R, which is the resistance of the whole circuit. It remains to correct for incidental losses in order to get at the coil resistance.

First, as to the measuring apparatus. If this is a thermo-junction; it consists of a very fine wire, and its H.F. resistance will probably be the same as that for D.C., which is easily measured. In the case of the Moullin voltmeter, the problem is not so simple, for in its effect at various frequencies this is like a very small capacity of rather bad power factor; which means that the equivalent series resistance thrown in by it will vary as either frequency or the total capacity in circuit changes.

As far as my own tests have gone, it appears that this power factor is constant; but the resulting resistance is so small that it is not easy to measure accurately. If this is actually the case (as, in fact, one would expect) then, calling R' the equivalent series resistance added to the main circuit by the meter, we have

$$R' = \frac{M\lambda}{C^2}$$

where M is a constant of the instrument and C the total capacity of the circuit.

By rigging up two voltmeters and accurately measuring the resistance of a circuit with each while the other is first connected and then disconnected, we can find the R' of each for given values of λ and C. From this we get M, and thence can always allow for R' when making other tests.

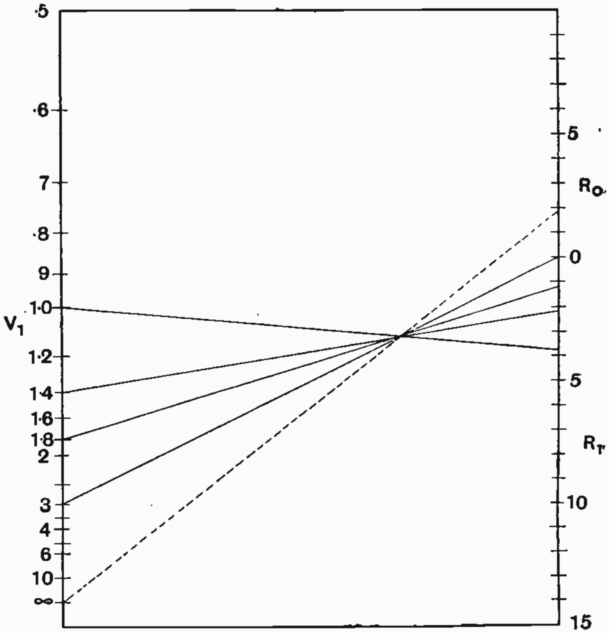


Fig. 13.

Similar allowance can be made for the loss in a coil-holder, if used. In my own case I find that at 377 metres, with the main condenser at .0003μF, the meter and the coil-holder each throw in about 0.1 ohm.

The general wiring of the test circuit can have its D.C. resistance calculated or measured, and the H.F. skin effect allowed for. In my own case the total resistance is of the order of 0.5 ohm at 377 metres (including that of the copper link used as dummy resistor). There are, of course, losses from radiation and eddy currents and dielectric loss in surrounding objects. A very rough estimate of these shows that they should be negligible with ordinary care.

Lastly, there is the loss in the main condenser. This, unfortunately, cannot be measured in any way with the circuit as it stands. It can only be obtained (with this set-up of apparatus) by substituting for it a condenser of known loss, and measureing the resistance in each case. E.W. & W.E. possesses a condenser of which the loss has been measured at the N.P.L., and can therefore make this test on any suitable condenser. When one such test has been made on any (good) condenser, it is known that, to a first approximation, its effective series resistance is given by the same formula as above, with an experimental value for M.

Hence, if we have the "M's" for the coil-holder, voltmeter, and main condenser, we can say

$$R' = (M_1+M_2+M_3)\,\frac{\lambda}{C^2}.$$

If, as suggested above, all testing is done at a standard total capacity, this can be simplified still more, to

$$R' = N\lambda,$$

where

$$N = \frac{M_1+M_2+M_3}{C^2}.$$

In my own case, the complete correction in ohms, including the resistance of leads, is

$$R' = \frac{2\lambda}{1\,000} + .05 \text{ ohms},$$

which is very simple.

As we have already said, the resistance, even when corrected for the rest of the circuit, is not the pure resistance of the coil itself. Before going further, it is necessary to know the self-capacity of the coil, and its inductance will also be wanted.

If one wishes to measure the resistance at some definite capacity, one must of course know the self-capacity before measuring the resistance, so I usually begin by finding this and the inductance. This is done in the well-known way, by measuring the wave-length to which the coil tunes with various capacities, which gives both the inductance and the self-capacity. This is done with the same circuit arrangement as already shown.

If we call the *total* capacity when the resistance was measured C_T, and the self-capacity of the coil C_s, then C_v, the capacity of the condenser, is connected with the other two by

$$C_T = C_s + C_v,$$

and if the measured resistance corrected for the rest of the circuit is R', the resistance of the coil apart from self-capacity effects is

$$R_c = \left(\frac{C_v}{C_T}\right)^2 R'.$$

It is true that in any circuit in which the coil is used, this self-capacity effect will be there and must be reckoned with. But obviously it will vary with the amount of capacity in use, so we must find R_c and correct it for each case.

Finally, if we want to arrive at an opinion of the coil's merit, we should find the power factor. Assuming that we have found L, the inductance (in microhenries), and know the wave-length λ at which the resistance test was made, we have

$$\psi = \frac{R'\lambda}{1\,885L}.$$

Working at the wave-length given by $C_T = 0.000\,3\mu F$, a first-rate low-loss coil may give $\psi = 0.004$. A rather bad coil might have ψ as high as 0.03: the worst I have yet measured gave 0.05.

An Experimenter's Wireless Laboratory.

By Leonard A. Sayce, M.Sc., Ph.D., A.I.C., and
James Taylor, M.Sc., Ph.D., A.Inst.P. [R201

Part II.

Alternating Current Measurements.

HITHERTO we have devoted the whole of our attention to currents which flow steadily in one direction only. When we come to apply Ohm's Law to "alternating currents" which are constantly changing their strength and direction, a number of complications arise: we must therefore consider this new aspect.

Theory.

In a circuit in which an alternating current is flowing, both the current in the circuit and the voltage across any portion of it are varying in a definite manner. Such variations may occur in an infinite number of ways, but the simplest type, and the one to which we shall confine our attention, is said to be "simple harmonic" or of "sine wave form." When the voltage across any part of a circuit carrying such a current is examined from instant to instant it is found that, at a certain time, it is zero. The voltage then increases to a maximum, or "peak" value, E_0, after which it decreases to zero again. It does not stop here, however, but increases in the opposite or negative direction, attaining a maximum negative value of E_0 and again decreasing to zero. This cycle of changes is repeated at a definite frequency, n, each repetition being of exactly the same form and executed in precisely the same time.

A simple harmonic voltage such as this can be represented very conveniently by the graph of Fig. 17 and may be expressed by the equation :—

$$V = E_0 \sin 2\pi nt \quad \ldots \quad \ldots \quad (7)$$

where V = voltage at any instant,
E_0 = maximum, or "peak," voltage (called the "amplitude" of the voltage equation),
n = number of cycles per second, or "frequency,"
and t = time that has elapsed since the commencement of the cycle.

When an alternating voltage is applied to a resistance we have, from Ohm's Law, $i = V/R$ and from equation 7—

$$i = \frac{E_0}{R} \sin 2\pi nt \quad \ldots \quad (8)$$

where i = current at any instant,
and R = resistance.

Thus the current is alternating and simple harmonic in form like the voltage.

In a general way we are not interested in the peak values of current or voltage nor in their values at any particular instant. A voltmeter or ammeter of the type we have so far considered will not give any indication when included in an alternating current circuit, because the voltage and

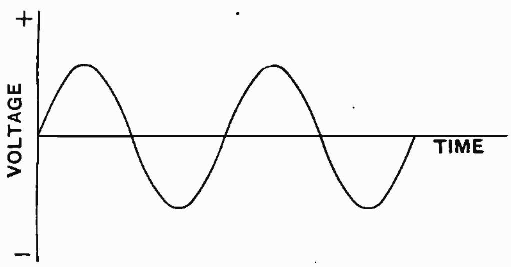


Fig. 17.

current are as often in one direction as the other, the net effect being that the instrument cannot follow the changes fast enough and, therefore, registers their algebraical mean, zero. If, however, instruments of the "hot-wire" type are used (one or two other types are also applicable), then the case is different because the heating in a wire is independent of the direction of the current in the wire and is, therefore, effected by alternating as by direct current. Since these instruments utilise the heating effect of the current, and this is proportional to the square of the current, they will measure the square root of the current squared at any time. With alternating currents, they will measure *the square root of the average* *square* of the current, since the latter is constantly varying, and the same applies equally well to the measurement of alternating voltages. This measured quantity is called the "root mean square" or "virtual" value and is usually abbreviated to "R.M.S."

We may state any alternating current or voltage in three ways, for we can give either the peak, R.M.S. or the average value. In the case of the currents we are considering, however, these values are easily convertible one to the other, for—

R.M.S. value $=0.707\times$peak value,
Average value$=0.637\times$peak value.

In applying Ohm's Law to alternating currents there are several complications.

Direct currents are resisted or "impeded" only by "resistance"—the property of a conductor which results in the absorption of energy by conversion into heat. We have this property to consider in relation to alternating currents, too, and we call it "ohmic resistance." But we have two other factors which impede an alternating current.

Firstly, a coiled wire, by reason of its magnetic properties when bearing a current, opposes any change in the current through it. This opposition when defined scientifically is called the "inductance" of the wire, and at a given frequency, n, it behaves like a resistance of $2\pi nL$ ohms, where L expresses the inductance in henries.

Secondly, a condenser, of course, will not allow a direct current to pass through it, but if an alternating voltage is applied to it, the charging of one side of the condenser causes a similar charge to be repelled from the other side and a current *appears* to pass through it. Thus, in its ability virtually to conduct an alternating current, a condenser behaves like a conductor having a resistance of $1/2\pi nC$ ohms, where C expresses the capacity in farads.

When a circuit contains both inductance and capacity the two together have a combined impeding effect, or "reactance," X ohms, such that—

$$X = 2\pi nL - \frac{1}{2\pi nC} \qquad \ldots \quad (9)$$

Every practical circuit, however, possesses ohmic resistance in addition, and the combined impeding effect of inductance, capacity and ohmic resistance is called the "impedance" of the circuit. If Z expresses this impedance in ohms, then :—

$$Z = \sqrt{R^2 + \left(2\pi nL - \frac{1}{2\pi nC}\right)^2} \qquad (10)$$

Now, at last, we are able to apply Ohm's Law to any circuit, with the result that :—

$$I = \frac{E}{Z},$$

i.e., $$I = \frac{E}{\sqrt{R^2+\left(2\pi nL-\frac{1}{2\pi nC}\right)^2}} \qquad \ldots \quad (11)$$

where I and E are expressed in R.M.S., average or peak values.

The term "alternating current" may be applied to any frequency, but is usually reserved for frequencies below about 100 cycles. A current whose frequency is between 100 cycles and 10,000 cycles is said to be of "audio" or "telephonic" frequency. A frequency greater than 10,000, or thereabouts, is said to be of "radio" or "high" frequency. For the moment, we shall confine ourselves to a consideration of the measurements associated with low frequency alternating currents and shall reserve those appertaining to the higher frequencies for subsequent treatment.

Our fundamental instrument, the microammeter, which has enabled us, so far, to make all kinds of D.C. measurements, is not applicable directly to the measurement of alternating currents. It is convenient to show, first of all, how it may be adapted to measure A.C. voltages.

Measurement of Alternating Voltages.

The Diode Voltmeter.

The following method, described more fully elsewhere,* has recently been developed for the measurement of alternating voltages over about ten volts. It can, however, be used with success down to two or three volts. Theoretically, at least, there is no upper limit to the voltages with which it will deal, and it is applicable both to low and high frequencies. The following is the general principle :—

Let us suppose that we are provided with

* Taylor, *Journ. Scientific Instruments* (1925).

a resistance R, of the order of one megohm, connected in series with the microammeter. If a direct voltage is applied to this combination the meter will show a current of about 1μA for every volt applied. If, on the other hand, the voltage is alternating the instrument will show nothing at all, for the pointer cannot respond to the rapid alternations. Let us suppose, however, that the high resistance will allow a current to pass through it *in one direction only*. If an alternating current is *now* applied to the resistance and microammeter, a current will flow only when the voltage is in the conducting direction. In other words, for exactly one-half of each cycle the resistance is infinite and for the other half it is about one megohm. Thus the meter will indicate a current of about 1μA for every two volts applied, as shown by the relation

$$\bar{I} = \tfrac{1}{2} \cdot \frac{\bar{V}}{R} \quad \ldots \quad \ldots \; (12)$$

where $\bar{V}$ is the average voltage (arithmetical) of the A.C. applied. Further, if the A.C. voltage were replaced by a D.C. voltage applied in the conducting direction, it is obvious from Ohm's Law that the current registered would be given by the relation $I = VR$.

Thus, if our hypothetical "unilateral" resistance could be obtained, we should have a voltmeter which would measure alternating voltages as the voltmeter shown in Fig. 13 measured direct voltages. A further great advantage would be that the voltmeter could be calibrated by direct current, for, if the resistance were made so that the microammeter gave two divisions per volt on D.C., then its readings would be one division per volt (*average* volts) for A.C. Now, the R.M.S. value of an A.C. voltage bears a constant ratio to the average value for a simple harmonic wave-form, so, by suitable adjustment of R, the instrument could be made to give R.M.S. values directly.

Thanks to the thermionic valve, the "unilateral" high resistance can, to a large extent, be realised, for we can obtain our theoretical ideal fairly accurately by connecting an ordinary high resistance R in series with a diode V (*e.g.*, an ordinary triode valve with grid connected to its plate). This arrangement is shown in Fig. 18, where the voltage to be measured is applied across the terminals T_1 and T_2. As a rule, a small current is indicated even when T_1 and T_2 are short-circuited. This is due to the pressure of the electrons given off by the filament and may be suppressed entirely

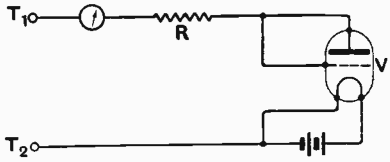


Fig. 18.

if the slight complication shown in Fig. 19(*a*) is made and the potentiometer is adjusted with T_1 and T_2 shorted until the current is reduced to zero. An even simpler method is to obtain the required potential directly from the filament lighting battery, Fig. 19(*b*).

If the resistance R is high, then the variation of the resistance of the valve is negligibly small compared with it and the instrument has a "straight-line calibration." The lower limit for linear calibration is reached when R becomes so small that the resistance of the valve which, of course,

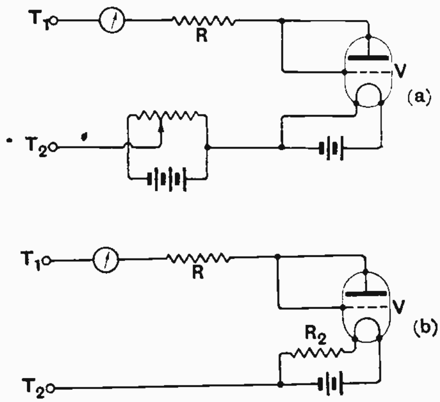


Fig. 19.

does *not* obey Ohm's Law, is no longer negligible. The A.C. voltage scale is linear, however, down to a voltage of about ten and the D.C.-to-A.C. ratio is almost constant down to as low a voltage as two or three volts.

An "A.C. Voltage Converter," made in

accordance with the above principles, is shown in the photograph of Fig. 20 and the diagram of Fig. 21. A "V-24" valve is used by reason of its compactness, but it must be emphasised that the instrument is practically independent of the type of valve used. Whether it be an "R" valve, dull-

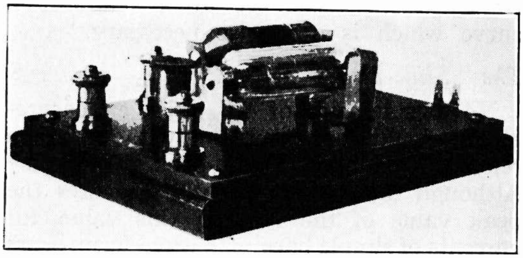


Fig. 20.

emitter or power valve makes little difference when R (Fig. 18) is a megohm or more. We recommend, however, that this and other instruments to be described be adapted for a filament voltage supply of six volts. A six-volt accumulator is to be found in the equipment of almost every experimenter and we suggest that it should be wired up to several wall-plugs on the "wireless" bench. Each of the instruments, whether voltmeter, oscillator or what not, can then be "plugged-in" without delay by equipping them with a permanent twin lead and suitable plugs.

In the present instrument, a resistance,

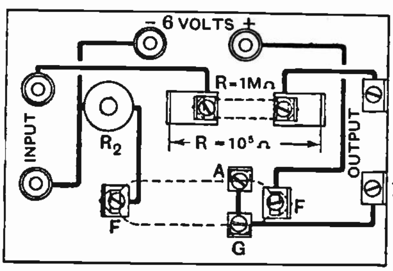


Fig. 21.

R_2, is included in the filament circuit, both to limit the current through the valve and to counteract the effect of the electron pressure. This resistance is wound with No. 26 D.C.C. Eureka wire, and is adjusted until, with the input terminals short-circuited, the reading of the microammeter connected to the "hooks" X and Y (Fig. 21) is *just* reduced to zero.

For high voltage ranges where it is a megohm or more, the high resistance, R, is rather a problem. It must be constant in value and both expense and space prohibit a wire-wound resistance. Whilst a really *constant* high resistance is difficult to make, it is still more difficult to obtain such a high resistance which shall be both constant and of an accurately pre-determined value. We have, therefore, compromised by using grid-leaks and "anode resistances" of the cartridge type and have found them fairly constant in value, for, of course, the current through them is never more than 120μA. The range of the instrument can be changed very easily by clipping-in a resistance of another value. In the instrument shown in the photograph the clips are made to take either a grid-leak or an anode resistance. The latter was in use when the photograph was taken. The nominal values of these resistances cannot be taken as correct and so it is always necessary to calibrate the instrument with its own special resistance.

μA (R)	D.C. Volts. (v)	~R.M.S. Volts. (= 2.22v)
115.0	11.75	26.1
107.2	11.0	24.4
97.0	10.0	22.2
86.4	9.0	20.0
75.4	8.0	17.8
63.7	7.0	15.5
52.4	6.0	13.3
41.0	5.0	11.1
30.5	4.0	8.9
20.8	3.0	6.7
15.5	2.5	5.6
11.0	2.0	4.4
7.3	1.5	3.3
3.8	1.0	2.2
1.1	0.5	1.1

Fig. 22.

To perform this calibration, a gradually increasing D.C. voltage, in the conducting direction, is applied to the instrument from a battery whose voltage has previously been measured in the manner already described (Fig. 13). The reading, R, of the micro-ammeter, corresponding to each voltage V, is noted and the results are tabulated as shown in the table of Fig. 22. Now, the R.M.S. A.C. voltage that produces a given current through the microammeter is 2.22 times greater than the D.C. voltage that produces this effect. Thus, the third column of Fig. 22 is obtained by multiplying the figures in the second column by the factor 2.22. Finally, the first and third columns are plotted as a graph, as shown in Fig. 23.

It may not be out of place to mention here that in drawing graphs it is a recognised convention that the *cause* of the change be shown along the horizontal and the *effect*

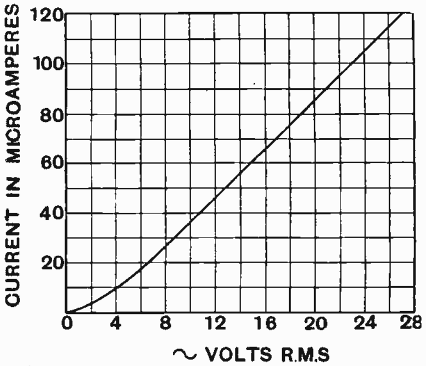


Fig. 23.

of the change along the vertical axis. Thus in this case the voltage is horizontal and the current vertical. It would save much confusion if this convention were followed invariably by all writers.

The graph of Fig. 23 is the calibration-curve of the instrument and, in the ordinary way, we should have to refer to this curve every time the voltmeter is used. This very cumbersome procedure can however be avoided by a very simple alternative, an alternative which can be adopted in any

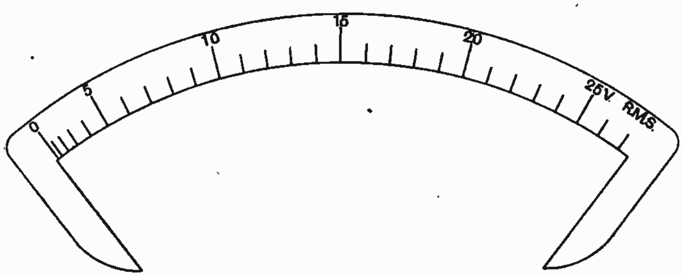


Fig. 24.

case where the microammeter scale is not "direct-reading." Cut out a piece of stout paste-board to fit the glass-covered opening of the microammeter case, shaping it so that only the scale of the instrument is covered. Then mark upon this card the A.C. voltages (column 3, Fig. 22) corresponding to the various currents (column 1) as indicated upon the instrument scale. An example of the result is shown in Fig. 24. This plan of making supplementary scales for the microammeter can be applied without loss of accuracy to any instrument having a "parallax" mirror and it avoids entirely the tiresome reference to a calibration curve which is otherwise necessary.

The "Slide-Back" Method.

No consideration of A.C. voltage measurement would be complete without some reference to the "slide-back" method.* Although the method actually measures the peak value of the voltage, this value, for currents of simple harmonic wave-form, bears a constant relationship to the R.M.S. value, and can thus readily be calculated. Further, the method can be applied both to low

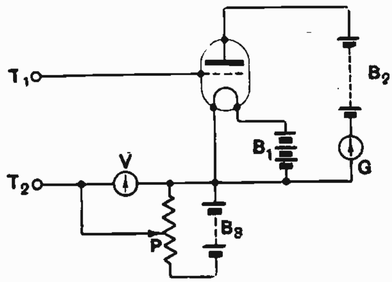


Fig. 25. *An Experimenter's Wireless Laboratory.*

frequency and to high frequency measurements. Its principle is shown in the circuit of Fig. 25.

The circuit consists simply of a triode valve, a galvanometer G, and battery B_2, in the anode circuit and a potentiometer P and battery B_3 used for varying the grid potential. The latter is measured by the voltmeter V.

The measurement of a peak voltage involves two operations: Firstly, with terminals T_1 and T_2 shorted, the negative bias upon the grid is increased by means of the potentiometer until the anode current, as shown by G, is *just* reduced to zero. The

* *Radio Review* (1921), (2303).

grid bias V_1, required to do this, is noted. Secondly, the link between T_1 and T_2 is removed and the A.C. voltage to be measured is applied to these terminals. An anode current is again indicated by the galvanometer and the potentiometer is again adjusted until the current in the anode circuit is just reduced to zero. If the reading of the voltmeter is now V_2 the peak value of the A.C. voltage is $V_2—V_1$. The R.M.S. value is, of course, $0.707 \times (V_2—V_1)$.

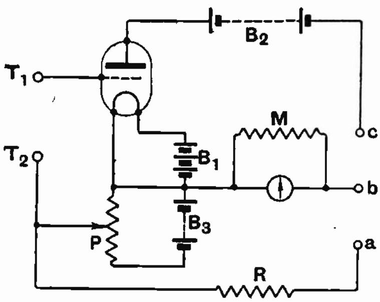


Fig. 26.

In our present position, with only one measuring instrument, we must make the latter serve both as the voltmeter V and as the galvanometer G, and this can be effected by the experimental arrangement shown in Fig. 26, where B_1 is the filament heating battery, B_2 the anode battery and B_3 the potentiometer battery across the ends of the potentiometer P. The latter may be one of the many circular potentiometers upon the market having a resistance of 300 to 400 ohms. R is the 10,000 ohm resistance (Fig. 9), and one side of the change-over switch (Fig. 7) is used as the single-pole double-throw switch, *abc*. Whether the microammeter is shunted or not depends upon the peak voltage to be measured.

The slide-back method has its limitations. It requires three batteries of which B_3 must have an E.M.F. larger than the peak voltage to be measured. Reference to the characteristic curve of a triode valve will show another disadvantage; the curve flattens out so very much as it approaches the voltage axis that it is difficult to tell the voltage at which the anode current has really been suppressed. Notwithstanding these drawbacks, however, the slide-back method can be of great service, particularly in the measurement of small voltages.

The Moullin Voltmeter.

In considering the diode voltmeter described above, we saw how the "unilateral conductivity" of the anode-filament path could be applied to measure alternating voltages. When such voltages are small, however, we can obtain very much greater sensitivity by using a *triode* valve and applying the voltages between grid and filament.

There are two ways in which alternating voltages between grid and filament may cause corresponding changes in the mean conductivity of the anode-filament circuit. These methods are known respectively as "anode rectification" and "leaky grid" rectification, and both have been applied very successfully by Moullin to our present problem.

The Leaky Grid Type.—The circuit for this form of Moullin voltmeter is shown in Fig. 27. The A.C. voltage to be measured is applied to the terminals T_1 and T_2 and, owing to the unilateral conductivity of the grid-filament circuit, the grid becomes progressively more and more negative, with the result that the plate current, as shown by the measuring instrument M, is correspondingly reduced. It is inherent in the method that a certain amount of energy

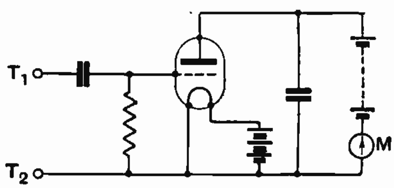


Fig. 27.

must be withdrawn from the input circuit. This method is more sensitive than that dependent upon anode rectification: sensitivity is, however, generally required when the energy abstracted can least be spared. For this reason this type of Moullin voltmeter will not be described at great length.

The Anode Rectification Type.—This type is shown in Fig. 28 and, as before, the voltage is applied between the terminals T_1 and T_2. A battery B_3 is provided, however, of such a value that, when T_1 and T_2 are short-circuited, the anode current shown by M is nearly zero. If now the link between T_1 and T_2 is withdrawn and an A.C. voltage is applied in its place, every positive impulse upon the grid causes a big increase in the anode current through M but every negative impulse causes a comparatively small decrease in the normal current. Thus the A.C. voltage can be measured by the increase in the reading of M.

Two conditions are essential to the satisfactory application of this method:—

1. There must be a conducting path between T_1 and T_2 to convey the bias from B_3 to the grid. This condition is almost invariably complied with in wireless measurements. (When it is impossible to do this we are forced to use the " leaky grid " type).

2. The value of B_3 must be greater than the peak value of the highest voltage to be measured. If this condition is observed then the voltmeter exerts very little effect upon the circuit to which it is applied, for the grid is never allowed to become positive and grid current is never allowed to flow. The small amount of energy that is absorbed may be reduced still further by connecting a condenser C_1, of fairly large value, say, .003μF, across the battery and measuring instrument.

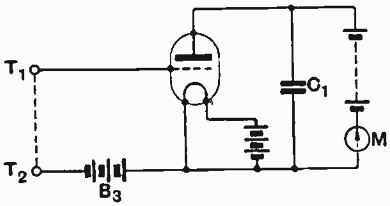


Fig. 28.

In designing a practical form of Moullin voltmeter, we shall assume that the characteristics of the valve itself remain constant. It will be observed that the instrument depends for its constancy of calibration upon the constancy of the three batteries used respectively, for biasing the grid, heating the filament and furnishing the anode current. The uncertainty due to these three variables may, however, be very largely removed by using the circuit shown in Fig. 29. Here V is a valve requiring 2 volts to heat its filament and B_1 is a 6-volt accumulator, whose voltage is not subject to considerable variations. Thus, when R is adjusted so that the filament of V is properly heated, the lower end of R is four volts more negative than the negative end of the filament. This potential is transferred as an automatic grid bias by the metallic connection between T_1 and T_2.

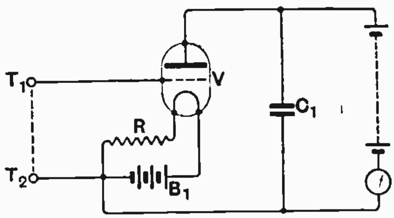


Fig. 29.

It is this grid bias that fixes the upper limit of the A.C. voltage that can be measured. Under the above circumstances, its peak value must not exceed four volts, or, in other words, its R.M.S. value must not exceed 4×0.707, say, 2.8 volts.

The only other variable quantity affecting the calibration of the voltmeter is the anode voltage. Seeing that we require the greatest possible sensitivity at low A.C. voltages, the anode potential must be so chosen that we are working from the point on the grid voltage-anode current curve at which the maximum change of curvature occurs. With a certain valve this point was found to correspond to an anode current of 8μA. The anode voltage was decided, therefore, by short-circuiting T_1 and T_2 and varying the H.T. battery until a current of 8μA was shown. Thus 8μA corresponded to zero A.C. volts and the H.T. battery was used as a kind of " zero adjustment."

The instrument may be made very conveniently as an attachment for the micro-

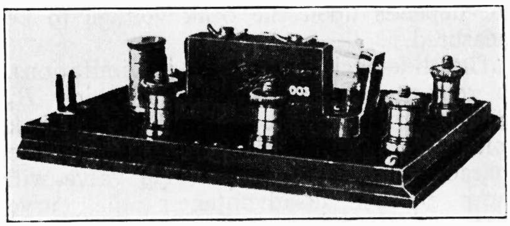


Fig. 30.

ammeter, and can then take the form shown in the photograph Fig. 30, of which Fig. 31 is the circuit diagram. The ebonite baseboard, measuring $5\frac{1}{4}$ in. × 4 in. × $\frac{3}{16}$ in., is provided with six terminals—for batteries and input respectively—and two slotted brass strips by which it is connected to the microammeter. The valve used in this

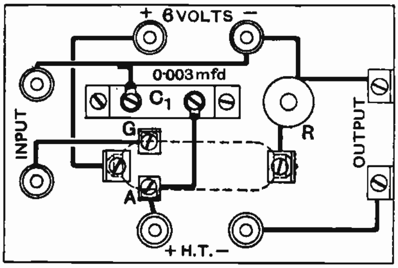


Fig. 31.

actual instrument is the "D.E.V." Although really intended for 3 volts, it works quite satisfactorily on 2 volts and is then, of course, very unlikely to change or "burn out." It is probable that the "D.E.Q." valve would be still more suitable as it is especially made for "anode rectification."

The resistance *R* is wound upon the small bobbin shown in Fig. 30 and consists of about 4 yds. of No. 30 S.W.G. D.C.C. "Eureka" wire. Its exact length is not critical and is determined in the following manner: Connect the filament of the valve in series with the microammeter, shunted for 0-1.2A, and a 2-*volt* accumulator, and measure the current. Then connect the meter in series with a 4-*volt* accumulator and about 5 yds. of the above resistance wire. Finally, shorten the resistance wire until the current through the meter is the same as before. When the resistance and valve are mounted in series in the instrument and six volts are applied to them, there will be a drop of 4 volts across the resistance and 2 volts across the filament.

The Moullin voltmeter, unlike the Taylor diode voltmeter, has no simple proportionality between its A.C. and D.C. calibration. In the next article, therefore, we shall show several methods of affecting this calibration.

BRITISH WIRELESS EXPORTS.

During 1925 the British wireless industry exported goods to the value of £1,335,087, according to interesting figures given in *The Wireless Trader*, which justly remarks that a total annual figure of one and a third millions is one that an industry scarcely three years old can view with satisfaction.

The highest figures relate to Japan, to which goods were exported to a value of over £200,000. Australia purchased an almost equal quantity. European countries appearing high in the list are Holland, Spain, Italy and Denmark.

BINDING CASE AND INDEX.

Binding cases and indexes are now ready for the volumes of E.W. & W.E. and *The Wireless World*, completed in December last.

For E.W. & W.E. the index (separate) is 7d. post free; binding case (separate) 3/3 post free, or together 3/9 post free.

The cost of binding case and index for *The Wireless World* is 2/10 post free. These are obtainable from the publishers, Iliffe & Sons, Ltd., Dorset House, Tudor Street, London, E.C.4.

Loud-Speakers. [R376·3

A LECTURE delivered by N. W. McLACHLAN, D.Sc., M.I.E.E., before the Radio Society of Great Britain, on 27th January, 1926.

I HAVE a very definite reason, I think, for dealing with the subject of loud-speakers. About eighteen months ago I had three loud-speakers of the horn type and their musical performance seemed so unsatisfactory that I thought it was about time we tried to get something better. In general the question of loud-speakers is more one of design and utilising known principles than of trying to get some entirely novel instrument working, say, on a new effect. You have first to get the effect before you can design the apparatus. Sometimes you are lucky and you discover a new effect and can apply it. So far as loud-speakers are concerned, up to the present there are no new effects that one can employ, so that it is necessary to exercise one's ingenuity and design something out of known principles. The subject of loud-speakers is now so wide that it would take a course of twelve lectures to cover the whole of the ground, Therefore, the only thing I can do is to touch on the more salient points.

When I say that a diaphragm loud-speaker is better than a horn loud-speaker, there are some who may not agree, but there are scientific reasons for such a statement. Apart from scientific reasons, one has only to hear the two types of loud-speaker side by side to appreciate the difference. Of course, the amplifier plays a very important part in the procedure and in designing loud-speakers I have always endeavoured to do so in such a manner that in the average broadcast transmission—I do not mean a landline transmission—the input to the loud-speaker is, as far as possible, uniform at all frequencies.

The prime mover of the diaphragm loud-speaker is in general a vibrating reed which is polarised by a permanent magnet. If we take the diaphragm type of loud-speaker and assume that a reed or something working on the same principle is used, the reed is a tuned system which has got a definite resonance frequency, and unless something is added which makes the system aperiodic there is going to be resonance, and in general, if sufficient damping is added to get aperiodicity, the result is a loss in intensity. In fact, the intensity is so weak that the loud-speaker is of little account.

It is not possible to eliminate entirely the resonance of the reed, and a certain amount of acoustic colouration must be tolerated.

Now we come to the diaphragm. It does not matter what diaphragm is used, there will be resonance. It will have, in general, a fundamental frequency of vibration, although it may not necessarily be very pronounced. This will be accompanied by a series of overtones which may be two, three, four or five times the frequency. They may not be exactly three or four times, or any even number, it may be 1.78, for instance, and that makes the resonance more complicated. The diaphragm, therefore, is another resonance system and if you pitch the resonance of the diaphragm lower down than the reed another curve is obtained. (See Fig. 1.)

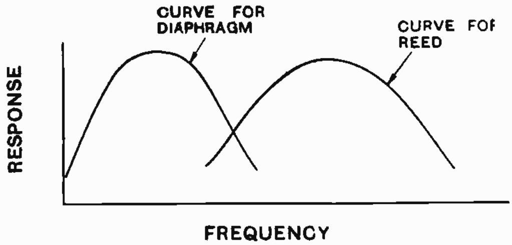


Fig. 1.

Then, if we consider the fundamental vibrations for a moment, when the diaphragm is actuated by a reed, there is a composite vibrating system as with two tuned circuits tightly coupled. When two electrical circuits are closely coupled, the resonance curve has two distinct humps, and that is approximately the condition which obtains in a loud-speaker. Taking a rough curve of response and frequency for any diaphragm type of loud-speaker, we get the result shown in Fig. 2.

We have omitted the overtones of the diaphragm and the reed. The effect of these is to superimpose little ripples on the main curves and the result is a composite curve in which there are a series of resonances. There is no use in attempting to evade the

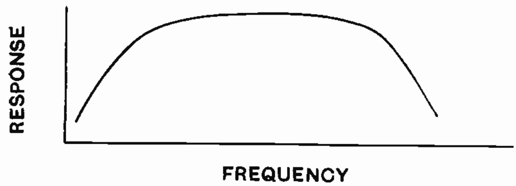


Fig. 2.

fact that the system has resonances, although some listeners will say the reproduction is perfect, we know quite well that it is not. If you listen carefully, resonances or acoustic colouration can be detected. If you cannot detect them, then make it loud enough and you will. When the resonance occurs in the bass range—70 to 200 cycles—there will be an indistinctness, since the damping of the lower frequencies is less than that of the higher frequencies.

The essence of the argument is as follows: When using tunable pieces of apparatus, such as reeds and diaphragms, the result is a composite curve with resonances and with a characteristic which shows a cut off at the bottom and at the top of the acoustic register. In other words part of the notes in the lower register and part of the notes in the upper register are cut off. If the lower register is full the upper register suffers, and vice versa. Therefore it is essential to compromise and strike the resonance in such a position that an average is secured. Although the resonance is still there it is sometimes difficult to detect unless a standard of comparison is available in which resonance is almost entirely absent.

Now let us consider the effect of the size of the diaphragm. If we imagine the diaphragm to be freely supported at the edge, as in the case of the small cone shown in Fig. 3, it is not easy to predict the performance immediately from theory, but when you have conducted a series of experiments you know exactly what will happen. There is going to be no bass, and the reason is two-fold. If there were no cone at all, the excursion of the reed would never exceed a certain amount, *i.e.*, the motion is limited. It is obviously determined by the design of the movement and the thickness of the reed. If a small cone is used the reed is underloaded, and since the excursions at low frequencies are limited and, furthermore, since the projected area is very small, the amount of air displaced is also small. Thus the low frequencies are cut off. If the size of the cone is gradually increased there is a greater purchase on the air and a greater intensity at low frequencies. In other words the impedance of the cone is matched to the impedance of the reed, so that the low frequencies are radiated. When the vibrations of the reed are communicated to the cone, they travel down it with a definite velocity. Consider a cone 12 inches in projected diameter at a low frequency. The velocity of propagation down the cone (which is tolerably stiff), is so high compared with the frequency that practically the whole cone can be considered to move simultaneously. At high frequencies, when

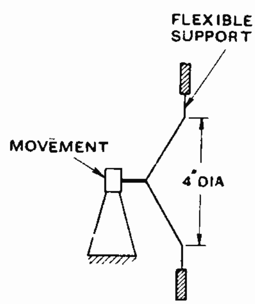


Fig. 3.

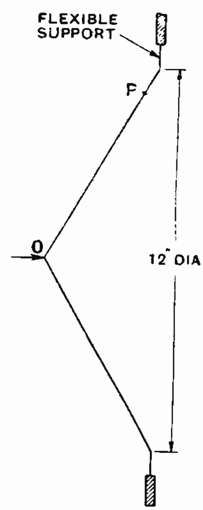


Fig. 4.

the to-and-fro motion of the reed is very rapid compared with the velocity of propagation, the disturbance travels down the cone with a definite velocity. The result is a phrase difference between the motion of the points *O* and *P* in Fig. 4. Therefore at high frequencies with a large cone, in all probability, the vortex will be moving in one direction, whilst the periphery will be moving in the opposite direction. Work is being done on the air in two opposite directions and there is a reduction in output. Then, again, there is a transmission loss; due to the energy being transmitted down the cone; and the higher the frequency the greater the loss. There are clearly three reasons for the cut off at high frequencies, first, the tunability of the reed; second, the fact that the velocity of propagation down the cone is relatively low, and third, the large attenuation loss due to energy being propagated down the cone.

Now we come to the bass register. I have indicated that a large cone is required, but what should be the size? That can only be determined by experiment. From 12 to 18 inches is a good size. Suppose a very large cone is used it will have a large inertia and a large proportion of available energy will be expended in pushing it backwards and forwards. There will be too much energy radiated at low frequencies and too little at the high frequencies. Thus it is essential to limit the diameter of the cone in order to get an adequate upper register.

If the cone could be replaced by a disc of sufficient stiffness, *i.e.*, suppose we could find a piece of paper a thousand times as stiff as a piece of notepaper and put it into the form of a disc, 12 to 15 inches in diameter, with a reed on it, it would act quite well. It is only a question of stiffness and of obtaining a high ratio of elasticity to mass. This means a large velocity of propagation and the higher the velocity of propagation the greater the portion of the disc which moves at the high frequencies.

There is another aspect of the question relating to the lower frequencies. In 1868, the late Lord Rayleigh carried out an extremely interesting experiment in which he showed that by preventing the circulation of air between the two sides of a vibrating tuning fork the sound from the fork was increased in intensity (see Fig. 5). Professor Stokes carried out a series of mathematical researches which he applied to various problems and the late Lord Rayleigh's experiments were based on the investigations of the late Professor Stokes.

Professor Stokes calculated, in connection with middle C on the piano, that if the air in front of the wire moved in a thin strip, *i.e.*, if there was no lateral motion at all, and the motion of the air were entirely in the plane of the wire, the energy of the unaided wire would be 40,000 times as great as it actually is. That shows the great effect of preventing lateral motion of the air. You have an example of that in a bell where the inside and the outside will be at a different pressure and if the circulation of air is prevented the radiation from the bell will be increased.

Referring again to Fig. 5, suppose one prong of the fork is moving toward B, the pressure of the air at B will be increased above the normal atmospheric pressure, and clearly the pressure at A will be decreased. We have, therefore, at two points in the air, which are very near together, a quite definite difference of pressure, with the consequence that air flows from B to A. What Lord Rayleigh did was to put a sheet of cardboard in such a position as to prevent the circulation and he found that the intensity of the sound from the tuning fork was enhanced. This principle has been incorporated in modern loud-speakers of the diaphragm type by Siemens and Halske in Germany, the General Electric Co. in America, and I have done the same in this country.

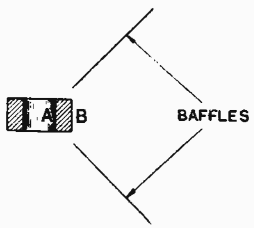


Fig. 5.

There is another way of obtaining the same result. It is not necessary to have a large baffle, since a box can be used.

Fig. 6 shows the principle of preventing lateral motion of the air between two sides of a diaphragm, applied to a cone loud-speaker. The reed is connected rigidly to the point of the cone. The cone is supported by rubber or, as I prefer, cloth. As a matter of fact, I use stockinette because it is good and stretches. It does not matter whether wood or cardboard is used for the baffle, although cardboard is useful for experimental purposes. The effect, therefore, is to enhance the amount of sound radiated, but it is most pronounced in the bass, and the reason is very simple. Consider a pressure wave travelling round from the back to the front of a conical diaphragm (Fig. 7), it travels, of course, at the velocity of a pressure wave of air of the velocity of sound, 1,100 ft. per second. Consider the cone to be moving very rapidly. If it moves

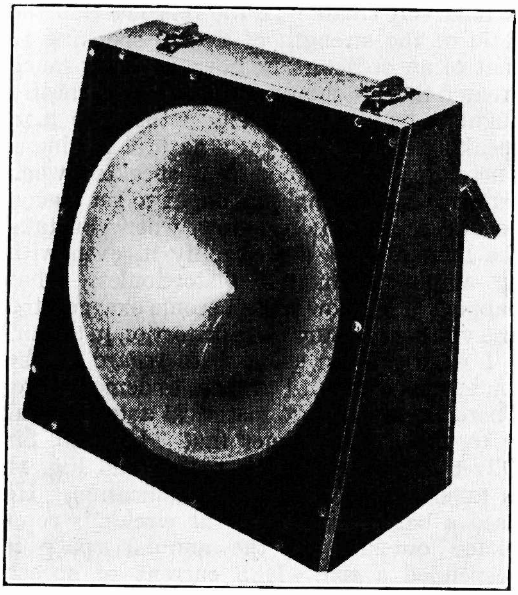


Fig. 6.

forward a positive pressure is created and, of course, the pressure wave immediately starts travelling round to the back. If the frequency is very high the cone has moved backwards and created a negative pressure wave before the pressure wave from the front has had time to get round to the back. Therefore, at high frequencies, the effect of preventing circulation of the air is small. At a low frequency of vibration you can quite see that the velocity with which the air travels round is very considerable compared with the movement of the diaphragm and therefore the prevention of lateral motion enhances the radiation in a remarkable degree. The larger the baffle the greater the radiation on the very low tones.

The next point I wish to discuss is the distribution of sound from a diaphragm. It is well known that a horn focuses sound. Take a horn loud-speaker into the open, and walk round it. The intensity is much greater in front than at the side, and very much weaker at the back. The same result is obtained in a somewhat modified degree with any cone type of loud-speaker.

Suppose we consider a cone as shown in Fig. 8 moving backwards and forwards in accordance with speech and musical frequencies. We will assume that the air cannot get round to the back. We can imagine that the cone is built into a hole in the wall, so that the radiation from the two sides are quite separate. When the cone moves forward, in the absence of lateral motion of the air, there would be a cylindrical column set into vibration. There would be a beam effect, and anyone situated at the point *P* would hear nothing, but, fortunately in practice, the air spreads out laterally. If you walk round it, when a note of 100 cycles is sounded, the intensity will be tolerably uniform all the way round, *i.e.*, if you walk round in a semi-circle. That is due to the air spreading out comparatively uniformly at low frequencies. But suppose the frequency is raised to 2,000 per second, what happens then? The cone moves backwards and forwards 2,000 times per second. There is lateral movement of the air but the motion of the cone is so rapid that the air has little time to spread out before the cone is moving in the opposite direction. Therefore the sound is projected out in the form of a beam. The radiation at various frequencies is portrayed roughly in Fig. 9. As a matter of fact, in an actual room you will find that the quality of the sound varies as you go round the loud-speaker, because

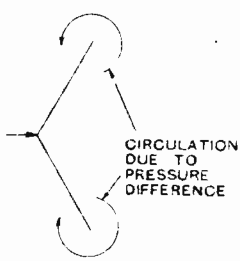


Fig. 7.

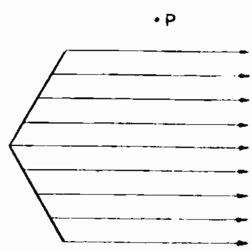


Fig. 8.

at the side very many of the high tones have disappeared, but at the front they are felt in full force. With a cone loud-speaker in the open, where there are no reflections, the beam effect is more pronounced.

The next point is the amplifier. Loud-speakers should be designed to work on a circuit giving as far as possible uniform amplification. The audio-frequency amplifier I use has a practically uniform scale, and that, I think, is the thing to be aimed at, but there are conditions, such as distant listening, which have to be considered. If, for example, at Chelmsford three tuned anode circuits are used the effect is to cut off the high frequencies. Under this condition it is a great advantage to have a transformer in the amplifier designed to yield a rising characteristic in the upper frequencies and to that end I have utilised leakage which is sometimes regarded as an undesirable quality in a transformer.*

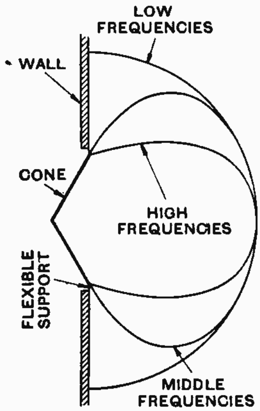


Fig. 9.

In many cases the high frequencies are not regained by the transformer and one has to be careful not to give judgment on a loud-speaker until the complete amplifier curve is known.

The next point to be considered is the loudness level. If we listen to an orchestra or a military band, and we are very near to it, the radiation is intense. One's ears get saturated; the effect is not exactly comfortable. At a short distance away one begins to resolve the band into its component instruments, so to speak, and you get a certain degree of loudness. You will notice that if you are comfortably near a band, you find the low tones are quite powerful. The energy, in music or speech, is carried in the low tones, and if you walk away from the band the low tones appear to get less and less. They get gradually less until finally, when you are 100 or 200 yards away, they are relatively weak. The human ear is more sensitive to frequencies in the upper register than in the lower register as indicated by the curve of Fig. 10. For equal threshold audibility the pressure on the ear is 50 times as great at 100 cycles as it is at 1,000 cycles, and that is a very important thing. In an ordinary household loud-speaker you have to expect a certain reduction in the bass register due to the reduction in the natural loudness of the music. On the other hand, when we come to human speech, we know that a man cannot speak as loud as an orchestra, hence the intensity is relatively small. In the reproduction the ratio of the strength of a man speaking to that of an orchestra is, however, very much greater than it should be, *i.e.*, the orchestra ought to be very much louder than the man speaking in order to get a natural loudness. Therefore, on a good loud-speaker, when someone is speaking, you ought to get a good natural reproduction. Now, when you take the human voice and amplify it, even with an amplifier which is distortionless, what happens? The low tones become exaggerated and you get pressure wave distortion in the air.

I want now to speak with regard to the loud-speaker which I propose to demonstrate. There are one or two historical details about it to which I will refer first. In 1898, Sir Oliver Lodge took out a patent and Fig. 11 is taken from his patent specification. He used a bar magnet, and the circuit is completed outside. In the annular space is suspended a coil. If a current of speech frequency traverses the coil, the latter will move up and down. Sir Oliver Lodge brought out a loud-speaker apparatus functioning in this manner. The principle has been applied to the Magnavox loud-speaker.

The photographs of Figs. 12 and 13 show my modern adaptation of that principle. It is the apparatus I have on the table. We have a magnet with a central pin, in

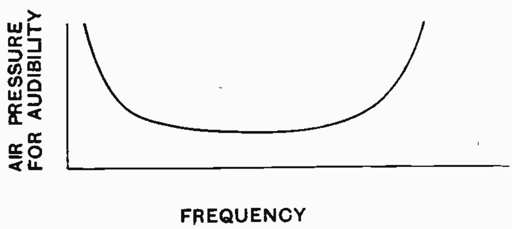


Fig. 10.

the same way as before, the magnet being energised by a coil as in the Magnavox. In this case the magnetising current is obtained from the 200-volt supply because it is more convenient. When this loud-speaker is carried about from place to place, a

* See N. W. McLachlan, *Wireless World and Radio Review*, 13th, 20th, 27th January, 1926.

magnetising coil is used which can be energised from a 6-volt battery. The moving coil is fixed to a paper cone. The paper is fairly stiff and is treated with aeroplane dope to render it weatherproof. The cone is supported at its periphery by stockinette merely to prevent it getting away. Rubber could also be used, but it is objectionable, especially in the tropics. The photographs show the operating unit of the loud-speaker.

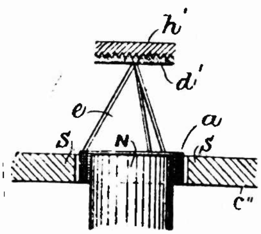


Fig. 11.

The cradle part of the apparatus which slides into the runners can clearly be seen. The box performs two functions. In the first place, it is a receptable for the cradle, and secondly, it acts as a baffle. The door at the back can be open or shut. Generally, for household work, it is necessary to have the door at the back slightly open, otherwise box resonance occurs. For public address purposes it is essential that the radiation from the diaphragm should not get back to

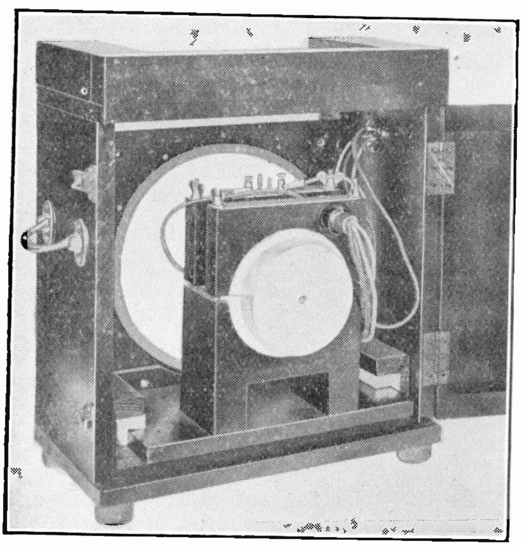


Fig. 12.

the microphone, and therefore it is advisable to design the loud-speaker to give a partial beam effect, not a very pronounced effect, but sufficient to prevent the speaker reacting back on the microphone and causing a howl. In this case the rear of the box can be closed. A front view of the instrument is shown in Fig. 14.

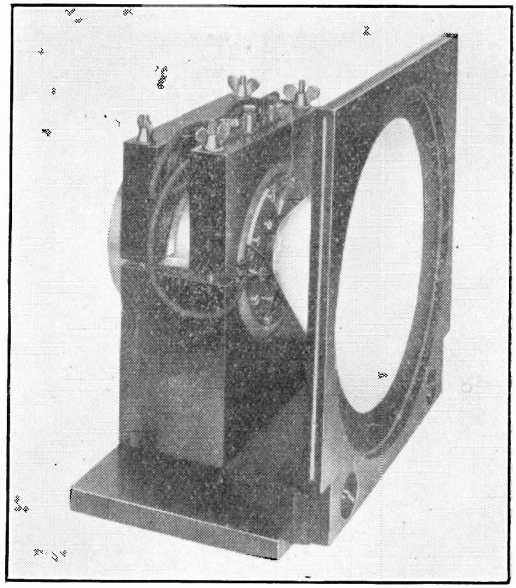


Fig. 13.

There is a hinged door with a large nickelled fine-mesh copper gauze window in front of the conical diaphragm. This serves to protect the diaphragm when the loud-speaker is used out of doors. For indoor work the cradle portion, complete with diaphragm, is removed from the box and placed in the felted runners on the top of the box. To prevent circulation of the air between the two sides of the diaphragm a large board or baffle of multi-ply wood is fixed on the four studs at the front of the box, the result being as shown in Fig. 15. This baffle is 3 ft. 6 ins. square, the hole being about 10 ins. in diameter. With this arrangement the radiation is greater since the rear of the diaphragm contributes its quota as well as the front. The distribution of the radiation at the higher frequencies is however quite different at the two sides of the diaphragm, since one side is concave whilst the other is convex. Also, the box and the magnet and cradle cause acoustic shadows. This is however of little moment since the reflections from the boundaries of the room tend to equalise matters. In another form, the cradle and diaphragm unit of Fig. 13 can be mounted on a wall bracket (corner or otherwise) and a suitable

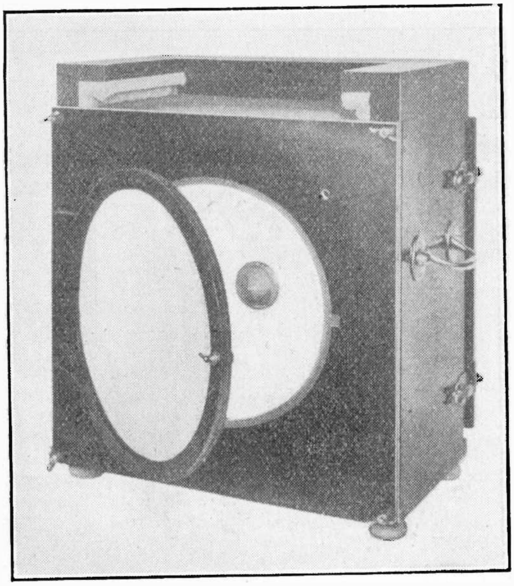


Fig. 14.

ornamental screen or baffle of curtain or other material mounted at the front.

There is no opportunity here to enter into the details of design, but it is of interest to note that the coil drive is much more amenable to calculation than the reed type. The proper proportions to secure uniform radiation at all frequencies are determined by calculation and by experiment. The mechanical and commercial aspects must of course be taken into account. For example, excessively small or excessively large diaphragms are clearly ruled out, apart from acoustic reasons. The smaller a diaphragm, the greater the amplitude and the greater the strain on the supporting ring at the edge. The larger the diaphragm, the more cumbersome is the apparatus.

The output for any given diaphragm is determined by the mass and L/R of the coil, the output transformer and the impedance of the power valve (or valves in parallel). By suitable design I have found it possible to obtain an overpowering bass or an overpowering treble register. It is desirable, of course, to work midway between these extremes. If the value of L/R is relatively large the valve impedance low, and the output transformer primary of adequate inductance (low resistance) the bass will be very pronounced. In the extreme case of zero resistance of valves transformer and coil when stationary, the only resistance would be that due to motion of the coil in the magnetic field. Since for given radiated power the amplitude increases approximately inversely as the square of the frequency, the resistance is greatest at low frequencies. In general, however, with a diaphragm of reasonable size* this resistance is of such a value that for equal grid voltages on the power valve at all frequencies the current through the moving coil decreases with increase in frequency due to the reactance ωL being greater than R (except at very low frequencies). Thus the bass register is very prominent. By inserting a suitable resistance in the coil circuit the current can be made tolerably equal at all frequencies thus giving a fairly uniform output.

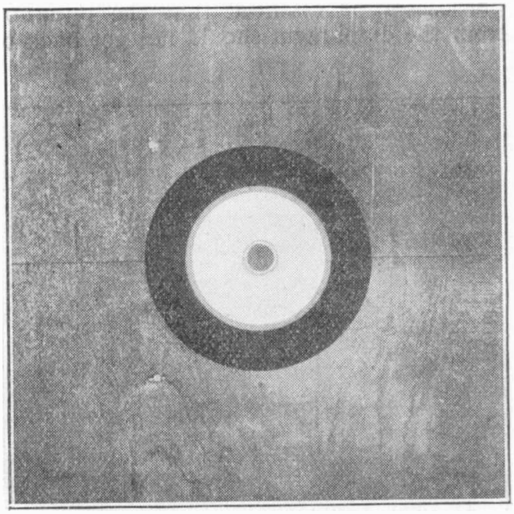


Fig. 15.

The chief feature of this instrument is the absence of resonating components. The paper cone has, naturally, a fundamental frequency with its accompanying series of

* The motional resistance obviously increases as the diameter of the diaphragm decreases, since the latter has to move farther for the same power output.

overtones. These, however, are of little account and do not detract seriously from the faithfulness of the reproduction.

Demonstration.

A demonstration was then given of the coil-driven cone loud-speaker on the table. The experiments conducted were as follows :—

(1) Orchestra at normal strength with uniform input at all frequencies.

(2) The same at an intensity greater than the original.

(3) No. 1 at reduced intensity showing the bass to be relatively weaker.

(4) The human voice at natural loudness.

(5) The human voice at the same loudness as the orchestra in No. 1, showing pressure wave distortion.

(6) The effect of cutting off the tones below 500 cycles, and for comparison the result of re-inserting them by means of a switch, thus giving a quick change over.

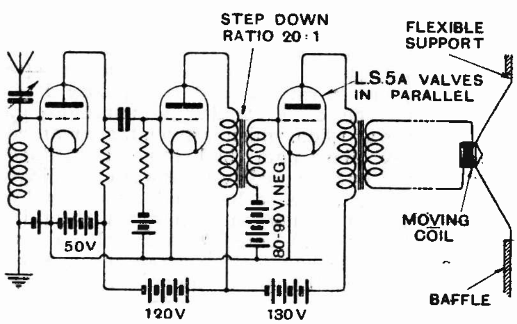


Fig. 16.

(7) The effect of reducing the high tones thus making the letter *S* sound like *F*.

(8) The effect of increasing the impedance of the power valve, thereby reducing the low tones.

(9) The partial beam effect when the diaphragm is used within the box, as in Fig. 14.

(10) The apparatus was arranged to operate under normal conditions giving natural loudness level. When the baffle was removed the low tones were reduced in a remarkable degree.

The orchestra during the test did not have any pronounced tones as in the usual studio transmissions where drums and double bass are used. The diagram of connections, minus the devices* used for items (6) and (7), is given in Fig. 16.

The lecturer stated that the intensity obtainable is well in excess of that obtained in the lecture demonstration and, using eight LS5A valves with 400 volts high tension, speech is quite distinct at 100 yards. There is no trace of resonance even with this intensity.

In conclusion, the lecturer thanked Mr. Child for assistance in erecting the apparatus; the Chloride Electrical Storage Co., for kindly supplying the accumulators; Messrs. McMichael for the detector unit; and the Marconi Co. for allowing him to demonstrate the instrument.

DISCUSSION.

Dr. R. L. Smith Rose, who opened the discussion, said : I was very pleased to come here to-night and listen to the paper, which Dr. McLachlan has delivered in his usual breezy style. He has made this popular subject very interesting, and it does seem to one who is not intimately in contact with loud-speaker development that we are getting down to an understanding of the scientific principles upon which loud-speakers should be designed and constructed; that being so, I am sure that we shall make progress much more rapidly than has hitherto been possible by the hit-and-miss methods of the past. It is interesting to learn that all the principles underlying the development of the loud-speaker were discovered and enunciated many years ago, even before the days when wireless became a practical proposition. For, as I understand it, this instrument is merely a development of a former device, patented many years ago by Sir Oliver Lodge, combined with the application of certain acoustical laws discovered even before that time. Another point that has impressed me is the question of obtaining uniform amplification. We have heard a lot about distortionless amplifiers and the construction of transformers which have uniform frequency-amplification characteristics, and the struggle there is to get a transformer which will amplify the low tones to the same extent as the high tones. In the demonstrations we have been shown an amplifier, which not only gives uniform amplification, but will also give a characteristic of practically any shape that one requires to give better reproduction, *i.e.*, either the upper or lower end of the musical scale can be exaggerated to correct for some defect elsewhere in the system. This shows that Dr. McLachlan has a very comprehensive grasp of the principles of amplification, and that he has this amplifier completely under his control throughout the whole range of audible frequency. I should like to know how these amplification characteristics are obtained at the lower end of the frequency scale, because it is so

* These are given in the *Wireless World*, 13th January, 1926, *et. seq.*

difficult to make measurements by audibility methods at the lower frequencies (*e.g.*, below 250 cycles per second).

Mr. H. Bevan Swift: I think this has been a most interesting and practical lecture, and there are one or two points which I should like to raise. The first is that Dr. McLachlan spoke about the bass tones disappearing first. I do not know whether you have ever heard a band in the distance, but I have always noticed that it is the bass drum which is heard first, which seems to show that it is the low tones which come through first. The other feature is the cone loud-speaker, and I am thoroughly in agreement with what Dr. McLachlan has said about this, because I have had one for about two years, and it has given the most wonderful results. Years ago, when broadcasting was first started, we had a great many straight-horn loud-speakers of a well-known make, but they were not designed or suitable for broadcasting reception, and I used to put mine inside a sideboard cupboard to make it bearable. This little paper cone loud-speaker, however, has been a revelation to me. It was made from the A type Brown earpiece, with a 10-in. paper cone fashioned out of ordinary cartridge drawing paper fixed by a small screw in the centre to the reed. There is one thing in the paper, however, on which I rather differ from Dr. McLachlan. In the aluminium cone used in the Brown earpiece there will be found a small ridge running all the way round the edge, and I repeated that in the paper cone because I found it was not practicable to fix the edge of the diaphragm direct to the board used, which was $\frac{3}{16}$-in. three-ply board. This little ridge gives the cone a certain amount of elasticity, enabling it to respond to the vibrations rather better. I notice that Dr. McLachlan uses an edging of stockinette, but I would be rather doubtful of the lasting quality of this material. I do not know whether the author has considered one point, and can give us his ideas on it: I mean the question of the weathering effect on the paper. I was rather interested to hear that Dr. McLachlan has used aeroplane dope on it. I tried using cellulose varnish, but it utterly spoiled the tone, and I had to take the paper cone out and put in a new one. We never got such good results as when we just left the bare cartridge paper, The usual minute screw in the Brown reed is removed and the hole tapped out for a 10 B.A. screw, and we fixed the apex of the cone over this with a little drop of Seccotine, which we found better than sealing wax, which a good many people have used and which is liable to crack.

Mr. P. G. A. H. Voigt: A little while ago I opened *The Wireless World* and observed in it some diagrams and an article by Dr. McLachlan, and now we have a lecture by the same gentleman. I had not time to read the article then, but, after what I have heard to-night, I am going to. I have been working on the subject of loud-speakers for rather longer than Dr. McLachlan, but not quite so fast. I started well over two years ago, but when one does not put in all one's time on one particular subject, one is apt to go slow, especially as the results I got at first were somewhat discouraging. I came to the conclusion, that the ordinary loud-speaker fails on low tones, for the very simple reason that the diaphragm or reed is incapable of moving over a big enough distance to reproduce these tones satisfactorily, and, like most other people at that time, I considered that the horn, with all its attendant overtones, etc., was in every way objectionable, and to be avoided at all costs. Therefore I worked on similar lines to those adopted by Dr. McLachlan, and developed a loud-speaker in which there was no reed and no horn. I used a moving coil system, without a reed, hung on bits of silk. From what I have heard of Dr. McLachlan's loud-speaker this evening, I should be inclined to think that the one he constructed does not get right down to the very lowest bass, because the diaphragm is incapable of moving freely. Dr. McLachlan did not tell us whether his moving coil is supported on some reed system or not, but I should be interested to hear. With my reproducer I could get down to such a low note that I could see the diaphragm move, and count how many times per second it moved, and I could also get well up the scale. Dr. McLachlan mentioned the time taken for a pressure to reach the edge of a diaphragm after it had started from the centre. I considered this matter, and came to the conclusion that, when a big force is applied to the point of a cone, it will crush and so I developed a new type of diaphragm which I thought would be stronger, stiffer and possibly less resonant. I calculated my resonance to be above 5,000 cycles, and made an experimental one, but a more awful noise you never heard. Its resonance came somewhere about 2,300. It was made of aluminium, fairly thin, but it rattled, and the quality I got was tinny. The corresponding aluminium cone has resonance at 1,800, which is much more marked, therefore my diaphragm had some advantages over the cone, but the quality I got was exceedingly tinny; in fact, it was so bad that I more or less dropped it. As a microphone however the thing gave good quality. Later a microphone was developed to give equal electric power for equal sound power, *i.e.*, the sound pressure and voltage output relation was to be constant. Compared with the B.B.C., it sounded as if there was a big condenser across my circuit somewhere, but I got an extraordinarily natural result. I looked for anything that might give this effect, but eventually came to the conclusion that it was the B.B.C. sending out on an " audibility " basis which tilted the whole tone scale upwards. Now to put this right, on all their outside broadcasts I use an additional note magnifier with a $250\mu F$ condenser across the primary. I now get such a natural effect from an ordinary loud-speaker that you can almost imagine someone standing and speaking where the loud-speaker is. There is a naturalness which I had never previously heard from the horn type of loud-speaker; with my own microphone, or the B.B.C. corrected, the quality I get from my experimental loud-speaker, if you ignore the rattles, is almost perfect. I should like to ask the author what is the efficiency of his loud-speaker? I have found that the fact that the air do not go off in a beam reduces the efficiency of low notes on a loud-speaker like the author's very considerably. This may be prevented by using a horn or distributor which will allow the air to expand slightly without expanding so much that there is loss of pressure. The only thing is that a horn of that sort is extremely unwieldy. I have calculated that the efficiency of such an instrument can be made about 40 per cent. If I ever give a demonstration with it as successful as Dr. McLachlan's to-night, I shall be very pleased.

Mr. A. E. Bawtree: I should like to thank the lecturer for an exceedingly instructive and interesting address, and for the very fine demonstration which he has given us. There is one technical point which I missed, although Dr. McLachlan explained it, and that is the way he tuned in order to emphasise or reduce the S's. If he would not mind explaining that again I should be extremely obliged. I am afraid I cannot agree with Dr. McLachlan and others who have spoken with regard to the point that the cone loud-speaker is superior to the horn type. I have carried on researches in connection with the phonograph for about eight years, and with loud-speakers for three years, and my opinion is decidedly the other way: that the reproduction from the best horn loud-speakers is far and away better than any I have ever heard from a cone loud-speaker. I do not consider that the reproduction from the cone loud-speaker is by any means equal to that obtained from the horn loud-speaker which I had the honour to describe before this Society last month.* There is another point, apart from the actual quality, and that is that there is a curious psychological difference between the two types of instrument. Our ears seem to possess very minute powers for determining the distance at which a sound is from us. I have noticed that I can tell, when two children are playing on the lawn outside the house, which of the two voices is the nearer, although they may only be a yard or two apart, and we have that power of determining the distance of sound. It is all right to use a cone loud-speaker in a hall of this size, but in a private room it would produce the very unpleasant sensation of bringing the person speaking, for instance, a great deal too near. On the other hand, in the horn type of instrument which I described, you cannot possibly get within 11 feet of the source of the sound, and then you have a more correct sense of perspective, and it increases the sense of naturalness.

Captain L. F. Plugge: I think it is very interesting to watch progress; and with regard to wireless, progress in the field of loud-speaker construction has been specially interesting to follow. A couple of years ago we had a lecturer here who spoke on "Perfect Reproduction." I was looking back in my scrap-book at some of the facts mentioned during discussion at that meeting and I remember that the lecturer of that meeting uttered the following sentence :—

"A horn adds efficiency to a loud-speaker."

I took part in the discussion and expressed my disagreement with the lecturer in regard to his statement, strongly urging the necessity for investigating the diaphragm loud-speaker, which at that time had received very little attention in this country. As I mentioned, two years have elapsed, and we are now listening to a very interesting lecture entirely about the diaphragm loud-speaker, and we can realise the enormous progress that has been made during these years with regard to the type I had advocated. What is especially interesting in the lecture to-night is the very clear way in which the lecturer has shown us the fundamental points involved. From these we can now see which direction we have got to travel on for further progress.

I do not think there is anybody here who would care to say that the horn adds to efficiency. We have heard from the lecturer to-night that one of the main difficulties with the diaphragm loud-speaker he has submitted is that of the slow speed of propagation of sound along the diaphragm owing to the fact that one is obliged to communicate motion at one point only. Direction of further progress is therefore clear. We have to work in order to get a diaphragm loud-speaker to which we can communicate vibration all over the surface of the diaphragm at the same time. It may be, in this connection, interesting to mention that such a loud-speaker has been evolved in Switzerland and I had the advantage of seeing it and testing it a year ago when visiting Zurich. The rights have been sold to a British firm and it is now sold in Great Britain under the name of the Stataphone. The principle of this loud-speaker, which is also a diaphragm type, is new. The diaphragm is one side of a condenser and the sound is produced by the strain which the dielectric undergoes owing to the variation of potential on the plates. Five hundred volts were necessary on the Swiss instrument, but in the British replica this has been reduced to two hundred. It was necessary to make this reduction in order to be able to place the instrument in the hands of the public. The use of a condenser loud-speaker also enables the use of a plane diaphragm. We have heard from the lecturer to-night that a diaphragm which is a plane would be theoretically the best. With the ordinary type of diaphragm loud-speaker it is necessary to increase the moment of inertia of the section in order to make it rigid. This is done by building the diaphragm in shape of a cone or by pleating it, as in certain types of well-known diaphragm loud-speakers. In the case of the condenser loud-speaker, the dielectric which is in mica forms the vibrating diaphragm. It is of a fairly large section and consequently it is possible owing to this fact to maintain it in the shape of a plane and yet keep it rigid. It can be seen that with this type of loud-speaker, the sound vibration is communicated simultaneously to all the points of the diaphragm and furthermore the change from the electrical field into the acoustic field takes place without any mechanical device such as a reed, which we have heard to-night, introduces an independent resonance system. I feel that it is in this direction that further progress will be made and I would be pleased if the lecturer could throw some further light on this new development.

Mr. E. C. Garton: There is one question I should like to ask. When the lecturer was demonstrating the effect of unnatural loudness in the voice, it occurred to me that this was caused, not so much

* R.S.G.B. Informal Meeting.

by a general increase of the low lones, as by resonance on one particular low note, probably below the middle C. Can the author agree that that is the fact, and, if not, what is the cause? There is one other point. Will he tell us the type of valve he is using in his last stage? It struck me as being very free from grid current distortion if it is an ordinary valve.

Dr. McLachlan, replying to the discussion, said: Dr. Smith Rose has asked about variable amplifiers, but I think that matter has been discussed in the last three issues of *The Wireless World*.* Mr. E. C. Cork of the Marconi Co. has taken measurements down to about 200 cycles, and there was no sign of the amplification falling off. I have made measurements of the permeability of the iron in transformers, from which it is possible to calculate the inductance, and it is a comparatively simple matter, if the inductance and the impedance of the valve are known, to find where the transformer begins seriously to cut off. With a low impedance valve like the DE5, calculation shows that the amplification begins to fall off at about 35 cycles per second. At 35 cycles it is about 95 per cent. of the value on the

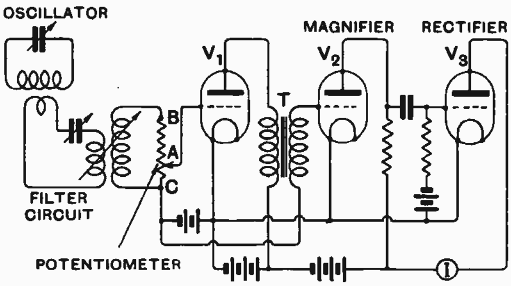


Fig. 17.

horizontal portion. If you want to cut off the high tones you can very easily do so by means of a condenser across the primary of the transformer. If you put a .003μF condenser across the primary of one of my special 2 to 1 transformers, the amplification is practically uniform throughout the scale. So far as measurement of amplification below 200 cycles is concerned the circuit shown in Fig. 17 may be useful. V_1 is associated with T, the transformer under test, whose secondary voltage is amplified by one or more valves V_2 and passed on to the rectifier V_3. By a switching arrangement the point A is connected to the grid of V_1 and then B is connected to the grid of V_2 so that V_1 is out of commission. The point A is adjusted until equal deflections are secured on I in both cases. The joint amplification of V_1 and T is clearly the ratio BC/AC. The switching must be arranged so that the filament, H.T. and grid bias conditions of the valves remain unaltered.

Mr. Bevan Swift raised the question of hearing the drum first. I quite agree with him. If you have sufficient energy on the low tones you will always hear them first, but I think you will agree that the drummer in a regimental band on the march hits the drum very hard in order that it may be heard all along the line. If you listen to a broadcast transmission, you will find that unless the amplification is uniform down to the lower frequencies the drum is not heard properly. In listening to a drum one has to be quite sure that it is the fundamental of the drum which is audible. Low tones are very often perceived by the overtones and not by the fundamental. The point is that we ought to hear the fundamental in proper proportion to the overtones.

It is easy to conduct an experiment when a band is playing by closing one's ears with the fingers. The low tone instruments will almost disappear (see Fig. 10) provided of course one is not too near the band. Mr. Bevan Swift raised the question of the edge of the diaphragm. I can quite believe what he said. The point is that if you rigidly fix it you immediately prevent free motion. By having the edge free, you immediately remove the constraint and the motion of the cone is not restricted at low frequencies (except by the reed) and you get no resonance effect from the member to which it is fixed. He will see that in all cases I have mentioned this evening the edges of the cones are "free," *i.e.*, the constraint axially is small. As to the lasting qualities of the stockinette, I cannot say, but from experience in the tropics I should say that it will last much better than rubber, but I must give rubber its due. I have had some of these rubber-edged cones a long time and they are as good as ever. How long they will last, however, I do not know. I tried celluloid amyl-acetate varnish and exposed it to snow, sleet and rain together with cones treated with aeroplane dope. The aeroplane dope seemed to be better and gave every satisfaction. Mr. Voigt has made a number of apparently contradictory statements about low tones, but I do not follow him when he says that the reed type of diaphragm cannot give low tones. It all depends how low the tones are. If you take about 30 cycles, I agree, but if you take 70 or 100, I do not agree. In general, compared with a coil drive system, which I have here, you certainly cannot get the low tones to nearly the same extent with a reed. That is obvious from what I said in the lecture. If you want the whole gamut of low tones, a coil drive is imperative. That is a theoretical deduction which has been confirmed by experiment. On the question of whether we get down to the low tones with this instrument, we get too much of them sometimes, but the orchestra during the demonstration did not have any pronounced low tones (chiefly jazz-music).

If Mr. Voigt reads the paper he will find his statement that the diaphragm cannot move freely is a pure fiction. The whole point of the design is the free motion of the diaphragm.

During the afternoon transmission of the organ from the Capitol Theatre the low tones were so powerful that the floor of the lecture theatre vibrated considerably. Mr. Voigt will perhaps appreciate that there are occasions when the very low tones are absent from the transmission, *e.g.*, certain classes of orchestra, the violin, flute, etc. I cannot quite grasp the visibility of low notes and I think Mr. Voigt has overcooked his egg. It is difficult to hear anything below 20 cycles and I believe any motion greater than 16 per second

* "Speech Amplifier Design," N. W. McLachlan, *Wireless World*, 13th, 20th, 27th January, 1926.

gives continuous vision, unless there is some irregularity superposed. This loud-speaker is just as efficient as the horn type working with the same power input. This has been tested in the open at a distance of 100 yards from each instrument. The only point is that the sound radiated from the horn type is more of a beam whereas in this loud-speaker, with the baffle, the radiation at the back is of the same order as at the front. If it does not sound so loud as the horn type at the front, one must remember that the horn type gives very little sound at the back. The basis of comparison is the mean spherical radiation. On the question of efficiency, most of the input is wasted in moving the coil and cone backwards and forwards. If the weight of the coil and the cone could be reduced to one-tenth its present value, you would probably want the instrument outside the lecture theatre, because it would be so loud. The resistances in the circuit are extremely small so that the reduction of efficiency is due to working on wattless current. Mr. Bawtree asked how the S's are reduced. This was effected by putting a condenser across the resistance in the anode circuit of V_1 of Fig. 16.

Mr. Bawtree thinks that the horn type is better than the cone type. I think this is largely a matter of listening under false conditions. Fundamentally, the horn type is bound to have resonance due to the air column and the horn itself. Then Mr. Bawtree says the cone loud-speaker sounds unpleasantly near in a private residence. All I can say is that my experience is not in accordance with his. The instrument sounds far away when the intensity is reduced, and when the intensity is increased there is nothing particularly unpleasant about it since resonance is absent and all the notes have equal prominence. Also the radiation of sound is more uniform. Captain Plugge mentioned an electrostatic loud-speaker using a plane diaphragm. Messrs. Siemens and Halske have an instrument with a flat diaphragm, about 8 inches square and it works on a principle which is similar to that used in the instrument I have here to-night, except that instead of a circular coil there are a series of straight copper strip on edge.* This gives tolerably uniform loading over the diaphragm. The strips are placed between the poles of an electromagnet, alternately north and south. It is a zigzag arrangement and the current passes through it and creates a magnetic field which reacts on the steady magnetic field of the magnets so that the plate moves in and out in the usual way. A baffle is also used. I do not think you can say that the reproduction from an instrument of this type is likely to be better than from the one I have designed. I consider that the reproduction from an instrument of the coil-drive type can only be critically judged when we have a microphone superior to those now in use. In any case, it is difficult to say which would be the better unless the two were heard side by side. According to accounts, the Siemens and Halske instrument does not reproduce the letter S; I do not think there would be any difficulty in getting the same effect on my loud-speaker if the coil was designed to have a very low resistance. In the Siemens and Halske case, I expect they had too high a value of L/R. If you have an inductance with a very low resistance, and supply an alternating current of varying frequency, it is quite obvious that the impedance of the coil is chiefly due to reactance. A current of high frequency will be choked off relatively to that at low frequencies, and I think that is what is happening in the Siemens and Halske speaker. The question of the electrostatic loud-speaker is another thing. I do not think you could theorise on it at random. It is one of those things in which you have to do experiments to find a hypothesis on which to base the theory. Apart from clearances between the plates and the relationship between force and distance it seems to me that such an instrument may have practical disadvantages, *e.g.*, high voltage. Some years ago I made an electrostatic loud-speaker and although I did not take much trouble with it, the reproduction seemed quite good.* Trouble was experienced due to rattling because I did not use a proper diaphragm. The question of stiffness is very interesting, and as stated in the lecture the cone could be replaced by a disc if you could get the ratio $\frac{\text{elasticity}}{\text{density}}$ large enough. It is another of those things in engineering in which we are limited by materials. There is, however, no trouble about the propagation of energy down the cone unless it is abnormally large. I do not think the pleated diaphragm is a good construction because it generally gives rise to a nasty resonance, but it depends on the geometrical form of the diaphragm.

Mr. Garton asked about resonance on the middle C and the unnatural loudness in the human voice. The deep tone is partly due to pressure wave distortion as explained in the lecture, but there may be a resonance. I have tested the loud-speaker and the amplifier, and there is no resonance in either. Where is it? It appears to be in the transmission! I know exactly what Mr. Garton means, because I have experienced that little trouble at various times. As to the last stage, referred to by Mr. Garton, the valves are of the LS5A type. To preserve the low tones, it is imperative to use a valve of low internal resistance, and it may be essential to connect several valves in parallel. I have four here, and if I want to get a still greater low tone effect I can double this number. There should be little grid current with 85 volts negative on the valves, unless an abnormal signal strength is applied.

Mr. G. G. Blake, proposing a vote of thanks to Dr. McLachlan, said: I feel sure I shall be voicing the feelings of everybody here when I say that we have enjoyed this evening some of the best quality reproduction with loud-speakers that many of us have ever heard. Certainly the reproduction has been very perfect indeed. Dr. McLachlan said it is hardly possible to reproduce the deep bass notes satisfactorily with the same instrument with which one can reproduce the human voice. That is only a constructional matter, and it can be done, but not very well, with the same instrument. It seems to me, therefore, that two instruments will be required, one for reproducing music, for musical people who want to get the best musical effects, and

* See N. W. McLachlan, "Loud-Speakers," *Wireless World*, 4th November, 1926.

* British Patent 206,601.

another for speech. A point which has apparently been overlooked during this discussion is the use of the board (on Dr. McLachlan's instrument), for cutting off sound-waves from the back of the cone. I was present a little while ago at the Institution of Electrical Engineers, when Captain Eckersley spoke to us on the latest developments of broadcasting, and at that meeting one of the speakers pointed out that in the studio at 2LO the microphone is somewhere near the centre of the room, or some distance from the wall, and therefore the deep notes tended to curl round rather than to play with full force upon the microphone, and it was suggested that it would be better if the microphone was let right into the wall. That would be something like the sound board which Dr. McLachlan has shown us to-night. The suggestion in question called forth a characteristic reply from Captain Eckersley, who said that it would be better, perhaps, if everybody could come up to the B.B.C. studio and listen to 2LO through a hole in the wall.

Mr. H. Bevan Swift seconded the vote of thanks, which was carried with acclamation.

Dr. McLachlan, acknowledging the vote of thanks, said : I thank you for the kind way in which my lecture has been received this evening. It has been a great pleasure to me to give a demonstration, because I think it is just as well to let people know what developments are going on, and healthy discussion does no harm. I should like to reply to Mr. Blake, who made an interesting statement with regard to the position of the microphone at 2LO. I usually put my loud-speaker on the top of the piano, and a long time ago I found that when it was moved towards the wall, the low tones disappeared. The pitch went up to a remarkable extent relatively, and, of course, the explanation was pretty obvious. Sound is radiated from both sides of the diaphragm. The sound at the back is reflected from the wall. Since the velocity of sound is great compared with the frequency of the low tones, the wave from the front interferes with the reflected wave from the wall, and the low tones are cut off. In any ordinary diaphragm loud-speaker without a baffle, I have found that by designing the diaphragm to have a definite low resonance point I can vary the tone. If the pitch is too low, I push the instrument against the wall, but one cannot always be pushing the instrument against the wall and taking it away again, although, if one is enthusiastic, one can devise a Lazy Tongs arrangement and pull it backwards and forwards from one's armchair. It all comes back to the question of the low tones. If one could always have the reproduction at its natural loudness there would be no difficulty. The loud speaker can be adjusted to the normal loudness of a man's natural voice, and then, on music, all is well. The low tones may sound rather weak, but it is possible to design the amplifier or loud-speaker to enhance the low tones, so that an adequate supply is obtained in a private residence.

The Piezo-Electric Effect and its Application to Wireless.

By C. W. Goyder (2SZ—2HM). **[R351.218**

(*Concluded from p. 100 of Feb. issue.*)

This concluding article describes the use of the Quartz Crystal in the Transmitter now in use at the Mill Hill School Station, 2SZ.

Practical Application of the Quartz Crystal to Transmitting.

THE writer found the use of the quartz crystal as an oscillator by far the most interesting. The transmitter now in use has a quartz crystal to control the frequency. As the energy obtainable from the crystal itself is very small, it is necessary to amplify considerably. In this case the final power is 250 watts.

The most noticeable advantage of using a quartz crystal as the frequency generator in a transmitter is, of course, the fact that the frequency is constant. No matter how much the aerial swings or how poor the regulation of the power supply may be, the frequency will not vary. The aerial may be disconnected, any part of the circuit may be adjusted, the valves, coils and chokes may heat up, and still the frequency will not change. The other great trouble of short wave work, keying, is also greatly simplified. The chirpy note so difficult to avoid with self-excited circuits is not possible with a crystal-controlled set.

The trouble caused by generators picking up speed between dots and dashes is, of course, also obviated.

When using a transmitter controlled by a crystal, it will be found that the quality of the note is invariably good. The extremely rough note produced if the high tension supply is not properly rectified or smoothed, when using a self-excited circuit, is due to frequency modulation of the radiated wave. This type of note, besides being difficult to read, causes undue interference. When using a crystal, frequency modulation is impossible. The ripple in the supply can only produce a slight variation in strength. It is surprising to find that full-wave rectification without any smoothing gives a pure note with only a slight modulation, produced by the variation in strength. It can be best described as a "D.C. note with a slight ripple." By using two valves in the self-rectification circuit, no rectifying valves are needed and yet a good note is possible.

Another advantage, not so obvious, is obtained. It is well known that telephony on the 45-metre band is subject to distortion which is apparently quite out of control of the transmitter or receiver. At certain times of the day or night it is possible to receive good telephony from amateurs, which at other times may be badly distorted. To illustrate the point, a test made by the writer is interesting. Four telephony transmissions, each of ten minutes duration, were made at midnight, 8.30 a.m., 3.0 p.m., and 7.0 p.m. Twelve reports were received from various parts of England from amateurs who listened to all four transmissions. The midnight transmission in all cases was subject to fading, bad distortion, and was weak; similarly the 8.30 a.m. transmission. The 7.0 p.m. test was strong and of good quality in some places, subject to fading, distortion, and weakness in others. The 3.0 p.m. transmission was reported strong and of good quality in every case, without exception. No alterations were made to the transmitter at this end during the tests. Judging from these and subsequent tests, it appears that the quality varies from time to time, depending upon the hour and atmospheric conditions.

It is usually possible to transmit good telephony all over England between 11 a.m. and 3 p.m. At other times of the day the quality may be good or bad, or vary every few minutes. In nearly all the cases mentioned above, the quality distortion occurs when fading is bad. This has been proved time after time. The position is, therefore, that the fading of a signal introduces quality distortion.

It is interesting to try and furnish an explanation for this. It is generally accepted that one cause of fading is produced by the interference between two waves arriving at a point by two different paths of different length, so that there is a difference of phase between them. Consider the effect produced by a frequency modulation of the carrier wave by telephony—at any instant the carrier wave will have one definite frequency. The next instant it may have varied ± 100 cycles, due to frequency modulation. Now, when fading occurs, the received wave is arriving by two paths of different length, therefore the first wave travelling by the longer path, and the second wave ± 100 cycles different in frequency, travelling by the shorter path, may arrive at the same instant. This would produce a

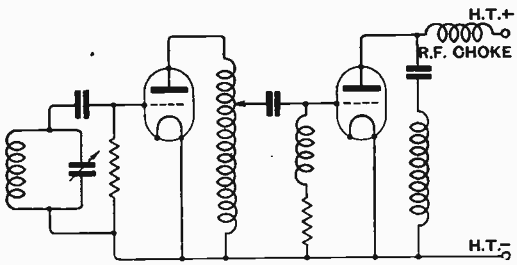


Fig. 13.

beat note of 100 cycles frequency. From instant to instant the value of this beat note would vary. The result would certainly be distortion of some kind. If this explanation is correct, it means that quality distortion on the short waves, due to fading, is caused by frequency modulation of the carrier.

It seems to the writer that it is quite impossible to modulate a set on 45 metres without getting appreciable frequency modulation. Take, for example, the set using choke control and a master oscillator as a set most unlikely to give frequency modulation. In an amateur set the H.T. supply for the drive circuit and the power amplifier is usually common, due to the expense of supplying two separate H.T. voltages. This being the case, the fluctuations of H.T. voltage on the amplifier due to modulation will affect the drive circuit. This will produce frequency modulation. Also, the method used for transferring the energy from the drive circuit to the grid of the amplifier is to take a tap on the plate coil of the drive circuit as shown in Fig. 13. The large variations in voltage on the plate of the amplifier due to modulation constantly vary the resistance of the plate-filament path, and therefore, of course, the grid-filament path. The grid-filament path is in parallel with a portion of the plate circuit of the drive valve. The variation of this resistance in parallel with the inductance varies the effective value of the inductance. This causes a direct modulation of the frequency of the drive circuit.

Using any self-excited circuit, the frequency modulation would be worse.

The above considerations prompted the writer to construct a quartz crystal-controlled transmitter as the only possible method of avoiding frequency modulation.

By using a constant frequency all distortion when fading occurs due to frequency modulation should disappear if the above reasoning is correct. Judging from the reports received, this is decidedly the case. *Not one report states any distortion taking place during fading, even at times of the day when fading is very pronounced.*

The quartz crystal controlled transmitter consists essentially of a crystal oscillator giving a maximum output of under ten watts, which is progressively amplified until the required power is obtained. This is a case of radio-frequency amplification on a very short wave-length, so some difficulty with the amplifiers and a relatively low efficiency may be expected.

There are two ways in which the problem may be solved. The crystal may be ground so that the fundamental response is on 45 metres, and this may be amplified to the required extent, or the crystal may be ground to some multiple of 45 metres, such as 90 metres. This necessitates a frequency change in one of the amplifiers.

With the first method, in which the fundamental frequency of the crystal is amplified, it is practically impossible to prevent self-oscillation in the amplifiers. If one considers the fundamental circuit shown in Fig. 14, remembering there are two or three successive stages, it is not difficult to see the reason why this is so. Consider the first amplifier. In the plate circuit is an inductance tuned to 45 metres, and the grid circuit is tapped on to a coil in the plate circuit of the previous valve, also tuned to 45 metres. If tapped on in position "*A*" the circuit is identical to that shown in Fig. 15, which is well known as probably the best self-excited transmitting circuit for this wave-length. The plate and grid circuit are both tuned to the same wave-length, and the necessary coupling to produce oscillation is afforded by the inter-electrode capacity of the valve. The result is that the amplifier oscillates very satisfactorily without any help from the crystal. This can be prevented by placing the grid tap in some position "*B*," such that the part of the coil *BC* is well removed from 45 metres, but the writer found this reduced the coupling to a prohibitive extent. It was found necessary to abandon the idea of amplifying on the 45 metre wave-length.

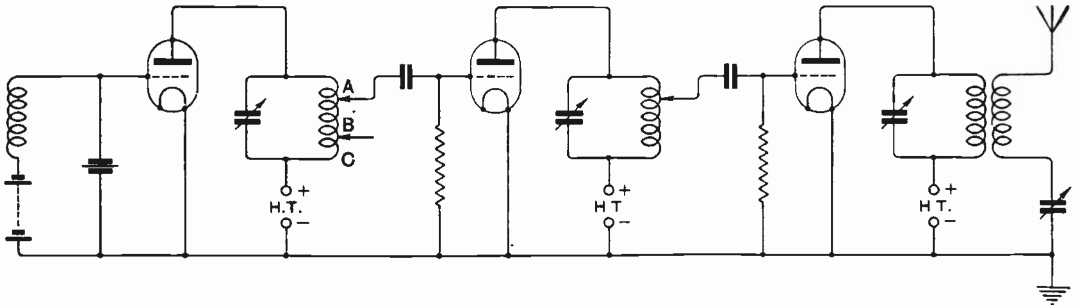


Fig. 14.

Another point against amplification on 45 metres is that the quartz crystal for this frequency would be less than half a millimetre in thickness. This would increase the difficulties of grinding, make it very fragile, and in some cases it is found that the oscillating properties of a crystal cease if it is ground to this extent.

The alternative is to grind the crystal to some multiple wave-length, in this case 90 metres, and to change the frequency in one of the amplifiers. Practically no trouble was experienced with self-oscillation on this wavelength; the amplification by each stage is greater, and the crystal is comparatively robust.

The crystal oscillator was shown in Fig. 7 (p. 96, Feb., 1926.) The plate circuit inductance can be wound with No. 22 wire on cardboard tubing. It may be tuned with a condenser, or simply by using the correct number of turns. The inductance of the grid choke should be such that its natural period is well above 90 metres. If this is not so, the circuit approximates to that shown in Fig. 15, and self-oscillation will occur. The grid bias is not critical. Any of the many types of low impedance power valves may be used in this stage, as the plate voltage should not exceed 350. The power obtainable from this stage is limited to this value, due to the fact that the crystal may crack. It must be remembered that the crystal is in mechanical vibration at a frequency of over three million cycles a second on this wave-length. An increase of plate voltage increases the amplitude of these vibrations until the elastic limit of the crystal is passed, causing it either to crack or burst into several pieces. A small crack or scratch destroys the oscillating property of a crystal.

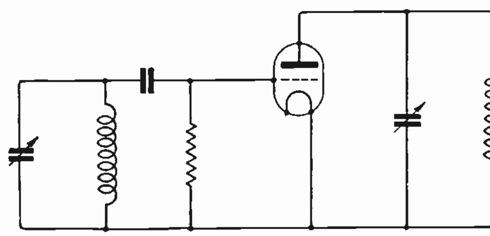


Fig. 15.

Mounting.

The mounting of a crystal used as an oscillator is very simple. The only essential is that the surfaces should be reasonably flat. Quite an inexpensive method is to mount the crystal between two pennies which have been ground smooth on one side. A hole may then be turned in a flat piece of ebonite to take the pennies, which may be kept in place by a spring. A pressure varying from a gram to a kilogram made no apparent difference to the oscillation of the crystal.

The other method of producing oscillations with a crystal (Fig. 16) is not advisable, as there is a greater tendency for the crystal to build up to such an amplitude that it will crack.

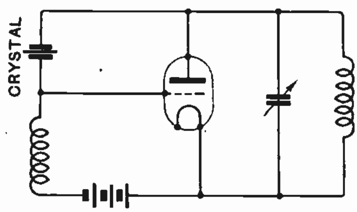


Fig. 16.

If the condenser tuning the plate inductance in the circuit shown in Fig. 7 (p. 96, Feb., 1926), is varied slowly, a position will be found where the plate current indicated by the plate milliammeter suddenly drops. The crystal is now oscillating. By tuning to approximately this frequency with a separate regenerative receiver, a beat note will be produced. If the condenser is now varied through the entire range over which the crystal will oscillate, the frequency of the crystal will vary as shown in Fig. 17. The total variation in frequency is extremely small, perhaps 100 cycles, and is only produced by a large variation in capacity of the condenser, in comparison with which all other variations due to H.T. changes, etc., are negligible. The position marked will be found best for normal working. At the true resonant frequency the crystal usually ceases to oscillate, as indicated by the break in the curve.

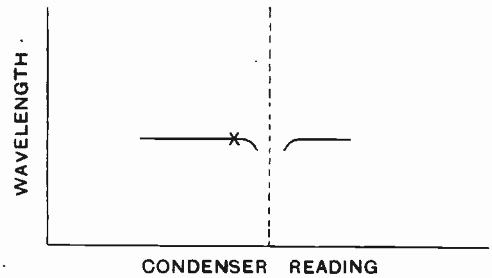


Fig. 17.

The first radio-frequency amplifier should be capable of handling 50 watts. Any valve, preferably of low impedance, capable of dissipating 20 or 30 watts at the anode, is suitable. The plate inductance can be made, as before, by winding No. 22 wire on tubing. The grid tap is gradually moved up the coil in the plate circuit of the crystal controlled valve until the maximum energy transfer, without self-oscillation, is obtained.

The second radio-frequency amplifier is essentially similar to the first. The valve should be of the 100 or 150 watt type.

In the third stage a 250-watt valve is used. The construction of the coils, etc., in these last two stages should, of course, be suitable to handle a considerable amount of high frequency energy. The adjustment of each stage should be completed before adding the next.

With such a set, using three stages of amplification, it is possible to amplify the three or four watts in the crystal stage to three or four hundred. The main losses occur in the frequency changing valve.

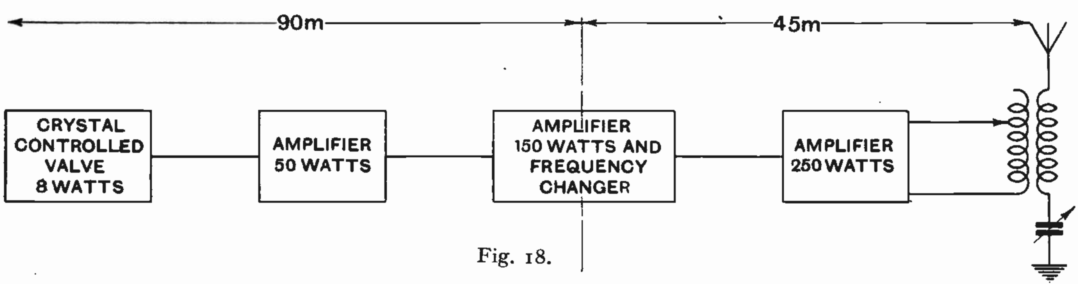


Fig. 18.

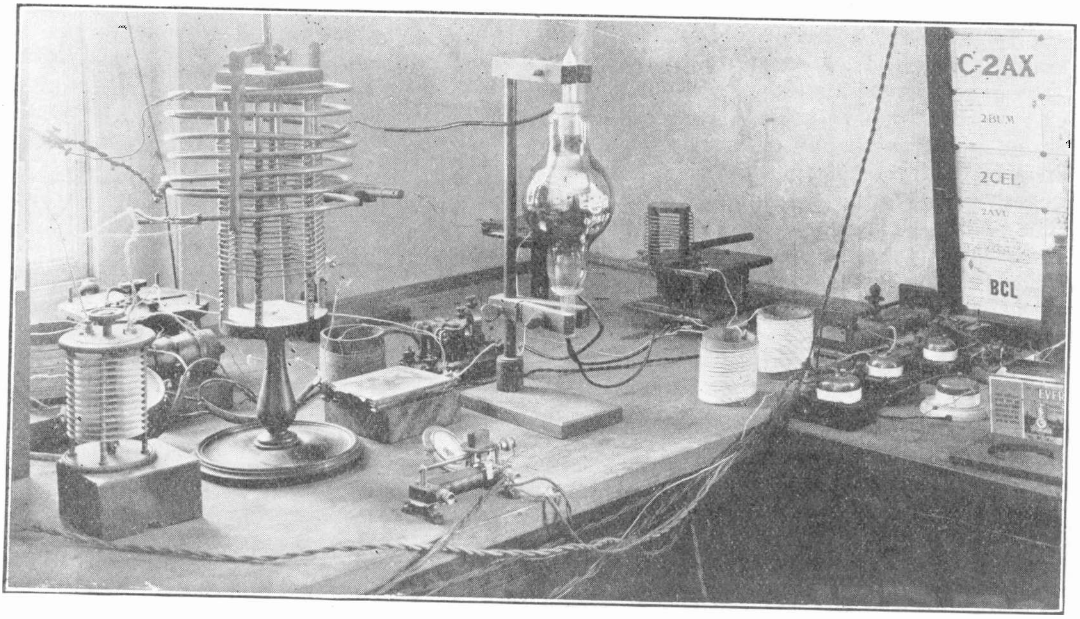


Fig. 19. *The final amplifier and frequency doubling valve. The plate inductance and aerial coupling coil are shown on the left.*

For the amateur allowed an input of 10 watts a crystal controlling a low impedance valve with 300 volts on the plate would constitute the "ideal" set. For a power input up to 100 watts, a crystal controlled valve using one stage of amplification would suffice. For the 10 or the 100 watt set, the crystal should be ground to 45 metres, and the fundamental amplified. It is comparatively simple to prevent self-oscillation if only one stage of amplification is used. It is the addition of the second and third stage necessitating a frequency change and the accompanying losses that reduces the overall efficiency of the set.

The frequency may be changed in the second amplifier, Fig. 18, or in the third amplifier, Fig. 20. Using the former method the second amplifier amplifies and changes the frequency at the same time, and the third stage then amplifies this changed frequency. In the latter method the first two stages amplify at 90 metres, while the third amplifies and changes the frequency at the same time. The plate circuit of this valve is coupled to the aerial. The second method was found to be the better. It is required to change to a frequency corresponding to 45 metres. The second harmonic of the amplifier is, therefore, required. In Fig. 21 (*a*), is represented the frequency of the original wave. In (*b*) is shown the double frequency which is required. In (*c*) is shown the form of a wave in which (*a*) (the fundamental) and (*b*) (the second harmonic) are combined. If it were possible to distort

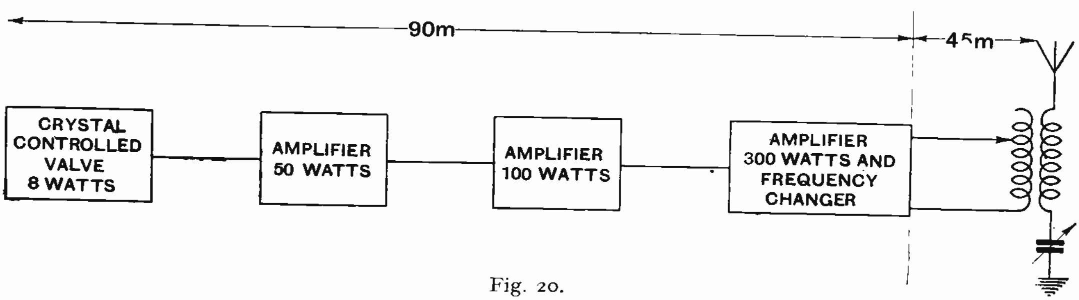


Fig. 20.

the form of the wave (*a*) to that of (*c*) the conditions would be ideal for obtaining a strong second harmonic. Although this is not possible, it is possible to distort the sine wave shown in (*a*) to some such form as (*d*) in which the second harmonic is present together with a series of higher harmonics. The second harmonic is then picked out by means of a tuned circuit. By making the grid of the frequency changing valve strongly negative, the wave form will be distorted as shown.

Fig. 22 shows the principal connections of the set used by the author. The crystal controlled valve has only 250 volts on the plate. By running this up to 400 it would be possible to do away with one stage of amplification, but in view of the scarcity and expense of crystals, it was not considered wise. The H.T. supply for the first two valves is half wave rectified and smoothed A.C. obtained from one transformer giving a maximum voltage of 1,000. The last two valves are supplied from the full wave rectifier which was used on the previous set. It would, of course, be possible to run all the valves from a common H.T. supply by using reducing resistances.

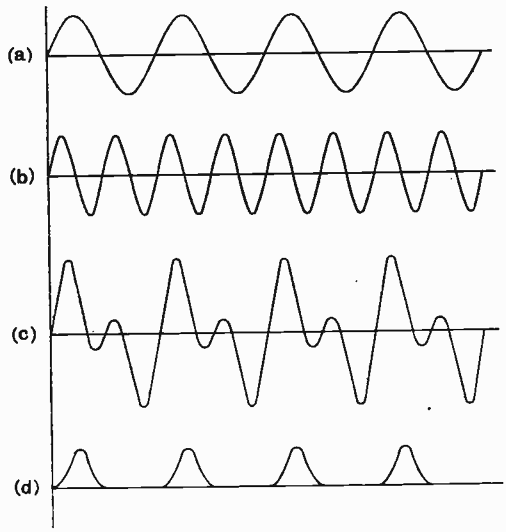


Fig. 21.

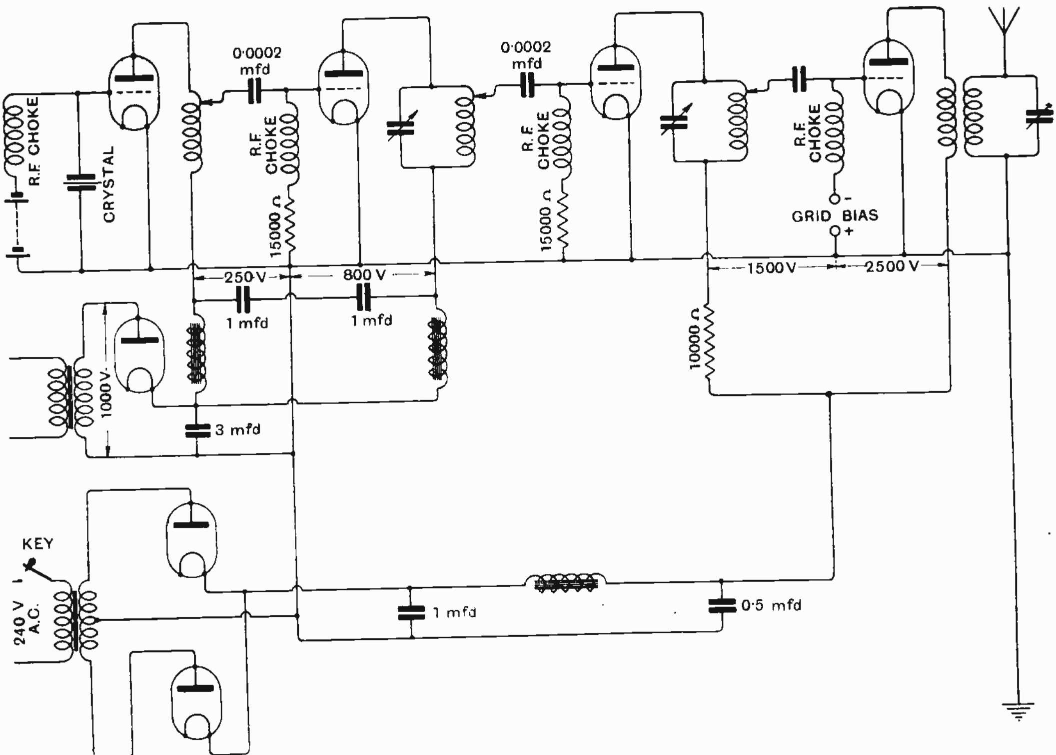


Fig. 22.

Modulation.

A set of this type may be modulated in any of the usual ways. Whichever method is used there will be no chance of frequency modulation. Modulating the grid of the last amplifier is a very simple and satisfactory method. In other circuits this usually gives so much frequency modulation that the telephony is unintelligible, but using this method with crystal control many

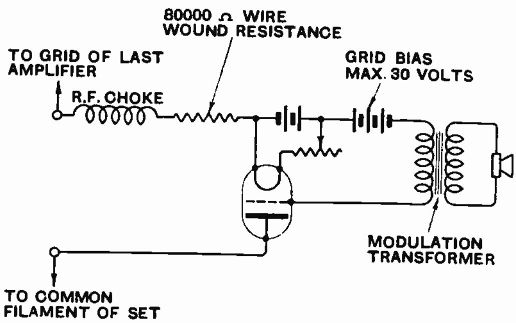


Fig. 23.

reports have been received and not one mentions any distortion. All state telephony very good and a good percentage report it the best telephony received on this wavelength.

It is very gratifying to get these results with such a simple method. The modulator valve is an ordinary general purpose receiving valve. The circuit is shown in Fig. 23. The grid of the last amplifier is connected through a choke to an 80,000 ohm leak then to the filament of the modulator valve. The plate is connected to the common filament terminal of the main set.

The large value grid leak is used to obtain the necessary grid bias. This may be replaced by a dry battery or a small transformer supplying rectified A.C. Still another method is to use a receiving valve as a grid leak, the value of resistance being governed by the filament temperature. If the filament temperature is gradually reduced the power output increases to a maximum and then drops again as the grid becomes too negative. This valve should not be used as a modulator also, as the filament temperature giving the correct resistance is not usually sufficient to give good quality telephony.

In comparing the amount of apparatus required for a crystal controlled set with that required for any other type of set for morse work where over 200 watts is required, it is rather excessive. If, however, good telephony is wanted a master oscillator and choke control must be used necessitating at least four power valves. This is as many as a crystal controlled set would require and the note and telephony of the latter would certainly be better.

Morse and telephony from the writer's set have been received in New Zealand, Australia, China, India, America, and various intermediate places.

In conclusion, it may be said that the beautiful steady note obtained and the absence of distortion when using telephony, has made the building of this set well worth while.

A New Slide Rule.

A NEW slide-rule specially designed for facilitating condenser calculations has been designed by Mr. P. R. Coursey of the Dubilier Condenser Company. The class of calculation to which it is applicable is that involving the connection between current, voltage, capacity and frequency or wavelength. It cannot be used for finding the area of plates which at a given spacing would give a required capacity, nor can it be used for calculating the capacity which, in combination with a given inductance, gives a required frequency, but it answers at once such questions as: What current will flow through a condenser of $0.001\mu F$ if $\lambda = 400$ metres and $V = 2{,}000$ volts? It has five scales with the following ranges:—

Frequency:	15,000 to 15 kilocycles.
Wavelength:	20 to 20,000 metres.
Capacity:	0.00005 to $0.05\mu F$.
Current:	0.5 to 500 amperes.
Voltage:	0.1 to 100 kilovolts.

Given any three of these four magnitudes, the rule enables one to read off the fourth.

Transformer Test Set.

Determination of Phase Shift and Amplification.

[R342.7.009

THE testing equipment to be described has been devised by P. W. Willans for testing the performance of intervalve transformers by measuring their voltage amplification in conjunction with an appropriate valve. It depends for its operation on a novel bridge arrangement whereby both the phase shift and scalar amplification are given as a result of a null observation.

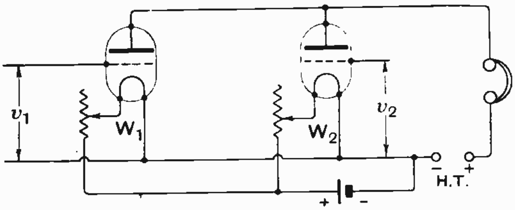


Fig. 1.

The method of making the observation may conveniently be considered in relation to Fig. 1. Here W_1 and W_2 are two valves, the filaments of which are controlled by separate rheostats. The anodes of these valves are connected in parallel through a pair of telephones and a source of H.T., and to the grids of the valves are applied alternating voltages v_1 and v_2 from any source whatever. Then it is clear that if the valves have linear characteristics and identical mutual conductances and if v_1 and v_2 are equal and in opposition of phase then no sound will be heard in the telephones.

In practice the valves can be adjusted so that their mutual conductances are equal, by first arranging that the applied voltages are exactly equal and in opposition of phase and then adjusting the filament resistance of either W_1 or W_2 until no sound is heard in the telephones. If then one of these voltages, say v_1, be replaced by a voltage which varies in conformity with the adjustments of any measuring apparatus, we can bring this voltage into equality and opposition of phase with v_2 by effecting an extinction of sound in the telephones. It is worth noting that such an extinction will in practice only be attainable with the fundamental frequency of the applied voltages if their wave-forms are not identical. This is an advantage since it helps to separate the effects of amplification on different frequencies.

The embodiment of a detecting device of this type for the purpose of measuring the voltage amplification of a valve and transformer is illustrated in Fig. 2, which is a simplified circuit diagram of the test set.

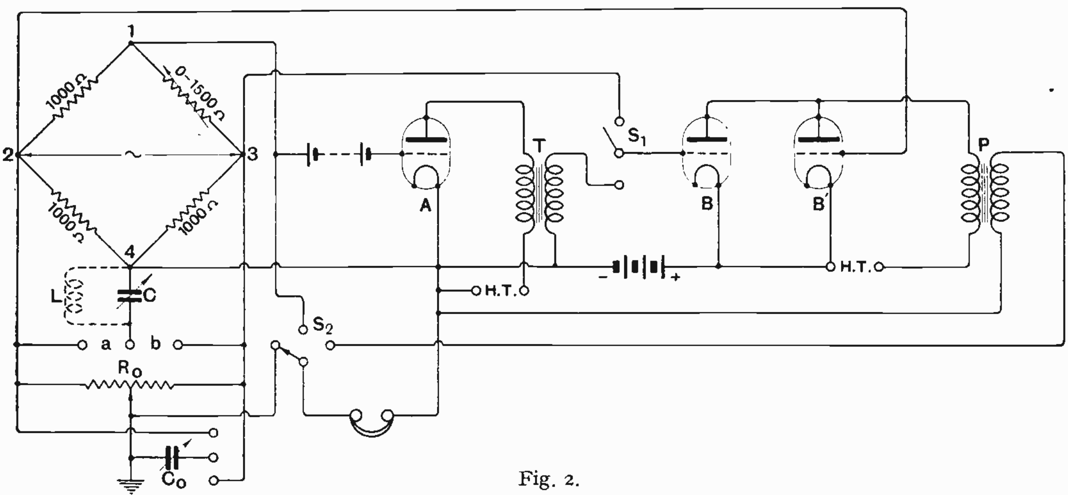


Fig. 2.

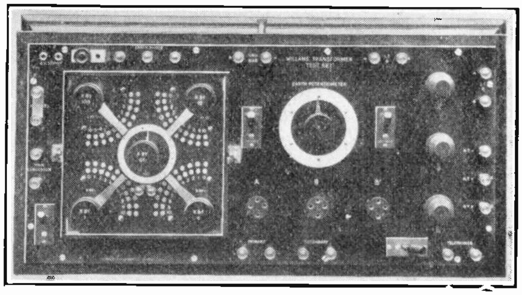
Here the valve A is followed by an inter-valve transformer T, and the object of the measurement is to ascertain the vector voltage amplification of this valve and transformer. The valves B and B' correspond to the two valves shown in Fig. 1, the anodes being connected in parallel and to the primary winding of a telephone transformer P. To the grid of the first valve is applied a fraction of the input voltage to a bridge, which consists essentially of four arms, three of 1,000 ohms resistance and one in general slightly different from that value. Further, either of the ratio arms of the bridge can be shunted by a variable condenser. Referring to the figure it will be seen that the condenser marked C can be connected either across the arm 2 4 or across 3 4 ; simultaneously we can throw the bridge out of balance in respect of resistance by the adjustment of the arm 1 3 which is variable from 0 to 1,500 ohms. The grid of the valve B' is permanently connected to point 2 on the bridge and the grid of B can be connected either to the output of the voltage amplifier or to the point 3 on the bridge, a switch S_1 being provided, for this purpose.

In order to effect the measurement we must first ensure that the mutual conductances of the valves B and B' are the same. For this purpose we connect the grid of valve B to the point 3 on the bridge, balance the latter exactly, thus making the applied voltages equal and opposite, and by means of the filament resistances of these valves reduce the sound heard in the telephones to zero. Having made this adjustment we throw over the switch S_1 on to the output of the voltage amplifier, then displace the balance of the bridge until the output voltage is such that no sound is heard in the telephones. We then know that the output voltage of the transformer is equal and opposite to the voltage across the arm 2 4 of the bridge and the input voltage to the amplifier is equal to the voltage across the diagonal 1 4. Consequently the amplification ratio is equal and opposite to the ratio of the voltages across 2 4 and 1 4 respectively. These voltages can very readily be calculated.

The resistance R_0 and the condenser C_0 constitute a Wagner earth connection, the arrangements being such that we can reduce to zero the voltage between the point 4 of the bridge and earth under all conditions of measurement. The resistance R_0 is of a total value of about 10,000 ohms and the condenser C_0 in consequence requires to be roughly 1/10th of the value of the capacity across the ratio arms, though it will deviate slightly from this value due to the stray capacities of batteries, etc., for which it is required to compensate.

The switch S_2 enables the telephones to be connected to the bridge diagonals direct, to the earth bridge or to the output of the valves B and B'.

In Fig. 2 an inductance L is shown as a dotted line across the condenser C. This may be used for the purposes of frequency measurement, the resonant circuit $L\ C$ being



Willans' transformer test set.

shunted across either ratio arm and the condenser and variable resistance arm being adjusted for exact balance of the bridge.

It is important to note the conditions of measurement, namely that there is practically speaking no impedance either in the input grid circuit or in the output anode circuit. In the first case the total impedance of the bridge is of the order of 1,000 ohms, which is negligible in comparison with the grid filament impedance of the valve at even fairly high frequencies. In the second case, since the adjustment is made in such a way that there is zero alternating current flowing through the telephone transformer windings, there is no alternating voltage on the plates of these valves and in consequence no retroactive effect on the amplifier. This reduces the conditions of operation to the simplest possible terms, and if it is required to observe the effect of input or output impedances these can deliberately be introduced in such a manner as not to interfere with the measuring apparatus.

The calculation of the amplification ratio differs according to the position of the condenser C. Referring to Fig. 3, which is a simplified diagram of the bridge itself, if we denote the two positions of the switch as (*a*) and (*b*) and the voltages across 2 4, 1 4, etc., by v_{24}, v_{14}, etc., the formulæ can readily be established :—

For switch in position (*a*) :—

$$\frac{v_{24}}{v_{14}} = \frac{R' + R}{R' - R - j\omega R^2 C}$$

For switch in position (*b*) :—

$$\frac{v_{24}}{v_{14}} = \frac{R' + R}{R' - \dfrac{R(1 - \omega^2 R^2 C^2)}{1 - \omega^4 R^4 C^4} + j\,\dfrac{\omega R^2 C}{1 + \omega^2 R^2 C^2}}$$

ω being, of course, the angular frequency of the applied alternating voltage.

In by far the greater number of practical cases the second formula can be simplified by neglecting $\omega^4 R^4 C^4$ in comparison with unity in the real term and $\omega^2 R^2 C^2$ in comparison with unity in the imaginary term. We then have, as an approximate formula with the switch in position (*b*) :—

$$\frac{v_{24}}{v_{14}} = \frac{R' + R}{R' - R + \omega^2 R^3 C^2 + j\omega R^2 C}$$

For the purpose of measuring voltage amplifications of very small value means are provided (not shown on Fig. 2) for connecting the grid of B' to a tapping point in the resistance of the arm 2 4. In this way the voltage amplification is equal and opposite to 1/10th of the ratio v_{24}/v_{14}, this ratio having the values given above.

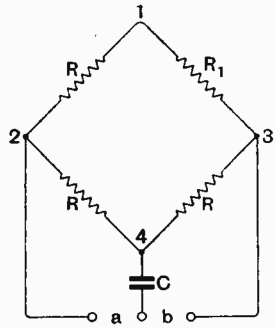


Fig. 3.

Numerous measurements have been carried out with this apparatus on intervalve transformers of all kinds and results more or less exactly in agreement with theory have been obtained. The analysis of a transformer is far more readily carried out in virtue of the fact that the vector ratio of amplification is yielded by the measurement, and it is possible to predict the amplification of the transformer at frequencies beyond the range of convenient measurement by extrapolation.

Amateur Radio Telegraphy.

By K. S. Wakefield (2AWD).

[R350

THIS article has, it is true, only a connection with experimental radio. Its purpose is to help those who would become more proficient at the telegraphy side of it. Though people may say this has nothing to do with experiments, or research, it is a very necessary side and, from what the writer has heard of amateur telegraphy, is on the whole a much neglected one.

Before describing a useful circuit whereby amateurs may either teach themselves or each other to send well and incidentally practice receiving, the writer intends to say something about the telegraphy side.

Sending.

The spring tension on the key should be adjusted to suit the operator and the gap if possible adjusted to something between $\frac{1}{32}$ in. and $\frac{1}{16}$ in. The key should be gripped as shown in Fig. 1, with the first joints of

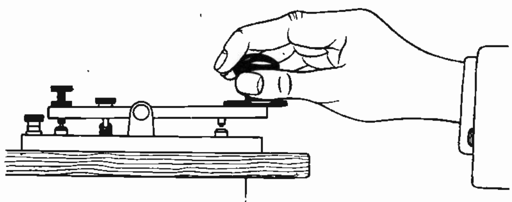


Fig. 1.

the first and second fingers just over the further edge of the key. The thumb should not touch the side of the key but during sending should slide up and down by its side. The movement of sending should be made from the wrist, which should not drop lower for a dash than for a dot, and the forearm kept in a horizontal position. The key should not be gripped but should, rather, rest lightly in the operator's hand. If the key is gripped, elbow too high, or wrist action stiff, cramp will result and the operator will begin to stumble, erase, and send badly.

It should be remembered here that an erasure should consist of eight dots but should never consist of less. If the first four letters of a word have not been sent correctly then the last word sent correctly should be repeated.

Great attention should be paid to spacing. The length, of course, depends on the speed of sending. A very good idea can be obtained of the correct time periods, for letter and word spacing, by just lifting the hand off the key between each letter and lifting it off the key on to the table, between key and sender, between each word. A great fault among amateurs is either to over or under accentuate dots or dashes.

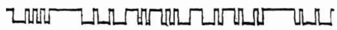


Fig. 2.

The accompanying specimen "RADIO" (Fig. 2) shows the relative lengths of dots and dashes as it should come out on a morse recorder. A dash should be the length of three dots—the space between two beats of a letter as long as a dot, that between two letters as long as three dots, and a word space as long as either five or seven dots (authorities differing on this length).

In practising a very slow speed should first be taken to form letters correctly—this speed can soon be worked up till the operator can send well and easily at twenty words per minute.

Receiving.

As to receiving, this can soon be "speeded up" by receiving radio stations, such as ships or commercial C.W. stations working slow "auto" or hand sending. "Auto," which is to say the sending as transmitted by an automatic transmitter, can be taken as what good sending should be like (the specimen in Fig. 2 was sent by an "auto") and it will be found how easy it is to read. Practice is, of course, had when receiving or working other amateurs, but their quality is so often bad that the writer, who can receive accurately up to about twenty-five words per minute, often finds difficulty in receiving them. It is not inferred here that there are not a great many very good senders among amateur transmitters such as . . . no! we won't give any names!

To learn to receive accurately at a good speed messages should be written. Some people find it easy enough to read plain language in their head far faster than they can write—especially at first. When practising writing, if a word or letter be missed, do not try and fill it in at the expense of losing the next word or two, but go straight on and it will be found that less and less will be lost every time till a good speed can be received accurately.

In taking a speed test, five minutes should be taken as the time. Nothing should be filled in after the word "Stop!" and all words not received wholly correctly scored out. Joining or splitting words does not matter as long as the letters are right. The words remaining should now be counted up, five letters being taken as one word and the total divided by five, giving the speed in words per minute.

Practice Circuit.

For those who are served by A.C. a very useful practice circuit can be made in the following way. There are no outside noises as with a buzzer—which usually "stays put" about five minutes—but a very good note can be heard in the phones. In sending practice the only way to know how you are sending is to hear how it sounds in the phones.

All the apparatus necessary is:—

(1) A good-sized morse key with good heavy contacts.

(2) One or more pairs of high resistance phones.

(3) A paper condenser of about .05μF and

(4) A little home-made iron-cored transformer with a step-up resistance ratio of about 20 to 1. The primary should be of about No. 22 S.W.G. D.C.C. wire and of a resistance of about 1 ohm. The secondary can be wound with the same gauge wire. These are connected as shown in Fig. 3.

The primary of the transformer is connected in series with the electric lamp in the operators' room. It will not affect its brilliancy as its resistance is so low.

Though the mains have a frequency usually of 50 cycles, a note of about 1 000 per second will be heard in the phones. This is due to the fact that the natural frequency of the circuit is now about 1,000 and so a twentieth harmonic of the A.C. is heard in the phones. The note can be altered to suit the operator merely by altering the capacity of the condenser.

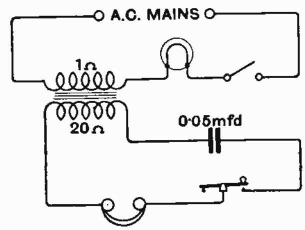


Fig. 3.

It will be seen that if frequency is to be, let us say, 1,000, then, allowing an inductance of about ½ henry, since

$$n = \frac{1}{2\pi\sqrt{LK}}$$

the capacity will be .05μF approximately.

The circuit is simple to fix up and is not at all dangerous as the P.D. across it is very small and there is no direct connection to the mains.

Assuming a 60 watt 240 volt lamp to be used the current would be 60/240 or ¼ amp and if the resistance of the primary is as much as one ohm, the P.D. across it C.R. will only be ¼ volt.

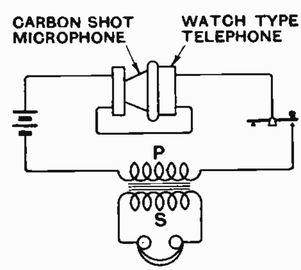


Fig. 4.

It should be added that the foregoing circuit should be successful with D.C. mains, as the commutator ripple is usually sufficient to actuate it.

Another very useful circuit which is within the reach of everyone—mains or no mains—is the following. It is cheap in construction and gives an excellent note, but being dependent on dry batteries is not quite as reliable as the last.

For the circuit see Fig. 4.* The transformer is the same as that in Fig. 3 of last method—phones being connected to the higher resistance winding. A carbon shot microphone is connected in series with an ordinary 24 ohm watch type phone and they are clamped, as shown, with diaphragms facing each other—the key, transformer primary and one or two dry cells complete the circuit.

When the key is depressed current flows through phone and the diaphragm is attracted, thus altering the microphone resistance and hence the current. Phone and microphone continue to react as long as the key is held down varying the amplitude of the current as in Fig. 5. It will be found that the circuit works much better with the battery connected up in one direction than in the other—the correct direction is found by experiment. The amplitude of current "vibrations" depends on the current strength and sensitiveness of the microphone and telephone, and the frequency, apparently, on natural frequency of phone diaphragm. Usually a clear musical note of about 1,000 per sec. is obtained. Any number of high resistance phones can be connected across the secondary.

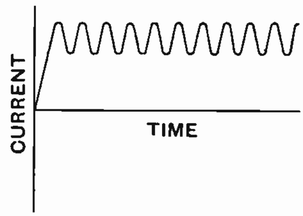


Fig. 5.

It is understood that a device of this nature is used by 2LO for his tuning note and by many tonic train stations.

It is hoped that this little article, with the help of the practice circuit described, may be of some assistance in the bettering of amateur radio telegraphy.

* This is an application of the well-known microphone hummer.—G.W.O.H.

Memorial to Hertz at Karlsruhe.

ON the 29th of last October and the following days the Technical College at Karlsruhe celebrated the centenary of its foundation. Suitable orations were delivered dealing with the history of the College, and with the part it has played in the scientific achievements of the last hundred years. Honorary degrees were conferred on a number of leading scientists; but to all of our readers the most interesting event of the celebrations took place on the 30th, when a memorial to Heinrich Hertz was unveiled. We have much pleasure in reproducing a photograph of the memorial. The inscription may be translated as follows:

IN THIS PLACE
HEINRICH HERTZ
DISCOVERED THE ELECTROMAGNETIC WAVES
DURING THE YEARS 1881-1883.

The Propagation of Radio Waves. [R113

Paper read by Mr. J. HOLLINGWORTH, M.A., B.Sc., before the Wireless Section, I.E.E., on 3rd February, 1926.

Abstract.

THE paper is communicated by the Radio Research Board, the work having been done for the Board's Committee on the Propagation of Waves.

In the introduction it is pointed out that work on signal strength measurement can be approached in two ways. The first is primarily concerned with obtaining data for reception and transmission purposes, and is mostly concerned with long distance transmission under working conditions. The second is of viewing the measurements chiefly as a convenient means of examining the electrical state of the intervening medium. The latter has been the guiding principle in the work described.

The apparatus used is not dealt with, it having been described in a previous communication.* The only notable difference is the substitution of a Dye transformer for a calibrated mutual inductance.

The features of the experiments are: (*a*) Distances are all comparatively short; (*b*) Observations have been simultaneous whenever possible; (*c*) Only daylight transmissions have been considered. This programme was adopted to reduce the number of independent and uncontrollable variables. Short distance reduces uncertainty with regard to variables, and removes the special cause of difficulty in long distance work in which the path contains both day and night sections. It also tends to higher accuracy of measurement owing to the more powerful signals in relation to disturbances.

Four receiving stations have been engaged on the work and have made routine observations since June or July, 1924. The earlier measurements were all made, on U.R.S.I. transmissions, those most used being Leafield (12.350m. at 14.00 G.M.T.), Nantes (9,000m. at 14.15), and Stavanger (12,140m. at 10.00).

The results from all stations have been reduced to a fixed aerial current, and each set averaged weekly. Daily results proved too cumbrous, while monthly averages might have obscured transient results of shorter period. The study of the curves suggests that the weekly meaning has been justified.

Fig. 1 of the paper (not reproduced here) gives the weekly averages of the observations on Nantes and Leafield at the four stations, from June, 1924, to December 1925. Several notable features appear. In the first months Nantes was stronger at Manchester (695km.) than at Slough (485km.). When variations occurred they usually appeared at all stations but not necessarily in the same direction, *i.e.*, an unusually high value at one station was generally accompanied by a low value elsewhere.

In September, 1924, day-to-day changes became much larger. In October big changes began to occur, culminating in sudden and enormous variations in the week 25th October to 1st November, the daily logs showing the majority of the changes between 27th and 30th October. Comparison is drawn between these, and results shown by Professor Mesny in *L'Onde Electrique*, and with the results shown in the Marconi Company's recent paper. (Abstracted in *E.W. & W.E.*, December, 1925.) In the following weeks, although day-to-day unsteadiness was marked, there was no definite return to summer values. In spring, 1925, signals gradually steadied down to practically the same values as in the previous summer. In autumn, 1925, the same abrupt change occurred again on practically the same days.

It is hardly possible to avoid the conclusion that these changes were due to some main cause operative over a large area; and the possibility is also suggested that all signal strength variations might be due to this cause, differing in degree rather than in kind.

Differences of land conductivity are dismissed by the fact that signals from Leafield at Glasgow, and from Stavanger at Aberdeen, were practically equal, although the former path is entirely overland and the latter over sea.

* *J.I.E.E.*, 1923; Vol 61, p. 501.

The paper then proceeds to consider the possibility of accounting for all the effects by a single cause, by considering the distribution in terms of Intensity and Distance The curves of Fig. 4 * are shown to illustrate the conditions before and after the transition period referred to. The actual intensities at each station being very different, the ordinates are given in the form of the ratio of the monthly average intensity to the mean annual intensity at that point. The relative changes at each station can thus be studied on a common scale. The characteristic features of these curves are the alternation of high and low values, and the complete reversal of form between the two months. They immediately suggest something in the nature of an interference phenomenon, and subsequent work has been chiefly to study this effect under the most favourable conditions.

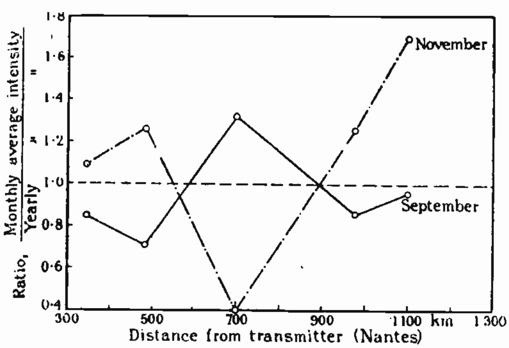


Fig. 4.

In order to make fuller investigation of the distance effect, provision was made for a portable set to provide a large number of points than can be obtained with fixed stations. As such work would necessarily occupy a few weeks, it could only be done at a time of the year when the day to day consistency was highest, *i.e.*, mid-May to mid-September. The U.R.S.I. signals not being suitable for a variable programme, the choice of a transmitting station finally fell on St. Assisse (FT., 14,350m.). Preliminary tests showed that the signals from this station usually maintained a steady value,

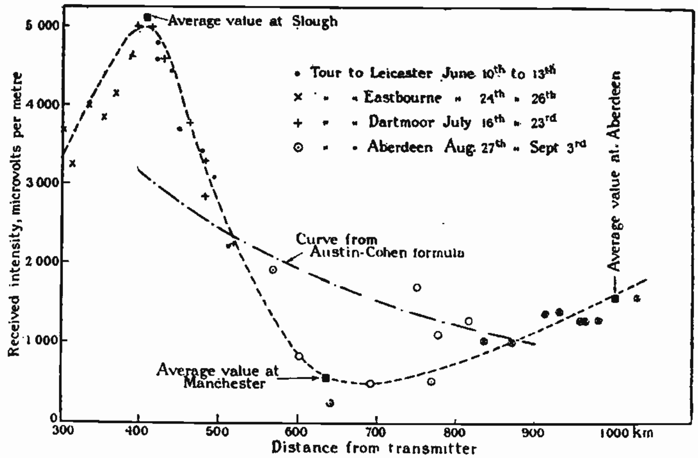


Fig. 5.

while it was also found that the strength at Manchester was only one-third of that received at Aberdeen, suggesting an interference phenomenon.

Fig. 5 gives the Intensity/Distance curve for a series of tours in the summer of last year.

In considering these results the paper briefly reviews the phenomenon of interference, and starts with the well-accepted Heaviside layer as an explanation. The simple case of a direct and indirect wave from A to B is illustrated in Fig. 7. On account of lack of knowledge as to the physical nature of the layer, it is impossible to say whether the effect is strictly one of reflection or refraction or, as seems likely, something of an intermediate nature.

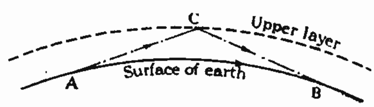


Fig. 7.

From consideration of Fig. 7, the distances at which maxima and minima should occur at various distances and for various heights of layer are plotted in Fig. 8 for the wavelength of FT.

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

Although the actual intensity at any point depends on the attenuation, the positions of maxima and minima are independent of the attenuation of either of the waves. Comparison of Figs. 5 and 8 suggest that the conditions are satisfied by a height of 75km. giving a maximum at 430km. and a minimum at 640km. From Fig. 4 (corrected for the

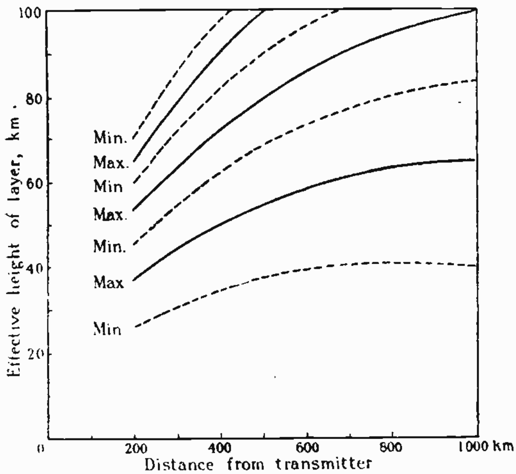


Fig. 8.

appropriate wave-length) a height of 72km. is suggested for September, and 85km. for November.

Present results are not sufficient to give details as to the physical nature of the layer, especially as to sharpness of surface, but it appears that the "effective height" would be different for different wave-lengths.

The results are then considered from the aspect of seasonal variations, *i.e.*, (i) comparison of summer and winter and (ii) comparison of the same period in successive years. The results of the four stations appear to group themselves into two sections, (A) May to September of very marked stability and (B) October to May with values differing largely from those of summer and with very marked day-to-day instability. As the marked change at the end of October seems to be consistent with a rise of layer height from 75 to 90km. it seems natural to suggest that some of the winter variations are due to the same cause. To examine this more fully a daily analysis is in progress but the preliminary arithmetical work is very heavy and it is not possible to say whether the analysis will be successful. From Fig. 8, however, it is clear that a change of height of only about 10km. may be sufficient to convert the signal at a given point from a maximum to a minimum.

Sunset effects are then considered, and illustrated by curves of intensity against time, for continuous observations over a few hours. Some results are shown in Fig. 9. Fig. 10 shows a case of remarkable consistency when two observers at stations 24km. apart, made the observations shown, each being unaware that the other was engaged on measurement. From these it is seen that the "sunset effect" cannot be classed under the general heading of "night increase." From comparison of Figs. 8 and 9, the variations are all explicable on the basis of a rise in effective layer height from 75 to 90km.

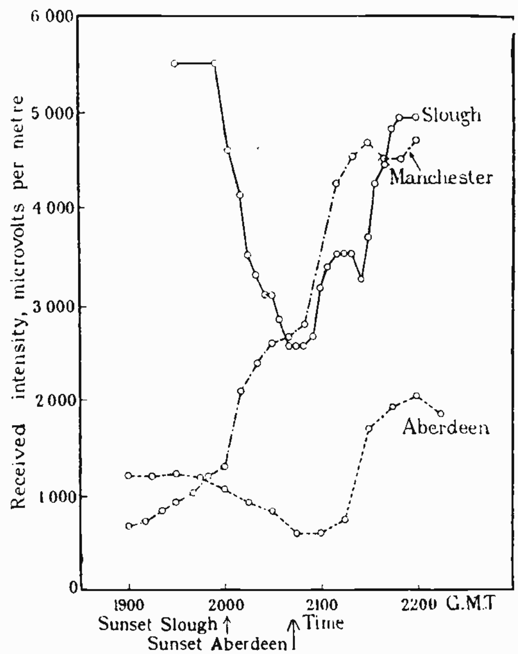


Fig. 9.

From the results it is possible to calculate the reflection co-efficient of and the angle of incidence on the layer. Results on St. Assisse, for the four stations are tabulated, showing reflection co-efficients varying from 0.16 to 0.42 at angles of incidence from 68.5° to 79.5°.

Lastly the paper considers the extension to long distances and short waves. The interference phenomenon discussed have an upper limit, but the idea of multiple reflection cannot be excluded. The signal from a distant station would thus consist of the vector sum of a series of multiple reflections, but their relative attenuations

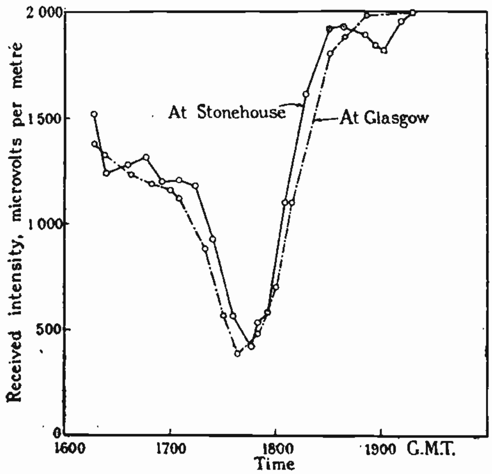


Fig. 10.

would probably allow only two or three to survive to a measurable extent.

There is danger in applying these results to wave-lengths below 1,000 metres, the difference in frequency being so great that there is no doubt but that the observed phenomena would be entirely different.

DISCUSSION.

In the discussion, **Prof. E. W. Marchant** dealt with observations made at Liverpool on Nantes and Nauen early in 1924, illustrating the measurements, and other measurements of signal strength variations by slides. He doubted the wisdom of weekly averages, and suggested that daily figures would be useful, especially in helping estimation of the height of the layer from day to day. He did not agree in attributing all the variations to interference due to reflection from the layer.

Dr. Reyner expressed appreciation of the work done under the Radio Research Board, including that of the author and his co-workers. He considered that signal strength measurements could now be made with more accuracy than could be given at the transmitting station measuring, say, 200 amperes. Increased accuracy at the transmitting end was now required.

Mr. T. L. Eckersley congratulated the author on the scientific spirit of the work. Referring to what he called the "November effect," he stated that it had been noticed by Captain Round as far back as 1911. The author by working at short distances had been able to separate different effects, *i.e.*, change of attenuation and the height of the layer. He suggested that the November effect was due to increase of both of these. He differed from the author's conclusion on the height of the layer as deduced from the maximum and minimum of the tour results. He held that it was impossible to calculate the path unless the change of phase was known. This change of phase was apparently sometimes of considerable value. From much information available he favoured a height of the order of 50km as a more likely value than the 70km. suggested by the author.

Mr. J. E. Taylor entirely disagreed from the inferences drawn from the observations, and suggested that treatment of propagations from the point of view of guided waves had received scant attention. He referred to waves along wires and their small decay after a hundred or a thousand miles. What was the difference in the case of a sheet conductor? The results observed were, he held, due to two waves, one direct and the other travelling round the earth, causing interference depending upon phase. He considered that this and all similar work was a waste of energy, time and money.

Dr. R. L. Smith Rose held that much information was now available in connection with the layer. He referred to work by Prof. E. V. Appleton and Mr. Barnett,* also by Mr. R. H. Barfield and himself, showing that waves do arrive at an angle to the earth, proving their arrival from an upper region. He dealt with separate measurements now in progress, of the electric and magnetic forces of the wave, and showed that the results could only be obtained by the arrival of the waves at an angle, and that this angle could be calculated from the results of the measurements. Curves of direction finding variations were illustrated, as were curves of d.f. variations with signal strength variations for the same period. These showed considerable correspondence. It was suggested that the variations were due to rotation of the plane of polarisation of the waves.

Mr. E. B. Moullin asked for more detail of day-to-day variation (*c.f.* Prof. Marchant), especially during the period of the "November effect." Results from a whole year might well be worth a detailed Fourier analysis, which *should* yield interesting information. He differed from Mr. Taylor as to the existence and effect of the layer.

Mr. Hollingworth briefly replied to some of the points raised in the discussion. Daily values were useful and informative, but were too bulky for publication. They were available however to anyone who wanted them. He agreed with Dr. Reyner as to the need for greater accuracy of the transmitter constants.

A cordial vote of thanks to the author was accorded on the motion of the Chairman (Major Binyon).

* See abstracts in E.W. & W.E., February, 1926.

Rectifiers for High-Tension Supply.

Part VII: High-Vacuum Rectifiers—The Two-Electrode Valve.

(Conclusion.)

By R. Mines, B.Sc. **[R355.5**

I.—General Survey.

WE have now covered the ground of rectification by devices using solid, liquid, and gaseous conductors (both dense and rarefied).

The first class of devices are primarily switches, which have to be operated in accordance with the control it is desired to exercise on the current flow.

In so far however as any such device can be made to operate itself automatically, by means incorporated in the complete apparatus, it may be called a valve—a valve being, in electrical parlance, a device that permits current to flow through it in one sense only when an alternating P.D. is applied to its terminals (*i.e.*, a " perfect rectifier). The two devices belonging to the last two classes however are in a different category; for once the essential asymmetry is established in them they behave after the same fashion as a valve—though many are but " imperfect " rectifiers.

II.—The Fourth Class.

There is yet another class of device that uses no material conductor at all—current flows through it solely by the passage of electrons from one electrode to the other.

Now it may be said with truth that this is just what happens in the " switch " type, the electrons flowing along whatever complete metallic path they may find; but there is this important difference, that in the new class to be considered, there is no material body present to facilitate the passage of the electrons.

On the contrary, in fact, it is found essential to get rid of all matter possible from the space where the electron flow is to take place, by exhausting it to as high a vacuum as is obtainable.

The figure usually reached commercially* gives the electron a mean free path of nearly a yard.

An alternative approach to the subject of the high-vacuum rectifier is permissible —to regard it as a development from the rarefied gas conduction types, by exhaustion far beyond the point where the quantity of gas present is sufficient for useful ionisation.

Now it has been postulated that conduction is by electron flow only—this implies the presence of some means of liberating electrons into the evacuated space.

The mere presence in this space of a body carrying free electrons—a conductor—is not sufficient because the boundary conditions (a kind of surface tension effect) prevent " evaporation " of electrons from its surface.

Some of the methods of releasing electrons from an electrode surface have already been considered; for example, the one always present in gas discharges, positive ion bombardment. Obviously this method is not available in high-vacuum apparatus.

III.—Alternative Sources of Electrons.

If an electrode is made from a suitable metal (preferably, strongly electro-positive, such as an " alkali " metal), then by virtue of the *photo-electric effect* electrons may be liberated from its surface by intense light falling upon it. In general this method is not used, partly because it is not practicable to use an appropriate electrode material, but chiefly because the supply of electrons thus obtainable is far too meagre.

Another possibility would be to provide the electrode with a layer of *radio-active material* that emits β-rays (which are high-velocity electrons). Owing again to the minute supply, also to the high speed of the electrons and to the emission in addition of α-rays (helium atoms, causing disintegration and lowering the vacuum) and γ-rays (penetrating X-rays, that are dangerous apart from their secondary effects), this method has not been used.

There remains the *thermionic emission.* The nature of this phenomenon has already been described; its application to the high-vacuum rectifier is not different, except that heating of the active electrode must

* The " gas pressure " is in the neighbourhood of 10^{-8} atmosphere.

always be by independent means—it is not possible to have a self-maintaining discharge so long as the high vacuum is preserved.

IV.—Emission Characteristics of the Filament.

We have implied* that the emission of negative ions increases rapidly with rise of the temperature of a metal. Various investigators have formulated equations representing the relationship between these two quantities, and mostly they agree that the emission current is inversely proportional to the quantity $\varepsilon^{b/T}$ (where T is the absolute temperature of the metal, b is a " constant " that varies only slightly between different materials, and ε is the " base of natural logarithms "), and that this is the predominating factor.†

The occurrence of T in the denominator of the index means that this quantity decreases with increase of T, but the reverse proportionality expresses the fact that the emission current increases with increase of temperature.

The quantity C is usually in the neighbourhood of 50,000 degrees, and the working temperatures used are usually round about 2,500 degrees; the quotient of these two is 20, which is the *index* of ε. This expresses the fact that the variation of this factor (and hence the emission) with change of temperature is extremely rapid.

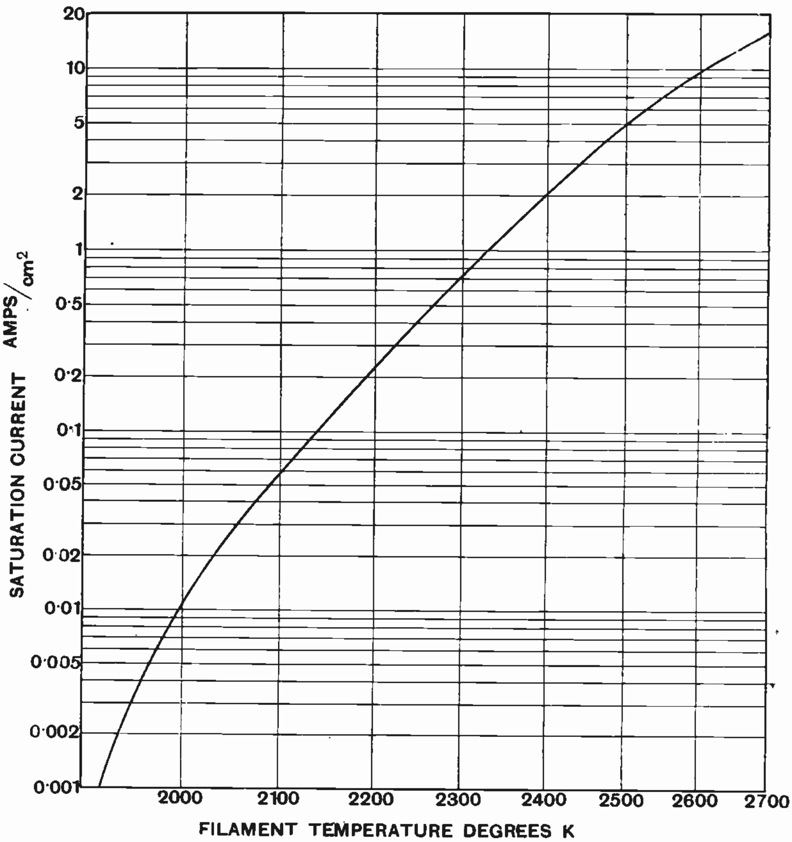


Fig. 1.

The relation is depicted in Fig. 1. The emission shown is the maximum current it is possible to draw from the filament,

* E.W. & W.E., p. 898, November, 1925.

† Richardson's equation introduces in addition the factor T^2, and one derived by Dushman and Richardson—the factor $\sqrt{T}$. Inspection of the curve given (Fig. 1), however, shows that if the relation be represented by $i=kT^n$, the index n is about 25 over the middle of the range—so it does not matter much whether 2 or $\frac{1}{2}$ is added to it.

and is called the "saturation current" corresponding to the temperature.

V.—Asymmetry.

The obvious way of making the high vacuum tube into a rectifier is to provide one only of the electrodes with means of emission of electrons, the other electrode being left incapable of emitting them.

Therein lies one of the chief advantages of this kind of apparatus over many of the other forms of rectifier that we have discussed —because the inactive electrode can be made *totally* inactive, and the "inverse current" made zero; the device is a "perfect rectifier" or valve.

This apparatus was originally given the name "Kenotron," whose Greek roots mean "empty appliance."

VI.—Form of Electrodes.

To provide for independent heating, accomplished most conveniently by passing an electric current through it, the active electrode is in the form of a filament, made of a refractory conductor, usually tungsten, as in the Tungar Rectifier. There are differences, however, the reasons for which will be discussed presently.

The inactive electrode again is different from that in the Tungar type. In this latter, as in all rectifiers using a gas discharge, there is a tendency for the discharge to concentrate into a small volume, since this favours intense ionisation—this is the more noticeable the heavier the discharge, and increases also with increasing gas pressure. This tendency leads to a concentration of the electrodes into a small size (provided the necessary heat dissipation permits it).

In the high-vacuum rectifier on the other hand these conditions are quite absent. In fact, due to their own mutual repulsion, the electrons drawn off from the heated filament tend to distribute themselves throughout the surrounding space—they being its sole occupants.

It is partly on this account that the inactive electrode is shaped to enclose the filament as much as possible. In the larger sizes the wire filament is doubled or looped; this enables both the end leads to be brought to one end of the rectifier (which is almost essential for a high tension rectifier) and simplifies the spring mounting that caters for the thermal expansion of the filament.

VII.—The Space Charge Effect.

Let us now consider the results of applying a P.D. between the electrodes in the "conductive" direction, *i.e.*, making the inactive electrode positive so that the electrons are "drawn off" from the filament.

Reference has been made to the mutual repulsion of the electrons tending to give them a uniform distribution in space. This distribution of negative charges constitutes a "space charge."

Actually the distribution is not uniform. The first reason for this is electric: neglecting for the time being the reaction of the "space charge" on the electric field, and assuming the latter is uniform in strength over the space between the two electrodes, the electrons will be subject to a uniform accelerating force, with the result that their velocity will be proportional to their radial position or distance from the filament, and their density will be inversely proportional to their radius.

A second reason, which is geometric, applies in the case of a filament lying along the axis of a cylindrical outer electrode; assuming for the moment, the electrons move outwards with constant velocity, their density in space will be inversely proportional to their radial position. This effect is in the same direction as the other, tending towards a higher electron density (*i.e.*, a higher value for the "space charge") near the filament than further from it.

Now we have met space charge before, in gas discharge devices, where it takes the form of a preponderance of positive ions—this occurring in close proximity to the negatively charged electrode and causing a high value of electric field and a large potential drop called the "cathode fall."

In the high-vacuum rectifier however, the space charge is negative, and because there are no positive ions, it extends right up to the positive electrode. This gives rise in the same way to a considerable increase of the electric stress near this outer electrode. This can occur only at the expense of the electric stress in other parts of the field, in a manner similar to that occurring in the point and plate discharge, previously described—in fact, when the supply of electrons is copious and the P.D. between the electrodes is not great, it commonly happens that the electric field changes sign in the immediate vicinity of the filament. In other words there is a place near the filament where the absolute potential is more negative than that of the filament itself—it does not reach the filament potential and begin to grow more positive until a place is reached still farther from the filament surface.

The most important result of this is the retarding effect of the reversed field at the surface of the filament which exerts a force on the electrons tending to drive them back into the filament instead of to draw them out.

This condition of affairs can only be maintained when the P.D. is high if the filament is strongly heated so that a sufficient proportion of the "thermions" are emitted with velocity enough to carry them over the "brow of the hill" represented by the negative to maximum of potential.

VIII.—Inherent Stability of the Discharge.

If the filament is not hot enough the retarding field succeeds in choking down the flow of electrons between the electrodes (see Fig. 2); but it is this flow that maintains the electron density, *i.e.*, the space charge, which is turn is the cause of the retarding field.

The two factors are not helping each other, but are in opposition over the whole range

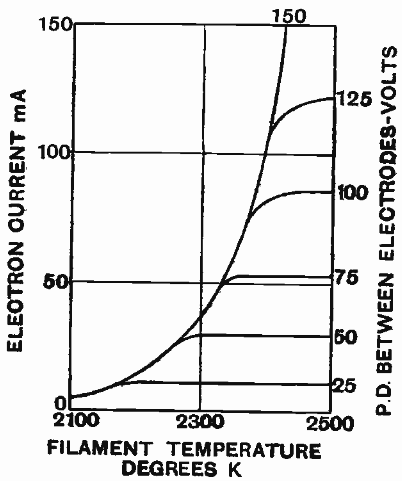


Fig. 2.

of their variations. Therefore however one factor may be varied by an external agency, the other will adjust itself to the corresponding value and will "stay put"—a condition of *stable equilibrium* will be attained.

Herein lies a great advantage of the high-vacuum discharge over those dependent on gaseous ionisation—for these latter we

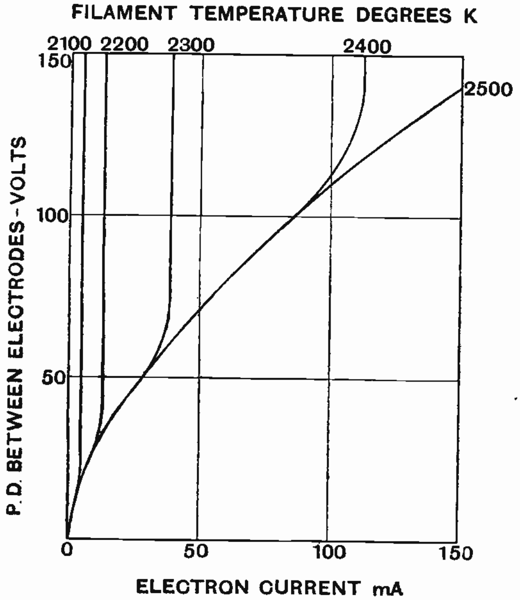


Fig. 3.

have seen behave in an unstable manner—until some additional factor is brought in to control their behaviour.

The chief practical value of this feature is that it permits a number of the rectifiers to be operated in parallel, since they will automatically share the load in correct proportion without the use of special regulators, stabilising resistors or reactors.

IX.—Effect of the P.D.—The Characteristic Curve.

It follows from the emission characteristics dealt with in Section IV, that it is impossible to exceed the saturation current, no matter how high the P.D. applied.

For intermediate values of P.D. the current is limited by the space charge in the manner described above. The relationship is shown in Fig. 3—this is called the *characteristic* of the apparatus. Note that nowhere is there a negative slope, which would be indicative of instability in the discharge.

It has been shown (by Child) that over this range the electron current is approximately proportional to the 3/2 power of the P.D. between the electrodes. It follows then that the expenditure of power in driving the electrons against their mutual repulsion varies approximately as the 5/2 power of the P.D. Care has to be exercised however in applying this result in calculating the losses, because the law is not fulfilled for the first and last portions of the characteristic. Thus when the P.D. across the rectifier is small compared with the drop along the filament due to the heating current, the effective value of the field becomes widely different for different parts of the filament. Another cause of discrepancy is the random distribution of velocity among the electrons given off by the hot filament.

X.—Losses in the Rectifier.

The primary loss of power in the rectifier is that described in the last section. This loss appears wholly as heat at the inactive electrode, which, as a consequence, rises in temperature until its heat radiation becomes sufficient to produce equilibrium.

There is also a secondary item of power on the debit side, viz: the power required to heat the filament. This item is independent of the load, and makes for poor efficiency therefore at light loads. Apart from this aspect though, whenever small powers are required to be rectified the filament power is found to be disproportionately large and this fact militates against the use of the thermionic valve for many purposes. Its real field of usefulness, from the efficiency point of view, lies in extra-high-tension work, such as the supply of steady power to X-ray tubes.

XI.—Points of Design.

It is assumed that from a knowledge of the load conditions of the rectifier system the power that must be dissipated by the inactive electrode can be determined. Now it has been specified as an essential condition for maintenance of rectification, that this electrode shall remain incapable of emitting electrons. This involves a definite limitation of its temperature, which is in direct opposition to the requirement that the temperature shall rise to dissipate the power as radiant heat (there being no convection in the high vacuum). In practice it is found that a bright red heat is permissible—for a tungsten or a molybdenum electrode the safe limit of temperature is about 1,600°*, which corresponds to a power dissipation of about 10 watts per square cm. This figure leads automatically to the radiating area of the electrode.

The shape of this electrode is the next consideration. Child has shown that for a given electron current, the potential drop in the rectifier, and hence the power loss due to space charge is proportional to the 4/3 power of the distance between the electrodes, with the outer electrode as a flat plate; with it as a cylinder, it is proportional to the 2/3 power of the distance. From this it appears that when a large power dissipation necessitates a large electrode, the cylindrical form is the more efficient, since the loss *increases less rapidly* with increase in dimensions. On the other hand for small rectifiers handling a very few watts, the flat plate type is better, because the loss *decreases more rapidly* with decrease of dimensions. In practice a compromise is usually effected in the latter case—the outer electrode is made like a flattened cylinder (not elliptical, but with plane sides) and the filament is a broad "V" instead of having its limbs nearly parallel.

The proportions of the outer electrode are partly dependent on the filament. Evidently the narrower the cylinder or the closer the plates the better from the point of view of space charge loss. In general there is a limit to the length allowable and this fixes a minimum diameter to give the predetermined radiating area. There is another consideration however which is of greater importance both in extra-high-tension rectifiers and in those of small dimensions. It is not possible to mount a filament accurately in the desired position —in practice there is a certain minimum error. The unbalanced electrostatic force on the filament is proportional to its percentage eccentricity and to the field strength, both of which factors are inversely proportional to the cylinder diameter or the plate separation. The degree of instability of the filament therefore varies inversely as the square of this dimension—so it is not safe to make it too small.

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* At this temperature the actual emission is still under 0.02mA/cm².

Similar considerations of mechanical stability control the proportions of the filament itself—the ratio of length to diameter should not exceed a safe figure. Their product, or the surface area, is predetermined by the maximum value of the current pulse that the rectifier must pass, once the working temperature has been decided upon. This latter factor is governed by the emission characteristic of the material just as with the other electrode—except that in this case the *highest* temperature possible is desirable. The practical limit is imposed by the useful

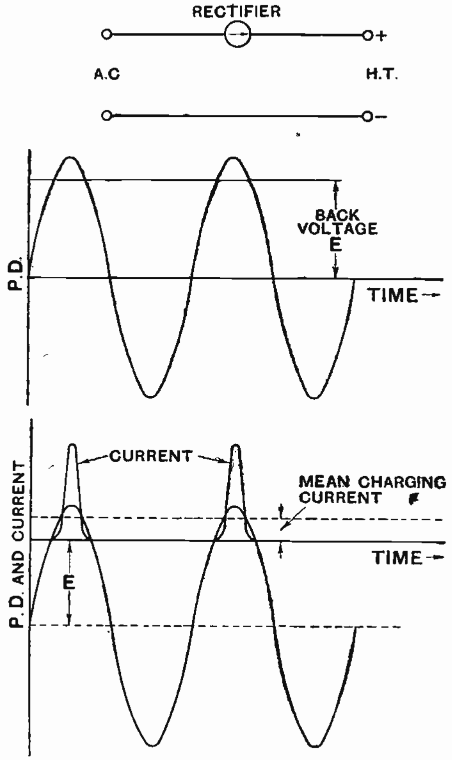


Fig. 4.

life of the filament—since as the temperature is raised, atoms of the filament material as well as electrons evaporate from it, causing it to waste away.

XII.—Conditions of Efficient Operation.

Reference to Fig. 4 reveals certain facts concerning the supply of power to a steady D.C. circuit through a rectifier, two of which become of special importance when a thermionic valve is used.

First is the relatively small value of P.D. available for pumping the current through the rectifier and into the output circuit, as compared with the P.D.s on the input side. This makes it essential to ensure

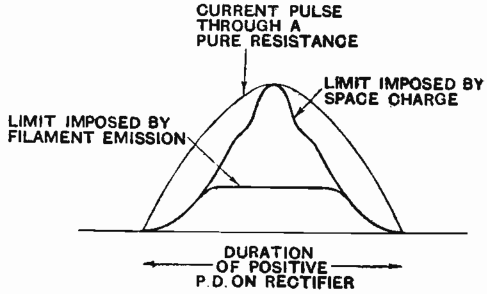


Fig. 5.

that the space charge shall not impose any undue limitation, merely from the point of view of getting the current through, apart from the question of wasted power.

Secondly there is the very high maximum value of the current as compared with its mean value (which latter is the value determining the *power* passed by the system). This makes it essential that there shall be no limitation imposed by sufficient emission not being available from the filament, if the full power is to be passed.

Fig. 5 shows diagrammatically what happens in these two eventualities.

When a thermionic rectifier supplies a resistance load or there is a considerable resistance drop in a filter circuit or a safety resistance, then insufficient filament emission involves serious consequences. For when the current falls off, the resistance drop falls off; and the surplus P.D. comes across the rectifier automatically. The extra power spent in the rectifier as a result appears as heat at the outer electrode, and if this becomes too hot, rectification will cease and the "valve" will short-circuit the output and input on the reverse half cycle. (This may arise either from spoiling of the vacuum or from emission from the heated anode.)

Should the design of the rectifier or the circuits in which it is used render this condition a safe one, then we find that the valve constitutes a very valuable safety device, in so far as it limits the amount of current that can be drawn from the output terminals in the event of a short-circuit.

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.

Supersonic Patents.

The Editor, E.W. & W.E.

SIR,—We must apologise for again referring to the matter of our patents covering the supersonic principle of detection, but we do not think it would be just that Mr. C. E. B. Wilkins' letter to you should contain the last word on the subject in your correspondence columns.

We have no hesitation whatever in saying that Mr. Wilkins and his adviser's interpretation of the patent law, as it exists in this country at the present time and applied to the matter under discussion, is erroneous.

There is absolutely no doubt whatever as to our position and our rights in this matter, and, as stated before, while we are perfectly willing to grant a licence under this patent to anybody who asks for it and pays the royalty of 30s., we have every intention of proceeding against anyone who infringes the patent.

Standard Telephones and Cables, Ltd.,
F. S. A. P. DISNEY, Secretary.

Another Question of Nomenclature.

The Editor, E.W. & W.E.

SIR,—I was very glad to see the article by Prof. Howe in the February number of E.W. & W.E. If I may be allowed to use such a frivolous expression, I should like to say that Prof. Howe's suggestion fills a long-felt want.

The application of the term impedance to the expression dV/dI, however, is not the only way in which this unfortunate word has been misused. As pointed out by Prof. Howe, its proper meaning, that is to say the meaning in which it has been used for many years in ordinary electrical literature, is to describe the quantity obtained by dividing the terminal voltage of an A.C. circuit by the current. Mathematically, the impedance is given by the equation: *

$$\text{Impedance} = \sqrt{R^2 + (L\omega - 1/C\omega)^2}.$$

It will be seen that this expression involves a combination of resistance and reactance, but in all cases it is a real quantity.

In making a rigid analysis of alternating current problems it is necessary to take account not only of the magnitude of the various quantities involved, but also of their phase relationships. The use of imaginary quantities in this connection is very convenient, and the method consists in regarding reactance as an imaginary resistance. The resistance R and the reactance

$$\{L\omega - 1/C\omega\}$$

are then combined to form the complex quantity

$$\{R + j\,(L\omega - 1/C\omega)\},$$

and problems are dealt with by means of a generalised form of Ohm's Law which is extended to apply to the complex quantities which enter into the equations.

The quantity $\{R + j\,(L\omega - 1/C\omega)\}$ has been referred to by various writers as "generalised resistance," "operator impedance," "operator," and so forth, and the appearance of these varied titles to describe a quantity which is constantly occurring in the mathematical work is a source of some annoyance to the ordinary reader. But when our old friend "impedance" is added to this list of titles the present writer feels that it is time to record a protest. The use of several titles for one mathematical expression is bad enough, but to use the same word to describe several different and inconsistent ideas is to invite muddle and confusion. The writer has therefore been roused by Prof. Howe's example to place on record this protest against any extension of the meaning which has always been attached to the word impedance. It remains to suggest a suitable title for the expression already referred to.

In ordinary algebra x and y are employed as variables, and in standard mathematical works dealing with the properties of the operator $(x+jy)$ it is commonly referred to as a complex variable. No departure from accepted nomenclature is therefore involved in calling

$$\{R + j(L\omega - 1/C\omega)\}$$

a *complex resistance*, and it is suggested that this title is both convenient and descriptive. The writer ventures to hope that it will be generally adopted.

K. E. EDGEWORTH, Lt.-Col.

* This formula is only for the case of resistance inductance and capacity connected in series.—G.W.O.H.

Dame Melba's Farewell.

The Editor, E.W. & W.E.

SIR,—Amid the sadness of bidding good-bye to so many good friends of mine up and down the country it has been a pleasure to note almost everywhere a quickening in musical appreciation. To-day there are gratifying signs that the British audience begins to hear as well as listen; and if the result is to be a musical revival the credit for it will be due in no small degree to men like Hallé, Henry Wood, Eugene Goossens, Landon Ronald, Albert Coates, Hamilton Harty and a number of other pioneers in London and certain provincial centres.

Yet mainly, so it seems to me, the secret of this new interest is to be found in the astonishing enlargement of the audience for music accomplished by the gramophone and broadcasting. Although I believe I was the first prima donna to make a gramophone record and the first to broadcast, I have not, whilst recognising the possibilities of these devices, ever accepted either of them uncritically, and I am well aware of the flaws in wireless as that science is practised to-day. But, just as I have followed the gradual perfecting of the gramophone, so I think one may look forward to like improvements in wireless. Broadcasting and the gramophone are certainly the two most eloquent missionaries to the musical heathen in our midst.

London, S.W.1. NELLIE MELBA.

From the World's Wireless Journals.

Abstracts of Technical Articles.

R000.—GENERAL PRINCIPLES AND THEORY.

R040.—Notes on Wireless Matters.—L. B. Turner. (*Electrician*, 8th January, 1926.)

A brief review of technical progress in 1925. Low-powered short-wave communication is first considered, including the Government stations under construction by the Marconi Company. Tuning-fork control of radiated frequency is then reviewed, with reference to the arrangement which has been in use at Northolt for some time and to the same plan in use at the new Rugby Station. The author then considers the interference problem in broadcasting, and the conditions to be fulfilled for non-interference. After a brief note on Transatlantic telephony, the paper concludes by reviewing recent research work, more especially on the upper ionised layer and its effect on propagation.

R100.—GENERAL PRINCIPLES AND THEORY.

R113.—An Investigation of Transmission on the Higher Radio Frequencies.—A. Hoyt Taylor. (*Proc. I.R.E.*, December, 1925).

The chart is a preliminary attempt graphically to summarise ranges for wireless *telegraphic* communication at various frequencies, with 5kW in an average aerial and for communication between points on the same meridian. For East and West or other lines of communication account of time difference (and transmission conditions) must be taken. The chart covers the ranges for 3,000 metres down to 15 metres and shows values for daylight and for night in summer and in winter, with references as to regions of unreliable communication, insufficiently explored, etc. The chart is based on experimental data of the U.S. Naval Laboratory, amateurs, commercial and other government sources.

R113.—Diagramme des Champs Electrique mesurés à Mendon, pendant le deuxième trimestre, 1925.—U.R.S.I. Communication. (*Onde Elec.*, December, 1925).

Five curves showing measurements of signal strength in microvolts-per-metre, made at Mendon on the following transmitting stations—Lafayette (Bordeaux) on 18,900m.; Nantes on 9,000m.; Rocky Point on 17,610m.; Rome on 10,860m., and Leafield on 12,350m. The curves shown are the ninth group to be published in this manner by U.R.S.I.

R113.1.—Remarques et Hypothèses sur le "Fading."—L. Deloy. (*Onde Elec.*, December, 1925).

The author refers to the apparent freedom of long waves from fading, and discusses the effects on short wave-lengths, quoting his own experiences (in 1923) on Transatlantic communication with small power on about 1 [illegible] metres. He suggests that it seems probable th[illegible]ing affects all wave-lengths, but in a differ[illegible]r according to their length. He refers particularly to the distortion of modulation on the short waves of KDKA, and suggests that it may be due to a fading with a period of a fraction of a second. Accordingly it is suggested that, on several thousand metres, the period of fading might be of the order of several hours; on a few hundred metres, as has been widely observed, it is of the order of a number of seconds; on a few "tens" of wave-lengths the fading would have a period of only a small fraction of a second. Such rapid fading is difficult to note, and irregularity observed may often be attributed to variations of modulation. It is suggested that a pure C.W. emission should be observed and measured (at a distance) by means of an oscillograph to detect rapid variation.

R113.1.3.—Direction and Intensity Changes of Radio Waves.—Dr. C. H. Bidwell. (*J. Franklin Inst.*, January, 1926.)

An account of measurements made in May and in August, 1925, on simultaneous observations of directional and intensity variations of signals in May from KDKA and in August from WGY. Result curves for both types of variation are given. The smoothed means show definite correspondence between the fluctuations in both, in some cases directional variation crests corresponding to intensity variation crests, and in others directional crests coinciding with intensity troughs. From these facts it is concluded that both changes are due to the same cause, which is meantime a matter of speculation. Changes in the height and contour of the Heaviside layer are suggested as possible explanations.

R125.1.—A New Directional Receiving System.—H. T. Friis. (*Proc. I.R.E.*, December, 1925).

A description of a unidirectional receiving system, suitable for the directional elimination of interference and atmospherics rather than for experimental direction finding. The method consists of the use of two receiving loops (as in Fig. 1) placed $\frac{1}{2}$ of a wave-length apart. The mid points of the loops are earthed to reduce antenna effect, only half of each loop being effectively used. Supersonic heterodyne reception is employed, each loop being joined to the input of a separate first rectifier valve, whose anode outputs are commoned and handed on through an intermediate frequency band-filter to the usual supersonic arrangements. The beating oscillation is applied to the signal from one of the loops by way of a crossed-coil phase-shifting transformer, so that any phase may be selected to obtain the unidirectional polar move. This curve is of the form shown in Fig. 2. A short-wave set (*i.e.*, up to 600 metres) is described and illustrated. The coils are mounted on the ends of a turntable, with the receiving gear housed at the centre. Experimental results on the reduction of interference are quoted. A long wave

(5,000-6,000 metres) set has also been used, without turntable facilities, since such a set would generally be used for the reception of signals from one direction only. Circuit diagrams for this set are

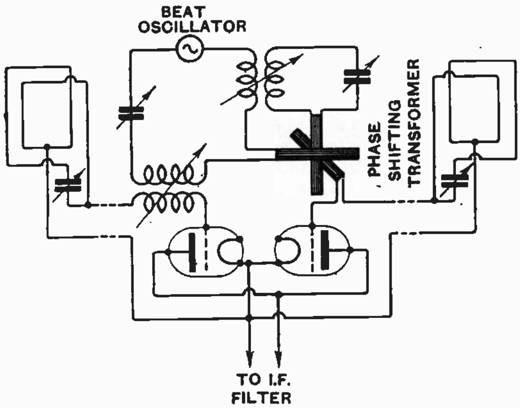


Fig. 1.

given. The adaptation of the system to the case of a single loop and a " condenser antenna " for the ordinary heart-shaped diagram is also described. The advantages claimed for the two loop system

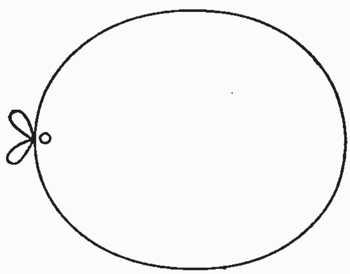


Fig. 2.

described are chiefly large reduction in atmospheric interference, with simple adjustments for the reduction of atmospheric or other interference.

R133.—Etude Analytique de l'Emission et de la Modulation par Lampes Triodes.—R. Maillet. (*Onde Elec.*, December, 1925).

A lengthy theoretical and mathematical article on the valve as a power oscillator and modulator from the large bulk of mathematics, it is not very suitable for abstract. It is pointed out that the elementary treatment of the valve oscillator is usually limited to the straight slope of the characteristic, but the present treatment is extended to deal with traverse of the representative point over the lower (zero) and higher (saturation) flats of the curve. The effects over the whole of the period covered are treated in detail. The considerations are applied to the design of an oscillator, having regard to the constants of the associated circuits, those of the valve itself, and phase angles. Tables and curves are given to facilitate calculation. Grid current is also considered, and a section deals with the use of the tables. The problem of modulation is then considered and expressions are given for various methods of modulation, *e.g.*, absorption, variation of mean grid potential, constant current, constant voltage, etc. Further tables are given for calculation. Lastly the case is considered of transmitters with independent extension, *i.e.*, master oscillator control, including the case of modulation on the voltage of the control oscillator valve.

R133.—Au Sujet du Rendement des Triodes.—Dr. B. van der Pol and K. Posthumus. (*Onde Elec.*, December, 1925).

A short contribution arising out of a previous article by the same authors (abstracted in E.W. & W.E., October, 1925). The present article considers the influence of the shape of the anode current on the output and power of a valve oscillator. Diagrams are given showing the input power and output as functions of the duration of current, and of the output as a function of the input power, in both cases for a sinusoidal and for a rectangular shape of anode current. It is shown that for a given input power the rectangular is the optimum shape.

R134.—The Rectification of Small Radio Frequency Potential Differences by means of Triode Valves.—Part III.—F. M. Colebrook. (E.W. & W.E., January, 1926).

R134.4.—An Analysis of Regenerative Amplification.—V. D. Landon and K. W. Jarvis. (*Proc. I.R.E.*, December, 1925.)

An important paper on the principles and use of reaction as an amplifying agency in a receiver. After criticising the defects of the usual methods of treatment, the authors develop an explanation on a basis of power balance. The reasoning is first applied to the case of a stage of tuned anode capacity-coupled, with reaction from the detector anode back to the tuned anode circuit, but the application of the same reasoning to the case of reaction on to the aerial is indicated in the end of the paper. The treatment consists in considering the power losses involved without reaction, and how these are modified when reaction is applied. The reasoning is well illustrated by curves. It is shown that in the absence of a signal and with reaction short of the value necessary for sustained oscillation, the sum of the losses considered is greater than the power supplied by the reaction coil. A signal voltage then prevents certain losses from occurring, thus upsetting the power balance between the power supplied by the reaction coil and the power losses of the circuit. This causes oscillation to occur, so that effectively reaction consists of self-oscillation started and controlled by the signal. The limit of amplification obtained in this way is due to variations in the anode and grid impedances, as the amplitude of the grid voltage increases. The effect of these variations in terms of power losses are shown in curves. The effect of a grid-leak and condenser are similarly dealt with in terms of power. It is concluded that they de[illegible]ase the voltage amplification, but that [illegible]ed detecting efficiency more than ma[illegible]r the difference when audio frequency output from the detector is considered. Resistance *in* the grid circuit decreases the amplification by increasing the effect of the impedance variations. The effect of reaction upon distortion is considered and it is shown that a low L/C ratio may cause a loss of high notes if a weak signal is being received with full reaction. It is shown that amplification, due to the effect of reaction, still occurs even when the valve is in a condition of weak self-oscillation, this applying both to audible beating and zero beating. Zero beating is illustrated by a series of vector diagrams. Lastly the sharpening of tuning due to reaction is considered.

R200.—MEASUREMENTS AND STANDARDS.

R281.—The Design and Use of an Air Condenser for High Voltages.—Dr. E. H. Rayner. (*Journ. Scien. Insts.*, December, 1925 and January, 1926).

A paper dealing with the use of a loss-free air condenser for bridge measurements, more especially where an accurate knowledge of phase angle is important. It is pointed out that such a condenser can move easily be made free from stray effects than can a resistance be made free from capacity, or inductance effects. An air condenser of concentric tubular design is described and illustrated, for use in bridge measurements at 50 cycles and 10,000 to 30,000 volts. The methods of use and precautions necessary are dealt with, and results are given for two methods of measurement of very small power factor, *i.e.*, of the order of 0.009.

R281.—Tentative Directions for the Determination of the Electric Strength of Solid Dielectrics. (*J.I.E.E.*, January, 1926).

A report from the British Electrical and Allied Industries Research Association. The main text deals with the general arrangements of dielectric tests and the varied conditions to be met in practice. Appendices deal with details of different cases. A section of text and a lengthy appendix are devoted to tests at wireless frequencies. It is pointed out that dielectric loss at high frequencies causes the breakdown voltage at such frequencies to be lower than at alternating power frequencies. The heating resulting from dielectric loss is often sufficient to render the material incapable of functioning as an insulator. Loss of insulating properties at radio frequencies may therefore occur without any evidence of definite puncture. Appendix VII. deals with the Determination of the Electrical Characteristics of Insulating Materials at High Frequencies. Two H.F. tests are dealt with in detail. (1) Power Factor and Permitivity and (2) High Voltage Failures. Under (1) two valve generating sets are illustrated and described for various wave-lengths, to be used with a measuring circuit shown, in which the material under test is used as a dielectric for a condenser. Details are given of circuit constants and methods of test, with expressions for the equivalent resistance of the specimen, and for its power factor and permitivity. Test (2) deals with electrical failures and flash-over voltages at high potentials of wireless frequencies. A circuit for such tests is shown, with remarks on test conditions, and details of tests for failure *through* the material or *across* the surface of the material.

R300.—APPARATUS AND EQUIPMENT.

R342.4—A New Reflex Circuit.—L. W. Hatry. (*Q.S.T.*, January, 1926.)

The article first deals with the general principles of reflex circuits, including the distortion due to incorrect L.F. transformer constants, and the effect of by-pass capacities. The author then considers the exclusion of radio frequency from the reflexing L.F. transformer. The arrangement recommended is that of parallel H.F. and L.F. inputs to the first valve (as shown in Fig. 1), with

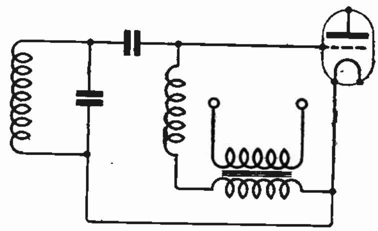


Fig. 1.

the "stopping condenser" and radio frequency choke to keep the H.F. component out of the L.F. transformer. The complete circuit of Fig. 2 is then shown, where the "stopping condenser" is shown, dotted at the filament end of the H.F. circuit. The following values are given ;—

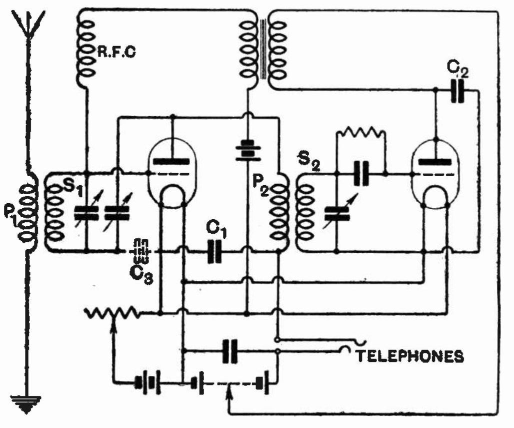


Fig. 2.

S_1 wound in two sections of 25 turns No. 22 D.C.C. on 3-inch tube.
P_1 20 turns wound on the same former as S_1.
S_2 45 turns No. 22 D.S.C. on 3-inch tube.
P_2 25 turns No. 30 D.S.C. inside S_2.
R.F.C. 500 turns on spool "lump wound" 32-36 wire.
C_1 and C_2 .001μF.
C_3 stopping condenser 50$\mu\mu$F.

A three-valve reflex on similar lines is also shown.

R342.6.—Un Amplificateur à Résonances Multiples et à Amortissement Réglable.—M. Jacquet. (*Radio Revue*, November—December, 1925.)

The article reviews some of the means of stabilising and handling several stages of H.F. amplification. As regards the difficulty of tuning several stages, the use of switching is advised, using first aperiodic stages and introducing the tuned stages one after the other. As regards the tendency to self-oscillation the use of a parallel resistance across the (tuned anode) circuit is recommended, 20,000 to 200,000 ohms being quoted as suitable values according to the circuits. The article also considers practical points of assembly and emphasises the need for the spacing of stages, short connections in each stage, separation of the input and output circuits of each stage, and arranging the coils of successive positions at right angles to each other.

R343.6.—Super-Heterodyne Radio Receivers. (*Electrical Review*, 1st January, 1926.)

An abstract of a paper read before the Junior Institution of Engineers by Mr. A. E. Bowyer-Lowe, dealing with the theory and practice of supersonic reception. After a brief review of the position as regards patent priority, the lecturer dealt with the production of the intermediate frequency and the design of a transformer to pass the necessary side bands. The use of steel cores was then discussed, but the author favoured air cored transformers at an intermediate frequency of 143 kilocycles. After dealing with the matching of the transformers the lecturer dealt with practical points of supersonic working, including an arrangement of joining the anode of the first detector valve (without H.T. voltage) to the grid circuit of the oscillator. This provides enough anode voltage for operation, and serves to couple the two valves, dispensing with a coupling coil, and being much less radiative than the usual method.

R345.—Etude de deux Systèmes de Modulation sur la Plaque.—(*Radio Revue*, November—December, 1925.)

A review of the "constant voltage" and "constant currents" methods of modulation. Both systems are illustrated and explained, and their relative advantages are discussed.

R351.—Practical Crystal Controlled Transmitters.—W. J. Lee and J. M. Clayton. (*Q.S.T.*, January, 1926.)

Descriptions of the arrangements of crystal controlled transmitters, one system (W. J. Lee) using D.C. supply, the other (J. M. Clayton) obtaining H.T. from A.C. source. The general circuits of the D.C. transmitter are shown in Fig. 1. The following constants are given with reference to the figure:—

L_1 and L_4 usual 100-turn radio frequency chokes.
L^2 "sensitising" inductance of 60 metres natural period.
L_3 20-turn 3½-inch space wound inductance.
L_5 20-turn 6-inch edgewound copper ribbon.
L_6 11-turn 3-inch No. 16 insulated wire.
R_1 5,000 ohms.
R_1 45 volts.
CO Piezo crystal.
C_1 C_3 C_4 .002 "stopping" condensers.
C_2, C_5 .0004 variable air condensers.
C_6 .00025 variable (neutralising) air condenser.
C_7, C_8 .00025 variable air condensers.

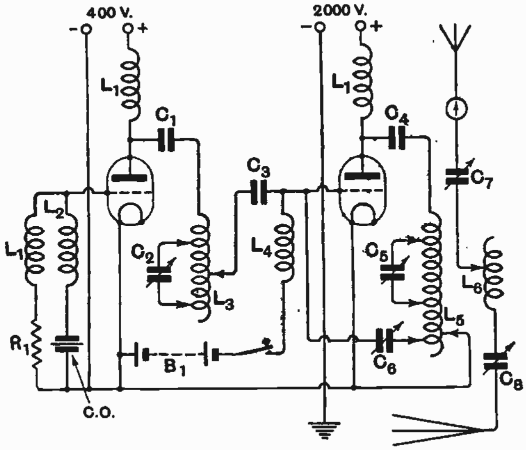


Fig. 1.

The set illustrated is for 40 metres. The "sensitising" inductance L_2 assists the crystal to oscillate and it is stated that this should have a natural wave-length about one-third higher than that of the crystal. The A.C. set uses substantially similar general arrangements, with two valves working in each position (control oscillator and power amplifier) each utilising opposite half waves of the stepped up A.C. Intermediate tappings are taken from the transformer for the smaller H.T. voltage for the oscillator. The mounting of the crystal and the assembly of the apparatus at each of the stations is illustrated.

R355.5.—The Epom Rectifier and Filter.—R. S. Kruse. (*Q.S.T.*, January, 1926.)

The rectifier described is rather similar to the Raytheon rectifier referred to in abstract in E.W. & W.E. for January, 1926. A large cathode supplies two point anodes, each dealing with

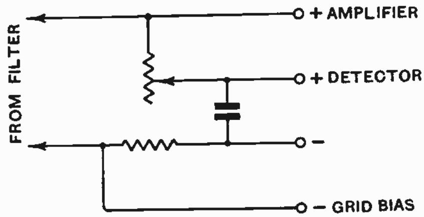


Fig. 1.

opposite half cycles to give double wave rectification. The ionised gas is Argon. Output curves are given, for output current against voltage. The usual type of filter is illustrated giving output tappings, as shown in Fig. 1, for the provisions of intermediate H.T. to the detector and for grid-bias.

R355.5—THE TONE METER.—L. F. Wolf. (*Q.S.T.*, January, 1926.)

An article dealing with the measurement of the ripple which still exists when high tension supply is obtained by rectification from an A.C. source. The arrangement suggested is to use a low reading A.C. voltmeter in series with a blocking condenser, joined across the H.T. mains. The condenser isolates the D.C., permitting A.C. voltage to be read. The calculation of the alternating component is illustrated.

R374.5.—PROPRIÉTÉS DÉTECTRICES DU BIOXYDE DE PLOMB.—J. Cayrel. (*Comptes Rendus*, 28th December, 1925.)

A piece of lead bioxide from an accumulator plate, or a film of that substance formed electrolytically on the surface of a plate of lead, platinum or carbon shows strong detection properties under certain conditions. The rectified current is in the direction bioxide to point. Points of aluminium, magnesium, calcium, zinc or tin gave best detection; points of platinum, gold, silver, nickel, copper or iron require extremely light contact. A rubbing contact also gave good results. Detection ceases when the current at the detecting electrode passes a certain limit. For feeble currents an electrode of greater surface (of the order of a centimetre square) may replace a point.

R376.—THE THEORY OF THE TELEPHONE RECEIVER.—W. H. Ingram. (*J. Franklin Inst.*, December, 1925.)

A mathematical treatment of various theories on the telephone receiver. The paper is not readily amenable to abstraction.

R381.4.—NOTES ON THE LAWS OF VARIABLE AIR CONDENSERS.—W. H. F. Griffiths. (E.W. & W.E., January, 1926.)

R382.1.—DESIGNS AND EFFICIENCIES OF LARGE AIR CORE INDUCTANCES.—W. W. Brown and J. E. Love. (*Proc. I.R.E.*, December, 1925.)

A paper dealing with large tuning inductances for transmitters. The design of outdoor coils is first considered, a porcelain spacing block for the winding is illustrated, and the use of the block to secure various windings is discussed. Various modern outdoor coils are shown in photograph, and efficiency test results quoted. The construction of coils for indoor use is then discussed and illustrated. Losses in the coils are considered and an expression is given for conductor eddy current power factor, with graphs for the calculation of the ohmic and eddy current conductor power factors of coils wound with finely stranded Litzendraht.

R382.5.—AN EFFICIENT TUNED RADIO FREQUENCY TRANSFORMER.—F. H. Drake and G. H. Browning. (*Proc. I.R.E.*, December, 1925.)

The paper discusses theoretical details of H.T. transformer coupling, with tuned secondary and untuned primary. The circuit is reduced to its "equivalent" form and an expression deduced for the maximum overall amplification in terms of calculable circuit constants. Curves show this value against coefficient of coupling (between the transformer coils) for various wave-lengths in the broadcasting band, *e.g.*, 300, 400 and 500 metres. The construction of a transformer from these considerations is then discussed. It is pointed out that capacity coupling between the coils must be kept down to negligible value, while at the same time a large value of inductive coupling coefficient is desirable. The transformer evolved had a secondary of 65 turns of No. 20 D.C.C. copper wire, wound on a tube of 4 inches diameter. The primary had 20 turns of No. 28 D.C.C. wound on a cylinder fitting tightly into the secondary, with the primary at the centre of the secondary. The behaviour of the transformer in operation is then discussed, first with reference to its reactance in circuit, sharpness of resonance and the control of stability. The circuit illustrated is the conventional one, with potentiometer for control of oscillation. Experimental verification of the calculated results is then described and illustrated graphically. A summary of design formulæ concludes as follows:—

(1) To compute L_2, the inductance of the transformer secondary, let λ_0 be the minimum wave-length desired to tune. Then L_2 in *millihenries* $= 5 \times 10^{-6} \lambda_0^2$.

(2) To satisfy the relation

$$\frac{M}{\sqrt{L_1 L_2}} = \frac{Rp}{L_1 \omega} \times \frac{R_2}{L_2 \omega}$$

(where Rp is the anode impedance), assume $\sqrt{M/L_1 L_2} = 0.5$, and substitute the value of $R_2/L_2\omega$. Knowing the anode impedance of the valve and the mean frequency to which it is desired to tune, L_1 can be computed.

(3) The secondary tuning condenser should be "low-loss" and of proper capacity to cover the wave-length band desired.

R500.—APPLICATIONS AND USES.

R514.—NEW METHOD OF DIRECTIONAL CONTROL. —P. D. Tyers. (*Electrician*, 8th January, 1926.)

An arrangement to assist a moving station (*e.g.*, ship or aeroplane) in maintaining a course on a fixed transmitter. A tuned frame aerial is joined to a high-frequency amplifier followed by a detector in whose anode circuit is joined a milliammeter. The usual scale is removed from the instrument and replaced by a rotatable disc with a zero line marked on it. The frame is to be oriented for the null position on the required transmitter, and the disc rotated to bring the zero line to the pointer. So long as this course is maintained the pointer will remain on the zero line, but will depart from it on deviation from the course when an E.M.F. will be induced in the loop, and the resultant P.D. applied to the detector grid will produce a change of anode current.

R520.—WIRELESS ON AIRCRAFT (*Electrician*, 30th October, 1925).

The article gives a general description, with three photographic illustrations, of aircraft wireless apparatus made by the Marconi Company. The various sets are prefixed by AD followed by a number denoting the type. AD4 is an aircraft D.F. set 600 to 1 000 metres, with 8-valve amplifier. AD5 is a 100-watt telephony transmitter, with an aerial fixed to wings and fuselage. The receiver consists of tuner 70 to 140m., with a 7-valve amplifier. AD6 is an all-purpose 150-watt set, with receiver, for telephony or telegraphy. AD6A is similar but of smaller tuning range for commercial communications. AD7 is a 50-watt set, for artillery-co-operation aircraft on 200-600m., with receiver and 4-valve amplifier in a separate box. AD8 is a 500-watt set for large aircraft, giving a range to ground stations of 200-300 miles. The transmitter and receiver are separate units, the former covering 600-1 500 metres, and the latter 600-4 000 metres. Ground receiving set AD10 is for portable use with artillery, using an easily erected 50 ft. mast. AD11 and AD11A are 40 and 100-watt transmitters respectively for aircraft signalling to AD10 on the ground. A receiver of the AD6 type can be added if required. An aircraft testing set is also illustrated, enabling the wireless maintenance staff to make routine ground tests of the aircraft sets, both transmitting and receiving.

R555.—The Pacific Coast Standard Frequency Station.—H. H. Henline (*Q.S.T.*, November, 1925.)

A description of the station at Stanford University, California, for the transmission of standard frequencies for the Pacific Coast, in conjunction with the Bureau of Standards. Two transmitters are described with photographs and circuit diagrams. One covers the range 120-1 500kC. (2 400 to 200 metres) and the other 1 500 to 6 000kC. (200 to 50 metres). The longer wave set is controlled by a master oscillator, while the short wave set is a 250-watt tube used directly with a Hartley circuit. Two aerials are used, one of 150 ft. length, 85 ft. high for frequencies of 125 to 1 000kC., the other 25 ft. long for 1 200 to 6 000kC. Two counterpoises are also in use, both together for the shorter and one only for the higher frequencies. Very complete details are given of the value of the various circuit constants.

R582.—The Voss Picture Transmitter.—R. S. Kruse (*Q.S.T.*, January, 1926.)

An account of a description from *Radio-Umschau*. The transmitter employs a photo-electric cell to modulate the output of a valve working to aerial or to a line. At the receiver use is made of an X-ray tube with a control grid in the path between the cathode and anode. A short description is given of the mechanical arrangements.

R582.—Practical Picture Transmission.—T. P. Dewhirst (*Q.S.T.*, December, 1925.)

A description of two popular picture transmitters now available for amateur use. The cylinders for transmission and reception are motor driven, the larger set having a synchronising device. The transmitters may be applied to existing C.W. or I.C.W. wireless transmitters, circuit diagrams for their application being given. The receiving portion can similarly be used with a standard receiver output giving a strong signal. Alternative arrangements of extra amplification, if required, are illustrated. Reception of the picture can be effected by carbon paper, with ink, or with a prepared electrolytic paper.

R600.—STATIONS: DESIGN, OPERATION AND MANAGEMENT.

R611.—The Rugby Radio Station.—(*Electrician*, 11th December, 1925.)

A short general account of the new Government station. The aerial system is described with a bird's-eye sketch of the layout showing the various dimensions. The general arrangements of the radio transmitter then follows, with an explanatory skeleton diagram. This apparatus falls into the groups: Tuning fork control unit, intermediate amplifying stages, power amplifier, and intermediate and aerial circuits. The power plant is described, and the whole article is well illustrated with photographs of mast, power plant, valve units, etc.

R611.—Rugby Radio Station.—A. S. Angwin and T. Walmsley (*Electrician*, 18th December, 1925.)

An abstract of a paper to be brought forward for discussion at the Institution of Civil Engineers. The paper sets forth considerations governing the selection of the Rugby site and describes the layout of the masts and buildings. Information is given on the design and construction of the masts, and of the calculations of stresses, etc., involved in the staying. The aerial and earth systems are dealt with, with a brief description of the power plant and water-cooled valves. The concluding portion of the paper describes tests upon masts, stay-sockets and insulators.

R612.—Transmission sur Ondes Courtes.—G. Archer. (*Radio Revue*, November—December, 1925.)

An addition to previous communications on the subject of short-wave transmission. In this

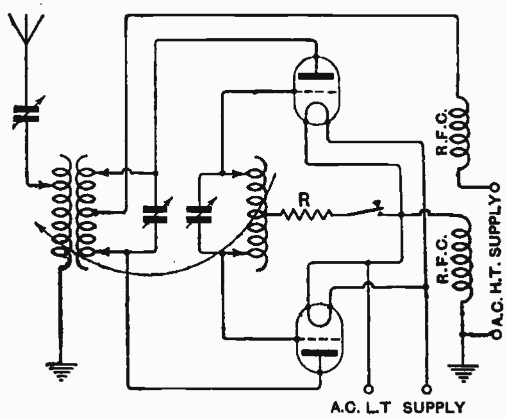


Fig. 1.

article details are given of the radio transmitter, the modulating circuits and the aerial arrangements. The transmitter circuits are as shown in

Fig. 1. L.T. and H.T. being supplied by A.C. and suitable transformers. The arrangement shown is for telegraphic transmission; if the power be too great for operation of the key at the position shown, it may be moved to between the junction of the H.T. and L.T. leads. The resistance *R* is formed by two valves, and two alternative schemes of modulation and amplification are shown for applying modulation across *R* for telephony. One arrangement uses transformer coupling and the other resistance and condenser coupling. The conclusion of the article deals with the aerial and earth or counterpoise arrangements which have been used on wave-lengths of 30 to 105 metres.

R612.—Imperial Wireless Communication.—(*Electrician*, 15th January, 1926; *Electrical Times*, 14th January, 1926.)

Both articles are descriptions of the beam stations nearing completion at Bodmin and Bridgwater, with notes on the masts, power arrangements, etc. The *Electrician* article is illustrated by photographs of masts and station plant.

R615.12.—Point-to-Point Radio Telephone Installation in Southern Persia.—F. Tomlinson (*Electrical Communication*, October, 1925).

A description of a wireless telephone system erected by the Western Electric Co. in Southern Persia. Local conditions rendering landline communication impracticable, radio telephony was finally chosen, with automatic calling and the simplest possible controls in the absence of skilled operators. Descriptions with circuit diagrams and photographs are given of the radio transmitter, the radio receiver, and the automatic signalling equipment.

The transmitter employs choke control modulation, using two oscillator valves, two modulator valves and one stage of amplification between microphone and modulator. The receiver provides for two stages of transformer coupled H.F. amplification with detector and one L.F. stage. One-way or two-way speech is provided for. In the simplex case, a push button beside the desk stand microphone operates a relay which provides the necessary aerial change over, and negatives the transmitter grids during reception. In the duplex case wave-lengths differing by 100 metres are used at transmitter and receiver, with appropriate rejector or wave-trap circuits between the receiving aerial and the amplifier.

For automatic calling the transmitter carrier-wave is modulated at 135 cycles, interrupted by a selector key to produce a pre-arranged code of impulses by means of a toothed wheel, clockwork driven. A double-throw key transfers the radio transmitter to the interrupter unit in the "Ring" position, and to the ordinary speaking circuits when thrown to "Talk." At the receiver, the 135 cycle modulation is received and amplified in the usual manner, passed through a transformer with peak at 135 cycles and finally fed through a condenser to an A.C. relay whose reed is tuned to this frequency. This relay operates a further system of relays and finally a selector unit which closes the local circuit of a bell when the correct code of impulses is received. Undesired signals and atmospherics are stated to have practically no effect, and regular commercial communication is given between two stations and also between each station and a spark station about 150 miles from each.

R800.—NON-RADIO SUBJECTS.

R616.57.—Small Broadcasting Apparatus.—(*Electrician*, 8th January, 1926.)

A short description of the Marconi 100W. type Q. broadcasting transmitter for use as a main or relay station in a small area. Four oscillating valves are used, with up to four stages of modulation amplification. The valves throughout are type L.S.5, all voltage supplies being from batteries. The microphone is of carbon type, aperiodic at all audio frequencies and free from packing. A magneto gramophone attachment can also be used.

621.382.385.—Reviews of Progress—Telegraphy and Telephony.—W. Cruickshank (*J.I.E.E.*, January, 1926).

A general review of line communication at home and abroad, dealing more especially with new and immediately future developments. A section of considerable interest to wireless readers deals with voice-frequency telegraphs, and describes systems in use in U.S.A. and Germany, with a note on experimental trials in England. In the American system ten different frequencies—each a multiple of 85, beginning with 425 and increasing by steps of 170—are used to give ten channels of communication on one line. The frequencies are supplied by alternators, filtered before application to the line, and are filtered and amplified at the receiving end, each frequency operating its own relay. The German system uses valve generation, with four electrode valves at the receiving end. The system is advantageous for use on underground telephone networks, and the standard telephone repeaters can be employed with it. The section on telephony deals particularly with automatic telephones, both here and in U.S.A., and with the international telephone system of Europe and the improvement of underground cables.

621.314.—Construction des Transformateurs.—P. Poirette (*Radio Revue*, November—December, 1926).

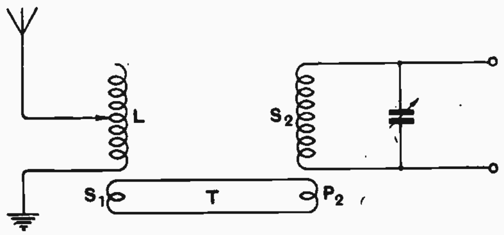
A continuation of a previous article on the principles of the transformer. The article under abstract deals particularly with small power transformers (*e.g.*, of the order of 120 watts) at commercial frequencies. The requisite flux and the dimensions of the iron are discussed, and the losses due to eddy currents and hysterics are shown graphically. The windings are then considered, with expressions for the winding space, number of turns, etc., and for the total losses (copper and iron) and efficiency. The latter part gives detailed calculation of a step-down transformer (as for accumulator charging), *i.e.*, 100 volts to 12 volts 10 amperes at 50 cycles. The expressions previously derived are used for the specific case.

Some Recent Patents [R008

AERIAL SEPARATION.

(*Application date, 20th October, 1924. No. 242,759.*)

A rather interesting method of operating a receiver at some distance from an aerial is claimed in the above British Patent by W. Rawsthorne. The object of the invention is to transfer the energy from an aerial circuit to the input circuit of a receiving system over some considerable distance with a minimum loss. In order to bring about this condition it is proposed to reduce the voltage over the transmission area and increase

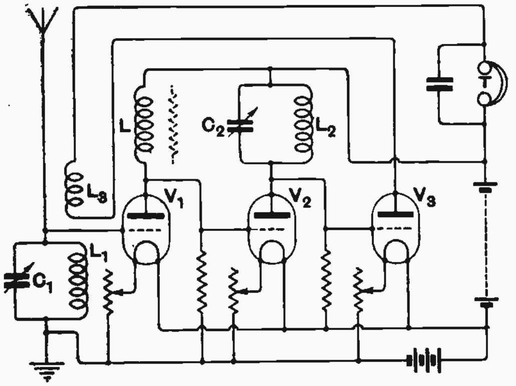


the current by means of transformers. The basic idea of the scheme is indicated diagrammatically in the accompanying illustration, in which the aerial circuit *L* comprises part of the primary winding of a step-down transformer, the secondary $S1$ of which is connected to the transmission lines *T*. The other ends of the transmission lines are connected to the primary $P2$ of a step-up transformer, secondary $S2$ of which constitutes the input circuit of the receiving system. The specification is fairly detailed, and provides for several modifications and additions, such as the introduction of amplifiers at any point, and also the introduction of tuning arrangements at any point. The circuit shown in the accompanying diagram, of course, does not appear in the least novel, as it resembles, for example, the early Marconi multiple tuner, but the novelty of the invention lies essentially in the method of carrying it into effect, and the relative positions and values of the components indicated.

PREVENTING SELF OSCILLATION.

(*Application date, 24th May, 1924. No. 243,038.*)

A very broad claim is made in the above British Patent by J. Scott-Taggart for the use of a series of critically tuned stages in an amplifier between which are interposed damped or semi-aperiodic or totally aperiodic stages. The idea of the invention can be gathered by reference to the accompanying illustration, which shows a normal high frequency amplifier coupling two stages of radio frequency amplification, the last valve being used as an accumulative grid rectifier. The anode circuit of the valve $V1$ contains an impedance *L*, while the anode circuit of the valve $V2$ contains a tuned circuit $L2$ $C2$. The circuit $L2$ $C2$ is tuned to the same frequency as the aerial circuit $L1$ $C1$. The anode circuit of the valve $V3$ includes a reaction

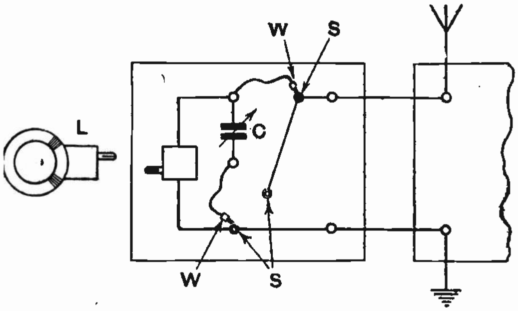


coil $L3$, and also the telephone receivers *T*. Regeneration is obtained between the inductance $L3$ and the aerial inductance $L1$. If the anode circuit of $L1$ $C1$ contained an ordinary sharply tuned circuit the valve capacities and other capacities would be sufficient to cause self oscillation. It is stated, however, that by making the damping of the anode circuit sufficiently high the tendency for oscillation can be avoided. It will further be seen that the sharpness of the tuning of the circuit $L2$ $C2$ will not cause the valve $V2$ to oscillate, or materially affect the other valves. This idea can be extended to any number of valves, arranging alternately sharply tune circuit and highly damped circuits.

A WAVE TRAP ARRANGEMENT.

(*Application date, 24th October, 1924. No. 244,227.*)

A rather peculiar wave trap arrangement is described in the above British Patent Specification by J. W. Combe. Apparently, the object of the invention is simply to tune out undesired stations, and the invention relates to an arrangement of an inductance and variable capacity combined as one unit which can be connected across the aerial and earth terminals of an ordinary receiving set. The specification states that if the receiver is tuned, for example, to London, and it is required to listen to Bournemouth, the device is connected in position, and by varying the condenser in the eliminating device Bournemouth can be tuned in without altering the tuning of the set for London. This seems, perhaps, a little peculiar. It appears that the device can be arranged simply as an ordinary series or parallel rejector or acceptor circuit. Referring to the illustration, it will be seen that the arrangement comprises a plug-in coil *L* and a variable condenser *C*. Two wander plugs *W* are also provided, which are adapted to be connected to a number of sockets *S*. Thus it will be seen

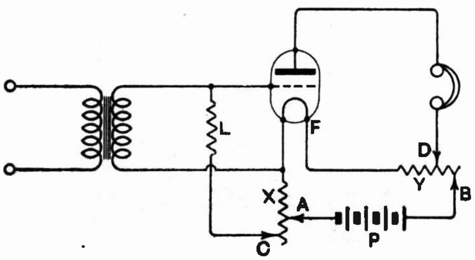


that the tuned circuit comprising *L* and *C* can be connected to the set in more than one position.

VALVE SUPPLY.

(*Convention date (Germany), 7th May*, 1924. *No.* 233,718.)

This invention is described in British Patent No. 233,718 by Die Radio-Rohren-Laboratorium Dr. Gerd Nickel G.M.B.H., and assigned to the Edison Swan Electric Company, Limited. The invention simply consists in supplying both the filament and the anode of a valve from the same source of power. Thus, in the accompanying illustration, it will be seen that a source of power *P*, which is shown as a battery, is connected through two resistances *X* and *Y*, which are in series with the filament *F*. Sliding contacts *A* and *B* work over the resistances so that the amount of current flowing through the filament will be determined

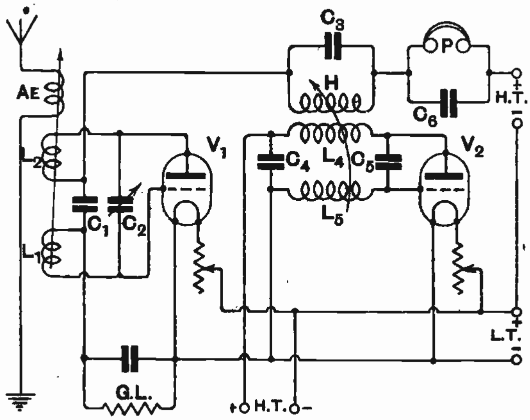


by the position of either or both of the contacts *A* and *B*. Additional contacts *C* and *D* are also provided, which work respectively over the resistances *X* and *Y*. Thus it will be seen that the potential of the anode will be determined by the position of the sliders *D* and *A*. Similarly, the grid potential is determined by the position of the sliders *C* and *A*. It is interesting to note that a grid-leak *L* is used to determine the grid potential, although the lower end of the transformer or other device to which the valve is connected is joined to the point *N*, that is, one side of the filament.

A QUENCHED RECEIVING SYSTEM.

(*Application date, 14th November*, 1924. *No.* 244,568.)

A form of super-regenerative receiver is described in the above British Patent Specification by C. Seymour, G. A. Irving, M.Sc., and J. C. W. Drabble. The accompanying illustration should make the circuit quite clear. It will be seen that the aerial circuit *AE* is shown coupled to the divided input circuit of a valve V_1. The input circuit of the valve comprises two inductances L_1 and L_2, tuned by a variable condenser C_2, a stopping condenser C_1 existing between them. The grid circuit contains a grid condenser and leak *GL*. The anode supply to the valve V_1 is through an inductance *H*, and telephone receivers *P*, shunted by a condenser C_6. Another valve V_2 is also shown, and is used for generating oscillations by virtue of the coupling between the anode



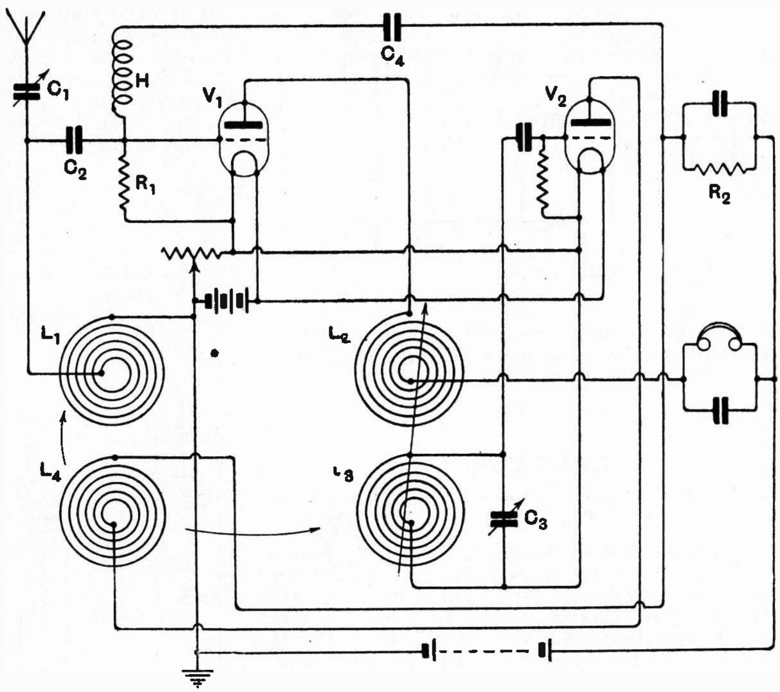
circuit and the grid circuit, comprising inductances L_4, L_5, and condensers C_4, C_5. The tuned circuit C_3H is tuned to the same frequency as that of the oscillations generated by the valve V_2, which comprises the source of quenching oscillations. Normally the valve V_1 is so adjusted with regard to grid potential and steady anode voltage from the normal anode supply that it will not quite oscillate. Thus it will be seen that by coupling the tuned circuit C_3H to the source of quenching oscillations sufficient voltage will be induced into that circuit and applied to the anode to cause the valve to oscillate for a certain period of one half-cycle of the quenching frequency. In this way a form of super-regenerative circuit is obtained which is exceedingly simple to handle, and in which the adjustments are far from critical. It is stated in the Specification that the anode circuit of the first valve can comprise a frame instead of a coupled aerial arrangement as shown.

CONTROLLING REGENERATION.

(*Application date*, 11*th September*, 1924. *No.* 244,169.)

A method of controlling regeneration, lying essentially in the respective dispositions of a number of tuning coils is described in the above British

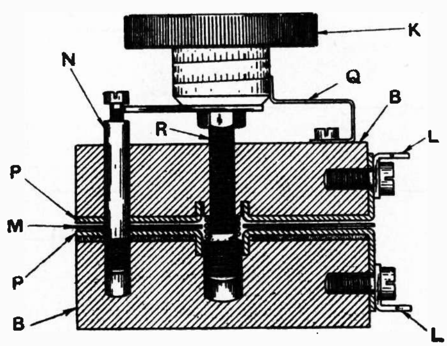
Patent, which is granted to N. P. H. Hinton, and Metropolitan-Vickers Electrical Company Limited. The invention will, perhaps, be better understood by reference to the accompanying illustration, which shows a two-valve receiver employing this method of regenerative control. It will be seen that the aerial circuit comprises a series condenser C_1 and an inductance L_1, which is connected between the grid and filament of the first valve through the medium of a small condenser C_2, a grid-leak R_1 being used to provide suitable grid bias. The anode circuit contains an inductance L_2, which is coupled to another inductance L_3, tuned by a variable condenser C_3, which comprises a tuned circuit tuned to the same frequency as the incoming signals. This tuned circuit L_3C_3 is connected between the grid and filament of the second valve V_2, which is provided with a grid condenser and leak, so that it acts as a rectifier. It will be noticed that the circuit is a dual or reflex arrangement, in which the first valve acts as a high or low frequency amplifier, and the second valve as a detector. The low frequency potentials produced in the anode circuit of the valve V_2 are transferred to the grid circuit of the second valve, by means of a resistance R_2, which is connected through a coupling condenser C_4 and a choke H. The anode circuit of the valve V_2 also contains a reaction coil L_4. The inductance L_2 and the inductance L_3 comprise a high-frequency transformer, and are arranged co-axially, one above the other. the distance between them preferably being fixed. The aerial inductance L_1 is placed some distance from the inductance L_2 and L_3, but on the same plane. The reaction coil L_4 is arranged so that it can be moved in a plane parallel with that in which the inductances L_1 and L_3 lie. The coils are so arranged in direction that by coupling the coil L_4 to the coil L_3 a regenerative effect is produced in that circuit, while movement in the opposite direction tends to oppose it. When the reaction coil L_4 is displaced from its mid position between the inductances L_1 and L_3, and moved towards the inductance L_1, reaction is introduced around both valves causing regeneration in their respective circuits.



A DIFFERENTIALLY-OPERATED CONDENSER.

(*Application date, 3rd July,* 1925. *No.* 244,009.)

A differentially-controlled condenser is described by B. Hesketh in the above British Patent. The condenser will be recognised as that which is incorporated in the McMichael supersonic unit. Referring to the accompanying illustration it will be seen that the condenser comprises two insulating blocks B of ebonite or similar material, to the inner faces of which are secured metal conducting plates P, forming the elements of the condenser.

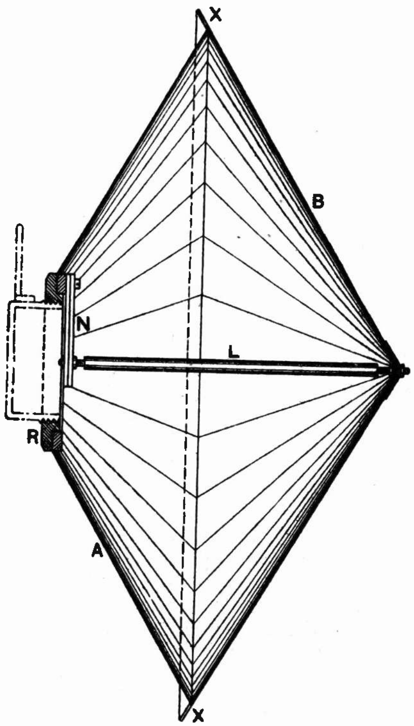


Between these is interposed a sheet of dielectric M of mica or similar material. The ends of the two plates are brought out and fixed to terminals provided with soldering lugs L. The two blocks are provided with threads of different pitch, a central rod R also provided with two differently pitched threads being placed between the two blocks. A locating pin N is screwed into the lower block, and is an easy fit in the hole H, through the upper block. The end of the rod R is provided with the usual knob K and suitable pointer. It will be seen that on rotating the knob K the rod will tend to rotate at different speeds in the two insulating blocks B, but since this cannot occur a differential action will be obtained, whereby the upper block will move towards the lower block. Thus it will be seen that the two elements constituting the condenser will be brought nearer together, thereby causing a variation in the capacity. The illustration shows that a form of micrometer head can be fixed to the knob K working against a pointer Q.

A DOUBLE CONE DIAPHRAGM.

(*Convention date* (*France*), *22nd September*, 1923. *No.* 239,245.)

P. G. H. d'Amour describes in the above British Patent Specification the construction of a double cone diaphragm. The accompanying illustration shows that the reproducing device, or diaphragm,

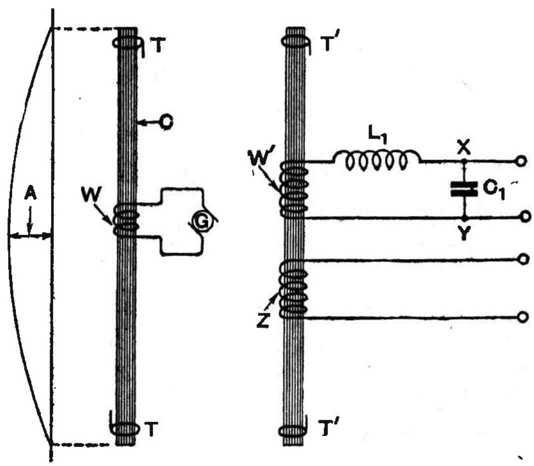


comprises two cones A and B, fixed together at their bases at X. The cone A is truncated and fixed to a ring R. The apex of the cone B is provided with a link L, the other end of which terminates in the region of the ring R, where it is connected to some actuating mechanism. This may either be an electro-magnetic device such as the diaphragm of an ordinary telephone receiver, or the link may be connected directly to a balanced armature. The specification also provides for operating the link purely mechanically. The specification is fairly detailed, and contains many modifications, not only of the cones themselves, but of the actuating mechanism. In the particular illustration shown the end of the link L is attached to two strips of preferably different material, as at N. Modifications of the cones include inverting the cone B so that it lies within the cone A, or truncating the cone B and refixing the truncated portion so that the apex points towards the apex of the cone A.

UTILISING THE MAGNETIC COMPONENT.

(*Convention date* (*France*), *6th June*, 1923. *No.* 217,245.)

A system of wave propagation and reception utilising the magnetic component of electro-magnetic waves described in the above British Patent by L. Levy. The accompanying diagram illustrates the broad idea of the system of transmission and reception. The aerial or radiator comprises a long body, of magnetic substance, preferably in the form of a cylinder C. Located about the middle of the magnetic body C is a winding W which is the seat of high-frequency currents, derived from a generator G. The aerial is composed of a number of strips, which are long in comparison with their width, and are arranged in a bundle, as indicated. The variation in longitudinal magnetic field at various points along the aerial is indicated on the left of the diagram. The actual propagation of waves takes place from W towards the two ends, and gives rise to stationary wave pehnomena by ordinary reflection at the ends, the antinode of the longitudinal magnetic field corresponding, of course, to the node of the transverse magnetic field. Movable short-circuited turns T are so arranged that they can be moved along the aerial so as to alter the position of the node, and hence alter the frequency at which the aerial oscillates.



A suitable reception aerial and its associated circuits is shown on the right of the illustration. Similar short-circuited turns T_1 are shown for the purpose of tuning, and a similar winding W_1 is arranged about the mid-point of the aerial, and energises the tuned circuit L_1C_1. It is stated that amplified potentials are set up across the points XY. The specification states that magnetic losses may be compensated by including a winding Z around the aerial, which may be energised from circuits which are the seat of amplified currents.

AN AUTOMATIC CALLING DEVICE.

(*Application date*, 31*st July*, 1924. *No.* 245,176.)

An automatic calling system is described by G. C. Beddington in British Patent No. 245,176. The method of calling exists in transmitting either simultaneously or consecutively signals of an appreciable length at predetermined frequencies. The receiving device is only rendered operative when both the signals are received simultaneously, or consecutively, as the case may be. The broad idea of the invention can be gathered by reference to the accompanying illustration. It will be seen that two tuned circuits L and L_1, presumably tuned by their self-capacity, are associated with suitable aerials for receiving the desired signals, or alternatively, the inductances L and L_1 may be suitable for passing on the effect of rectified or amplified high-frequency currents obtained from the aerial systems. It will be noticed that the inductances are connected between the filament and the grids of a double grid valve V. The anode circuit of the valve V contains a resistance R and a battery B_1, the negative side of which is connected to the grid of a three-electrode valve V_1, the anode circuit of which contains a relay K and the usual high tension battery. A small condenser C is also connected between the grid and filament of the three electrode valve. It will be further noticed that the grids of the double grid valve are negatively biased by means of the batteries B_2 and B_3, the bias being so arranged that the operation of the characteristic is substantially in the region of the origin. This means that substantially no current can flow in the anode circuit of the valve V. When signals are received by the coils L and L_1 the negative half cycles have no effect, but the valve will become partially conducting during the presence of positive half cycles. This means that the battery B_1 will cause the negative potentials to be transferred to the grid of the valve V_1, where it will accumulate, until the anode current of that valve has been reduced sufficiently to render the relay or calling device K operative. The presence of the condenser C, of course, tends to accumulate the charge and assist in the operation of the device. Another modification of the idea is shown in the lower half of the illustration. This scheme, of course, is intended to be used for a calling system in which the signals are sent consecutively. Here the coil L with its negative bias is connected to an ordinary three-electrode valve V, which in turn is connected through some form of resistance and battery to the grid of another three-electrode valve V_1. This in turn is connected to one of the grids of a double grid valve V_2. The other coil L_1 is connected between the filament and the other grid of the double grid valve. The anode circuit of the double grid valve is connected by a similar battery and resistance to the grid circuit of the lasr valve V_3, which again contains the calling device K. The method of operation should be obvious in the light of that described in connection with the first arrangement.