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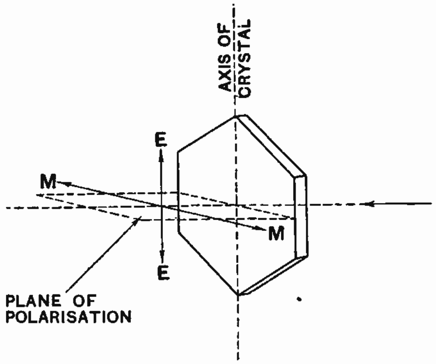
Editorial.

A Further Question of Nomenclature.
The Polarisation of Electromagnetic Waves.

When ordinary light passes through a slice of tourmaline cut in a plane parallel to the crystal axis, it is polarised, *i.e.*, the vibrations constituting the emerging light are all in the same direction, so that if another similar slice of the crystal is put in the path of the beam and turned so that the crystal axis is at right angles to the crystal axis in the first slice, no light can pass. This fact was known long before the electromagnetic nature of light was established, and the light after passing through the slice of tourmaline was simply said to be polarised. Light can be polarised in other ways than by passing it through tourmaline. To indicate the direction of the polarisation, the light was always said to be polarised in the plane at right angles to the axis of the tourmaline, but opinions differed as to whether the ether vibrations which constituted the light took place in this plane or at right angles to it.

MacCullagh maintained the former and Fresnel the latter view ; thus, according to MacCullagh, the vibrations were as shown by the horizontal arrows marked *M*, whereas according to Fresnel, they were represented by the vertical arrows marked *E*. When Clerk Maxwell propounded the electromagnetic theory of light it was seen that both schools had been right, since the beam of polarised light is merely an electromagnetic wave with the magnetic and electric fields at right angles. It was found that MacCullagh's vibrations in the so-called plane of polarisation were the magnetic vibrations, whilst those of Fresnel, normal to the plane, were the electric vibrations.



This convention as to the plane of polarisation is still maintained in optics and in the *Wireless World* of 17th March, p. 430, Mr. Williams, of King's College, takes Dr. Smith-Rose to task for using the opposite convention in speaking of wireless waves, to which the latter pleads guilty, but excuses himself on the ground that it is common practice among radio engineers to speak of the wave being polarised in the plane containing the electric vector. Wireless engineers refer to the radiation from a vertical aerial as being vertically polarised, whereas according to the classical optical convention it is polarised, at least, near the ground, in a horizontal plane. Dr. Smith-Rose suggests that the wireless practice is preferable to the older convention and suggests its adoption. The term polarisation as applied to light presupposes a vibration, and was originally used with reference to a supposed vibration of the ether; the choice of the conventional plane of polarisation was made in ignorance of the nature of the vibration and was not due to any preference for the magnetic as opposed to the electric oscillation, and one may perhaps claim that in the light of modern knowledge, the definition should come up for revision. In a view, however, of the old established usage in optics, a more practical suggestion is that radio engineers should always make their meaning quite clear, by introducing the word electric or magnetic. The radiation from a vertical aerial can hardly be said to have a vertically polarised electric field, since the electric field is only vertical near the earth's surface; nor can one speak of a vertical plane of polarisation since there are an infinite number all passing through the aerial. Near the ground one can say that the magnetic field is horizontally polarised, and can speak of a horizontal plane of polarisation, but at a height this is not so, since, although the magnetic field is horizontal, the direction of propagation is not horizontal, but along an inverted cone with the aerial at the apex.

Dr. Smith-Rose suggests that the classical usage should be modified and the plane of polarisation be referred to the electric vector because the electric force is more fundamental than the magnetic force, the latter being merely the result of the movement of the former. If one goes back as far as possible into the nature of things, there is the electron with its electric field, but no magnetic field unless the electron moves. Dr. Smith-Rose takes as his example, however, the case of an observer who, instead of remaining stationary, moves with the wave at the same velocity. To such an observer the magnetic force of the wave will not be perceptible; at least, so Dr. Smith-Rose assures us. If any reader finds the velocity of light rapid travelling for clear thinking, he may consider a bird flying across the ocean in the same direction and at the same speed as the waves. To a stationary observer the waves are due to a combination of displacement and velocity, the energy being partly potential due to the former, and partly kinetic due to the latter, just as the energy of the electromagnetic waves is partly electric and partly magnetic, but to the bird the waves are at rest and the whole ocean is covered with stationary corrugations representing a distribution of potential, but no kinetic energy. We must confess, however, that we do not like this argument; we feel somewhat sceptical about the evidence of an observer who admits that he was travelling with the velocity of light when he made the observations. If he knew anything about Maxwell's laws he would wonder how the unchanging electric field distribution about him was maintained, and why the line integral of electric force around a closed circuit was not zero, just as the bird might be troubled to account for the persistence of the stationary corrugations on the ocean. Far from concluding that there was no magnetic field, he might be led to the assumption of a steadily changing magnetic field as the only means of accounting for the electric field distribution round about him. If, however, he had heard of Lorentz and Einstein, he might have some very justifiable doubts about the applicability of Maxwell's laws to an observer travelling at the speed of light. Similarly, a closer examination of the state of the medium constituting the apparently stationary corrugations might cause the intelligent bird to have some doubts as to the absence of kinetic energy.

Although we are not impressed by the example chosen by Dr. Smith-Rose, we none the less agree that the electric field appears to be more fundamental than the magnetic field and that, if the discoverers of polarisation had known the nature of the beam of light, they might probably have chosen the plane of polarisation to coincide with the electric vector. As it is, however, we fear that the long established convention must remain and radio engineers must use a few more words to specify exactly what they mean when applying the term polarisation to electromagnetic waves.

Effective Resistance of Inductance Coils at Radio Frequency.—Part I.

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1. Introduction.

OUR main object in the following work is to develop formulæ suitable for the determination of the effective resistance of inductance coils at radio frequencies, and from these formulæ to obtain a scheme of design which aims at making the resistance as small as possible.

That there is need for such a scheme of design is clearly shown by quoting the constants of two coils, both constructed at the National Physical Laboratory, and both intended for use at a frequency of one million cycles per second. The first coil is one used in the Standard Harmonic Wavemeter[1] at the National Physical Laboratory, and is in the form of a flat spiral nearly 20 cms. in diameter, wound with copper strip. Its inductance is 45 microhenries and its resistance at a wavelength of 300 metres is 0.89 ohm, that is, 19.8 ohms per millihenry.

The second coil is that described by Mr. Wilmotte in the May number of *E.W. & W.E.* It is a square coil of side 7.5 cms. and winding length 4.5 cms. The wire used is No. 22 S.W.G. Its calculated inductance is 77 microhenries and its resistance at 300 metres is 1.58 ohms; that is, 20.5 ohms per millihenry. The point we wish to emphasise in regard to these two coils is that, although the former coil is much larger than the latter, and was decided upon after considerable experimental work, yet its efficiency as expressed in ohms per millihenry is practically the same as the much more modest coil of Mr. Wilmotte, which may be wound by any beginner at the cost of a few pence.

As regards the factors contributing to the high-frequency resistance of inductance coils, great stress has been laid recently upon the importance of dielectric losses. Now, although these losses may play a very important part in very large transmitting coils, or even in receiving coils when used at very short wave-lengths, it is easily possible, by taking very ordinary precautions, to reduce these losses to a small fraction of the whole in receiving coils intended for the broadcasting range of wavelengths. The present writer has wound coils with D.C.C. wire upon solid wooden formers, and on comparing the calculated copper resistance with the total measured resistance has found the ratio of copper to total loss to lie between 60 and 70 per cent. at a wavelength of 300 metres, while with coils for which the insulating material is carefully chosen the copper loss has been 80 to 90 per cent. of the whole. Clearly, therefore, any numerical scheme of design must aim at making the *copper* losses a minimum.

It will be shown that the copper losses in inductance coils in which the turns are well spaced divide themselves into two independent portions, one of which diminishes and the other increases as the diameter of the wire is increased. There is therefore a certain diameter of wire for which the two losses "balance"; that is, the rate of diminution with increase of diameter of the one loss is equal to the rate of increase of the other loss; so that at this diameter the losses are at a minimum.

The scheme of design, therefore, is to find for all reasonable shapes of coil the value of this best wire diameter and the corresponding loss. By comparing the minimum losses for each shape of coil we can then arrive at the best shape of coil to suit any prescribed conditions. Since the inductance required fixes the number of turns, it only remains to fix the mode of grouping of the turns in the winding section and the order in which the current shall pass through the turns.

The mode of grouping will only affect the copper losses slightly, and (except in so far as self-capacity modifies the effective resistance) the order of passage of the current through the turns has no influence upon the copper losses, so that these latter points

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[1] See the paper entitled "A Self-contained Standard Harmonic Wavemeter." Dye. *Phil. Trans., A,* Vol. 224, p. 259.

are determined by the mechanical means of winding and by the desirability of having low self-capacity. The correct mode of procedure will be illustrated by examples to be given later.

2. Copper Losses in Inductance Coils.—Preliminary Survey.

In Fig. 1 is drawn the section of a circular inductance coil of rectangular winding section, the turns being represented by small circles, each occupying its own small rectangular space. When current flows in the coil, a magnetic field is set up, the lines of force of which are approximately represented by the broken lines in the figure.

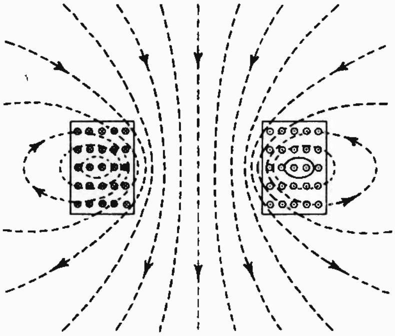

Fig. 1. *Cross section of circular inductance coil of rectangular winding section. The small circles represent the wires composing the turns of the coil and the broken lines are the magnetic lines of force produced by the current in the coil.*

When the current is alternating there are two distinct copper losses in the coil. The first loss occurs whether the current is alternating or not and, for well-spaced turns, is independent of the coiling. It is, in fact, merely the loss due to forcing the current against the resistance of the wire. This loss, however, depends upon the frequency of alternation of the current, increasing as the frequency increases. Since this loss is the same as when the wire is straight we may refer to it as the straight-wire loss, and denote the resistance representing it by R_s. For direct currents R_s, of course, reduces to the ordinary resistance R.

The second loss is due to the alternations of the general magnetic field of the coil. It is a fundamental principle of electro-magnetic induction that when the lines of force of a varying magnetic field thread through any conducting mass there is induced in that mass a circulating or eddy current. This eddy current requires energy for its maintenance, which must be supplied to the mass from the current producing the varying field, and thus the effective resistance of the coil carrying this current is increased. Applying this to the case of the inductance coil shown in Fig. 1, the variation of the general magnetic field of the coil induces eddy currents in each wire, and the energy required increases the effective resistance. Since the added resistance is due to the magnetic field of the coil we will denote it by R_h. We may look upon this resistance as being due to the presence of neighbouring wires, and from this point of view the added resistance is sometimes referred to as the "proximity" resistance.

It will readily be seen that the induced eddy currents do not alter the total current flowing over the whole cross-section of the wire, as they both go and return in the same section. They act rather in *distorting* the distribution of current throughout the section. It is well to consider this distortion more closely, as it will help us when we are dealing with the resistances in a quantitative manner.

The general principle governing the direction of induced currents is the well-known Law of Lenz, namely, that the induced effect always opposes the inducing cause. Since in the present case the inducing cause is the alternation of the magnetic field, the induced current will oppose the action most effectively if, by its own field, it annuls the magnetic field threading through the substance of the wire. The direction of the eddy current must therefore be such that the magnetic field it sets up opposes the inducing magnetic field inside the wire.

Thus, let the circle in Fig. 2 represent one of the right-hand upper wires of the coil of Fig. 1. At the moment when the current is flowing upwards from the paper the field within the wire and due to the current in the wire forms a series of circular counter-clockwise lines of force concentric with the circumference of the wire, while the general field due to the current in the remainder of the coil may be regarded as uniform over the section of the wire and directed up the page.

First, if the general field is absent, a radial wedge, such as *AO*, imagined cut in the wire, will have acting upon it a downward field. Therefore the eddy current in this wedge must produce an opposing upward field. To do this it must flow towards the observer at *A* and away from the observer at *O*. A similar eddy current is induced in every wedge such as *AO*, and it is immediately seen that the eddy current tends to weaken the main current in the central regions and to strengthen it in the outer regions of the wire. Thus the current tends to concentrate on the outer skin of the conductor, and as the virtual section of current flow is thus diminished the resistance of the wire is increased.

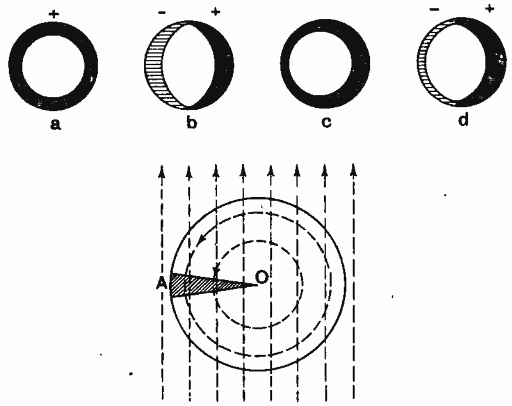

Fig. 2. *The full circle in the main figure represents a wire in the top right-hand half of the coil of Fig. 1. The broken circles in the main figure are the lines of force due to the current in this wire and the broken vertical lines are the lines of force due to the remaining wires.* AO *is a wedge imagined cut in the wire. The eddy currents induced in this wedge are considered in the text*: (a) *shows the current distribution in a solitary wire,* (b) *the current induced by a uniform field, and* (c) *and* (d) *the distorted distribution due to* (a) *and* (b) *combined,* (c) *holding when* (a) *predominates and* (d) *when* (b) *predominates.*

Next, if we suppose for the moment that the current in the wire is absent, the general field must produce an eddy current which by the Law of Lenz flows into the paper in the left half and out in the right half of the section of the wire. There are in this case two crescent-shaped sections of current, the left one negative and the right one positive. Superposing the main current, the distortion is seen to consist of a motion of the mean centre of the current in the wire towards the right and a general concentration of the current towards the surface. If the same reasoning be applied to every turn in the coil it is found that the current is, so to speak, trying to get to the nearest boundary of the winding section of the coil, the effort being more vigorous in the case of the inner turns because of the stronger general field there. The phenomenon is, in fact, an attempt to reproduce the "skin" effect for the whole winding section which has been seen to occur in the case of the individual wire.

We may also readily deduce that the two types of energy loss act independently, for while the main current, even when modified by the eddy currents due to the circular field has the same sign in both left and right halves of the wire section, the eddy current induced by the general field is of changed sign in the two halves. Thus if I_m and I_h be the two types of current in a filament of the wire in the right-hand half, the total current in this filament is $I_m + I_h$, while in a symmetrically disposed filament in the left half the total current is $I_m - I_h$. Now the energy loss is proportional to the square of the current, so that for the pair of filaments the energy loss is proportional to $(I_m + I_h)^2 + (I_m - I_h)^2$, that is to $I_m^2 + I_h^2$. Adding, for all filaments, the total energy loss is proportional to $\Sigma I_m^2 + \Sigma I_h^2$.

But this is the result we should have obtained if we had calculated each loss as if the other were absent and *then* added.

As the latter method will enormously simplify our problem it will be the one adopted in the following pages.

The problem of determining the copper resistance in inductance coils is thus capable of analysis into three portions, viz. :—

(*a*) The variation of resistance of a solitary wire with frequency.

(*b*) The energy losses in a wire when placed in an alternating magnetic field.

(*c*) The distribution of magnetic field throughout the winding section of various types of inductance coils.

These problems will be dealt with in turn in the following sections.

3. The Alternating Current Resistance of a Long Straight Wire.

Formulæ for the computation of the alternating current resistance of a long straight wire were supplied nearly forty years ago by Kelvin,[2] Rayleigh[3] and Heaviside.[4] The formulæ as given by them were not in such a form as to be easily used by the electrical engineer, so that, as the use of high frequency currents increased, various writers tried to simplify the mode of presentation. Tables of values of the alternating current resistance of wires of various diameters have been computed by Zenneck[5]; and Rosa and Grover[6] have given tables whereby the A.C. resistance may be found with great ease. The column headed $1+F$ in Table I. has been extracted from the latter set of Tables. Before giving the general solution we will consider the cases of low and high frequencies respectively.

3.1. *Case of Low Frequency.*

We have seen in Section 2 that the effect of the circular alternating field within the substance of a straight wire carrying alternating current is to produce an eddy current which flows in the same direction as the main current in the outer regions of the wire and returns *via* the central regions. The total energy loss in the wire is obtained by adding the energy loss due to this eddy current to the energy loss due to the main current. If the maximum value of the main current be I and the D.C. resistance be R the dissipation of power by the main current is

$$W_1 = \tfrac{1}{2} RI^2 \quad .. \quad .. \quad (1)$$

Now, as regards the eddy current, if E be the average value throughout the wire of the E.M.F. inducing this current and R' be the average value of the resistance of the eddy current path, the dissipation of power by the eddy current is

$$W_2 = \tfrac{1}{2}E^2/R' \quad .. \quad .. \quad (2)$$

as at low frequencies the inductance of the eddy current path may be neglected.

To estimate the value of E, let a be the radius of the wire and let the frequency be $\omega/2\pi$. The field intensity throughout the wedge AO varies uniformly from zero to $2I/a$ as we pass from O to A so that if the wire is of length l the total flux threading through the wedge is $la \times I/a = lI$, and the E.M.F. that acts on the filament of current path which bounds the wedge is ωlI. The mean E.M.F. must be less than this, so that as we are only seeking an approximate solution we will assume that the average E.M.F. is $\tfrac{1}{2}\omega lI$.

The resistance R' of the eddy current path may also be approximated to by imagining the wire to be divided into a central rod and outer tube each of the same resistance, viz., $2R$. If we suppose the eddy current to flow by the outer tube and return by the central rod the resistance R' is clearly $4R$ and then by (2) $W_2 = \omega^2 l^2 I^2/32R$.

It would be surprising if this were the correct result, as we have made two approximations. The equation is, however, correct in form and in actual fact will be correct in magnitude if we replace the number 32 by 24. Hence we write[7]

$$W_2 = \omega^2 l^2 I^2/24R \quad .. \quad (3)$$

Adding W_2 to W_1 the power loss is

$$W_s = W_1 + W_2 = \tfrac{1}{2}RI^2\left(1 + \frac{\omega^2 l^2}{12R^2}\right) .. \quad (4)$$

and therefore the A.C. resistance is

$$R_s = R\left(1 + \frac{\omega^2 l^2}{12R^2}\right) = R(1+F) \text{ say} \quad .. \quad (5)$$

3.2. Formula (4) will not carry us far up the scale of frequency, as when the term F is beginning to be appreciable the assumptions made in establishing (5) are no longer valid. The formula is, however, useful as it indicates the *form* which the final solution will take.

In regard to the correction F it is important to notice that it is a *pure number*,[8] as it has to be added to the pure number unity. It should also be noted that R in the expression for F must be in c.g.s. units. Since on this system of units an inductance is measured in centimetres, we may for the moment regard the length l as representing some inductance and then we see that F is of the nature of the square of the ratio of a reactance to a resistance, thus verifying its nature as a pure number.

Although the length of the wire appears

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[2] *Math. and Phys. Papers*, Vol. 3, 1889.

[3] *Phil. Mag.*, Vol. 21, 1886.

[4] *Electrical Papers*, Vol. 2, p. 64.

[5] Zenneck, *Wireless Telegraphy*, Table 7; Hoyle, *Standard Tables and Equations in Radio Telegraphy*, Table 18, p. 51.

[6] *Bulletin Bureau of Standards*, p. 226, 1912.

[7] All units are assumed to be electro-magnetic c.g.s. units and all alternating quantities are supposed represented by their maximum values.

[8] *I.e.*, *not* a length, a resistance, or any magnitude of that kind.—Ed.

in the expression for F, yet F is independent of this length, as R is also proportional to the length of the wire.

On expressing R in terms of the resistivity ρ and diameter d of the wire we get

$$F=\frac{\pi^2\omega^2 d^4}{192\rho^2}=\frac{z^4}{192} \text{ say} \quad .. \quad (6)$$

in which, for brevity, we have written

$$d\sqrt{\frac{\pi\omega}{\rho}}=\pi d\sqrt{\frac{2f}{\rho}}=z \quad .. \quad (7)$$

This form is chosen because when the simple form (6) no longer holds for F, F may still be expressed in simple series involving z and z only. To see that this is so we need only know that F always remains a pure number which depends only on d, f and ρ. Now, the only way in which we can associate d, f and ρ so as to yield a pure number is to combine expressions such as $A(d\sqrt{f/\rho})^n$ where A and n are mere numbers. As z is equal to $\pi d\sqrt{2f/\rho}$, we may therefore assert that F is a function of z and of z only.

This law is very important, as by its means we can, from measured values of the A.C. resistance of a particular wire at a series of frequencies, deduce the values of the A.C. resistances of wires of other diameters and of other materials. This is effected by plotting the ratio of A.C. resistance to D.C. resistance of the particular wire against the single variable z.

TABLE I.

Values of the Functions F and G.

d=diameter of wire (cm.) ; ρ=resistivity (c.g.s. units) ; f=frequency (cycles per sec.).

$z=\pi d\sqrt{2f/\rho}$. For copper of resistivity 1,700 c.g.s. units $d\sqrt{f}=9.28\ z$, or $z=0.1078\ d\sqrt{f}$.

z	$1+F$	G	z	$1+F$	G	z	$1+F$	G	z	$1+F$	G
0.0	1.000		2.5	1.175	0.2949	5.0	2.043	0.755	10.0	3.799	1.641
0.1	1.000		2.6	1.201	0.3184	5.2	2.114	0.790	11.0	4.151	1.818
0.2	1.000		2.7	1.228	0.3412	5.4	2.184	0.826	12.0	4.504	1.995
0.3	1.000	$z^4/64$	2.8	1.256	0.3632	5.6	2.254	0.861	13.0	4.856	2.171
0.4	1.000		2.9	1.286	0.3844	5.8	2.324	0.896	14.0	5.209	2.348
0.5	1.000	0.00097	3.0	1.318	0.4049	6.0	2.394	0.932	15.0	5.562	2.525
0.6	1.001	0.00202	3.1	1.351	0.4247	6.2	2.463	0.967	16.0	5.915	2.702
0.7	1.001	0.00373	3.2	1.385	0.4439	6.4	2.533	1.003	17.0	6.268	2.879
0.8	1.002	0.00632	3.3	1.420	0.4626	6.6	2.603	1.038	18.0	6.621	3.056
0.9	1.003	0.01006	3.4	1.456	0.4807	6.8	2.673	1.073	19.0	6.974	3.233
1.0	1.005	0.01519	3.5	1.492	0.4987	7.0	2.743	1.109	20.0	7.328	3.409
1.1	1.008	0.02196	3.6	1.529	0.5160	7.2	2.813	1.144	21.0	7.681	3.586
1.2	1.011	0.03059	3.7	1.566	0.5333	7.4	2.884	1.180	22.0	8.034	3.763
1.3	1.015	0.04127	3.8	1.603	0.5503	7.6	2.954	1.216	23.0	8.388	3.940
1.4	1.020	0.0541	3.9	1.640	0.5673	7.8	3.024	1.251	24.0	8.741	4.117
1.5	1.026	0.0691	4.0	1.678	0.5842	8.0	3.094	1.287	25.0	9.094	4.294
1.6	1.033	0.0863	4.1	1.715	0.601	8.2	3.165	1.322	30.0	10.86	5.177
1.7	1.042	0.1055	4.2	1.752	0.618	8.4	3.235	1.357	40.0	14.40	6.946
1.8	1.052	0.1265	4.3	1.789	0.635	8.6	3.306	1.393	50.0	17.93	8.713
1.9	1.064	0.1489	4.4	1.826	0.652	8.8	3.376	1.428	60.0	21.46	10.48
2.0	1.078	0.1724	4.5	1.863	0.669	9.0	3.446	1.464	70.0	25.00	12.25
2.1	1.094	0.1967	4.6	1.899	0.686	9.2	3.517	1.499	80.0	28.54	14.02
2.2	1.111	0.2214	4.7	1.935	0.703	9.4	3.587	1.534	90.0	32.07	15.78
2.3	1.131	0.2462	4.8	1.971	0.720	9.6	3.658	1.570	100.0	35.61	17.55
2.4	1.152	0.2708	4.9	2.007	0.738	9.8	3.728	1.605			
2.5	1.175	0.2949	5.0	2.043	0.755	10.0	3.799	1.641	Large	$(\sqrt{2}z+1)/4$	$(\sqrt{2}z-1)/8$

3.3. *Case of High Frequency.*

The form assumed by F at very high frequencies may be deduced from the knowledge that it is always a function of z and from the fact that the current is then concentrated upon the outer skin of the conductor. If the depth of penetration of the current is small compared with the diameter of the wire, this depth will be practically independent of the diameter of the wire. Under these circumstances the cross section of the path of the high frequency current is proportional to the circumference of the wire, that, is, to its diameter. Hence the high frequency resistance is proportional to $1/d$ or the ratio of the A.C. to D.C. resistance is proportional to d.

But the ratio is also a function of z, and by (7) these two properties can only be reconciled if the ratio is proportional to z. Thus we deduce that at high frequencies $1+F$ varies as the square root of the frequency and inversely as the square root of the resistivity. The numerical multiplier can only be found by recourse to mathematical analysis, and it is found that

$$1+F=\frac{\sqrt{2}}{4}\,z=0.354z \quad \ldots \quad (8)$$

We might go a step farther and assert that when z is not extremely large the above estimate is somewhat low, as the effect of the curvature of the wire must be to restrict the depth of penetration to some extent. In fact to a nearer approximation

$$1+F=\frac{(\sqrt{2}\,z+1)}{4} \quad \ldots \quad (9)$$

3.4 *Case of Moderate Frequencies.*

For intermediate frequencies the formulæ are complicated, and tables are necessary. The values of $1+F$ are given in Table I. It will be seen from the table that the simple formula (6) is good enough for most purposes up to $z=2$, and the simple formula (9) when z exceeds 5.

3.5. *Experimental Verification.*

An experimental verification of the law of increase of resistance of a straight wire with frequency has been made by Kennelly, Laws and Pierce.[9] These experimenters used a copper conductor 1.168 cms. diameter and a range of frequency from 60 to 5,000 cycles per second, so that the value of z ranges from zero to 9. Using a value of resistivity as deduced from the D.C. resistance, the following comparison Table holds.

Frequency		60	306	888	1600	2040	3065	3950	5000
R_s/R	Obsd.	1.005	1.108	1.560	2.045	2.27	2.71	3.03	3.37
	Calcd.	1.004	1.111	1.587	2.042	2.28	2.69	3.03	3.36

4. Eddy Current Losses in a Cylinder when Placed in a Uniform Alternating Magnetic Field.

The second type of copper loss in an inductance coil is that due to the general field of the coil. A glance at Fig. 1 shows that for coils in which the turns are well spaced this loss may be determined if we can obtain an expression for the loss in a wire when placed in a uniform alternating magnetic field the direction of which is perpendicular to the axis of the wire. For coils in which a wavy type of winding is employed the direction of the field is no longer at right angles to the axis of the wire. The loss in a cylinder inclined at any angle to a uniform field is capable of solution, but will not be dealt with here as there is no indication that a wavy winding possesses any electrical advantage over a straight winding.

Solutions of the problem of a cylinder in a transverse field which is alternating slowly have been given by many writers. We need only refer the reader to Howe[10] who gives the proof as a preliminary to a treatment of stranded conductors. At the other end of the scale of frequency the simplest form of solution of the problem met with by the writer is that due to Fortescue[11] A more general treatment covering the whole range of frequency and including

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[9] *Trans. Amer. I.E.E.*, Vol. 35, Part 2, 1953, 1915.

[10] *Proc. Roy. Soc., A*, Vol. 93, p. 468, 1917.

[11] *Journ. I.E.E.*, Vol. 61, p. 933, 1923.

the case where the field is not uniform over the section of the cylinder is to be found in a paper by the present writer.[12]

We will first establish the *form* of the expression for the eddy current loss and then deal in detail with the cases of low and of high frequency.

4.1. *Form of Equation for Eddy Current Losses.*

Let H be the strength of the field and let d be the diameter of the cylinder. Also let R be the D.C. resistance of the cylinder. The magnitude of the eddy current induced by the alternations of the field must be proportional to H, so that, since the energy loss is proportional to the square of the eddy current, it must be proportional to H^2. Now the "dimensions" of an energy loss are those of a resistance multiplied by the square of a current, while the "dimensions" of a field intensity are those of a current divided by a length (*e.g.*, the field intensity at distance r from a long straight wire carrying current I is $2I/r$). In order therefore to get the correct "dimensions" we multiply H^2 by d^2 to make it equivalent to the square of a current and then by R to make it equivalent to a rate of energy loss. The true energy loss must then be equal to Rd^2H^2 multiplied by some *numerical* quantity. The total energy loss in the wire is obviously proportional to its length, but this is provided for as the factor R is proportional to the length of the wire. Hence the numerical quantity sought must be independent of the length and can only depend upon the frequency f, the resistivity ρ and the diameter d of the cylinder. But the problem of determining the most general *numerical* quantity which depends only on the above physical quantities has already been dealt with in Section 3, and we conclude that the required numerical quantity is some function of the variable z defined in equation (7). We therefore write for the rate of energy loss due to the transverse field H,

$$W_h = Rd^2H^2G/8 \qquad \text{.. (10)}$$

where G is a function of z and the divisor 8 is merely introduced to simplify certain later equations.

4.2. *Value of G for Low Frequencies.*

If the frequency is low the magnitudes of the eddy currents are small and we may neglect the field they set up in comparison with the inducing field. This amounts to neglecting the inductance of the eddy current paths, so that the magnitude of the eddy currents may be determined using Ohm's Law.

We first determine the eddy current losses in a thin strip placed athwart the field H and then by supposing the cylinder to be built up of such strips determine by addition the eddy losses in the whole cylinder.

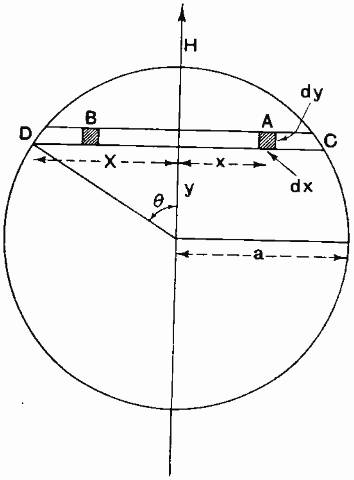

Fig. 3. *The circle represents the cross section of a cylinder of radius* a, *length* l *and resistivity* ρ. *A uniform magnetic field* H *alternating with frequency* $\omega/2\pi$ *is acting parallel to the arrow. Currents are induced in the cylinder which flow out on the right and in on the left.* A, B, *are the sections of path of one of these currents. The E.M.F.* e *producing this current is* $2\omega Hlx$ *and the resistance* r *of the current path is* $2\rho l/dx.dy$. *Hence the power loss in the path* A B *is* $e^2/2r = \omega^2 H^2 l x^2 dx.dy/\rho$. *The power loss in the whole cylinder is got by integrating with respect to* x *from* 0 *to* X, *thus obtaining the power loss in the strip* C D, *and then with respect to* y *from* $-a$ *to* $+a$. *The latter integration is effected by making the substitutions* $X = a \sin\theta$, $y = a\cos\theta$ *and then integrating with respect to* θ *from* 0 *to* π. *The result is*

$$W_h = \pi\omega^2 H^2 l a^4/8\rho.$$

Referring to Fig. 3 with its explanatory text we see that for low frequencies

$$W_h = \pi\omega^2H^2la^4/8\rho = \pi\omega^2H^2ld^4/128\rho \qquad \text{.. (11)}$$

But $\qquad Rd^2H^2/8 = \rho lH^2/2\pi,$

so that by (10)

$$G = \pi^2\omega^2d^4/64\rho^2 = z^4/64 \qquad \text{.. (12)}$$

This simple form will hold for values of z up to about unity.

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[12] *Phil. Trans, A*, Vol. 222, p. 57, 1921.

The equation is more useful than the corresponding one for F, as many cases arise in which, because of the large value of H, the eddy losses are of importance even when G is small. From equation (11) we see that the eddy losses vary directly as the fourth power of the diameter and inversely as the resistivity. As regards the change with diameter the loss is varying in an opposite way to the loss due to a current flowing in the wire. It thus appears that in an inductance coil any attempt to reduce the copper losses by employing wire of the maximum possible diameter may be defeated by the very large loss due to the general field.

As regards the change with resistivity, it is seen that if it is necessary to use metal rods in the neighbourhood of an inductance coil these rods should preferably be of *high* resistivity when the frequency is low. The term "low" frequency requires careful definition. The relevant quantity is the factor z, which involves the wire diameter and its resistivity as well as the frequency. When the term "low" frequency is employed with reference to wires or cylinders it will be taken to mean that z is less than unity.

4.3. *Value of G for High Frequencies.*

The form of G at extremely high frequencies may be deduced from the principle that if the eddy currents are sufficiently powerful they will practically annul the field within the substance of the wire. In the extreme case the distribution of the eddy current is as shown in Fig. 2(*b*) with the two crescent-shaped sections of current path concentrated closely upon the outer surface of the wire. The combined effect of the inducing field and that produced by the eddy currents is that the lines of force curve round instead of passing through the cylinder. In fact, the distribution of the lines of force at extreme frequencies are exactly analogous to the lines of flow of an ideal fluid past a cylindrical obstacle, and mathematically the problem may be dealt with by an analogous system of equations. It is important to notice that this distortion of the field increases the field intensity along the diameter of cross section which is perpendicular to the field and weakens it in directions parallel to the field. These facts will be made use of later in connection with single layer coils.

The depth of penetration of the eddy currents is practically independent of the diameter of the wire, but the dimension of the crescent-shaped path parallel to the direction of the field is equal to the diameter. Hence the cross section of the path is proportional to the diameter. Now the energy dissipated by the eddy current is inversely proportional to the resistance of its path, so that it is proportional to the cross section of the path or to the diameter of the wire. Since in (10) Rd^2 is independent of the diameter it follows that G is proportional to the diameter of the wire. This can only be so if G is merely a multiple of z. The complete theory shows that

$$G = \sqrt{2}z/8 \quad \ldots \quad \ldots \quad (13)$$

For finite values of Z this is only an approximation, being the first term of a series. If we include the next term we have

$$G = (\sqrt{2}z - 1)/8 \quad \ldots \quad (14)$$

This formula is a good approximation for values of z greater than 5.

From (13) we see that the eddy losses still increase with diameter of wire but the rate of increase is not so rapid as at low frequencies, being proportional to the first instead of the fourth power of the diameter.

From (10) and (13) we see that the eddy loss varies directly as the square root of the resistivity, so that at *high* frequencies improvement is obtained as regards losses in neighbouring metal rods by reducing the resistivity. This is opposite to the law at low frequencies. Therefore as the resistivity is increased there is for any particular rod a resistivity giving maximum eddy losses and any departure from this resistivity will reduce the losses.

When the value of z is such that neither of the simple formulæ (12) or (14) hold, a much more complicated mathematical analysis is necessary, and the values of G given in Table I. must be used.

(*To be continued.*)

The Mystery of Fading.

Some Notes of Observations taken on Broadcast Stations.

By Oliver Hall, D.Sc. **[R113.1.009**

EVERY possessor of a wireless receiving set who has made a practice of receiving telephony from a distant broadcasting station is familiar with the perplexing phenomenon of "fading." Yet of the very large number of such possessors of wireless sets, only a small percentage is sufficiently interested in the phenomenon to take careful observations when fading is noticeable during the reception of a distant station.

Now it is highly probable that a satisfactory explanation of fading will only be forthcoming after a very large number of observations has been collected and examined. Hence it is that fading constitutes a most promising field of investigation for the wireless experimenter who is interested in the problems connected with the travel of wireless waves through the ether.

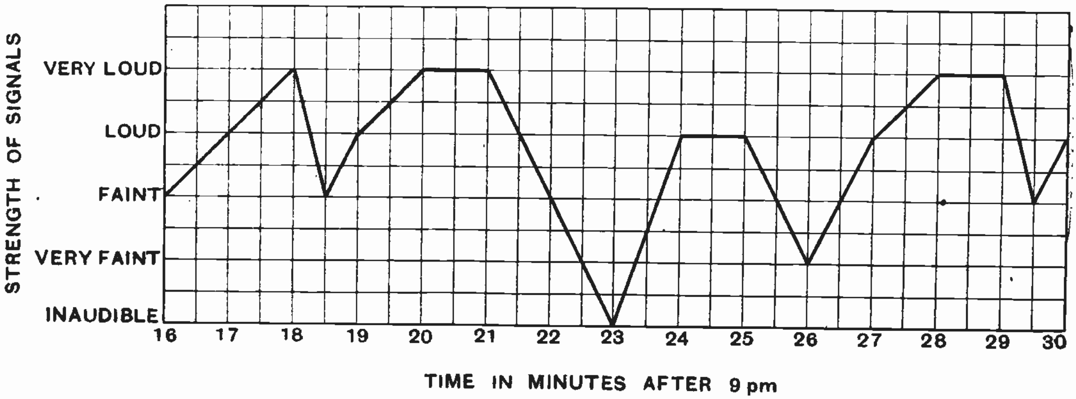


Fig. 1.

According to some careful observers, fading occurs at regular intervals. One such observer has placed on record the following curious case: An item, which was being simultaneously broadcast, was first received from London and this station was found to be fading regularly at intervals of three minutes. The same musical item was next received from Cardiff and, from the Welsh station, fading was found to be occurring every five minutes. The receiver was then set to a position intermediate to Cardiff and London on the tuning condenser and, although the fading was less distinct, it was found to be occurring at intervals of fifteen minutes.

It is unusual however, for fading to take place as regularly as this. In fact, such regularity is scarcely in keeping with the generally accepted explanation that fading is caused by the absorption and reflection of the waves by *irregular* masses of ionised gases in the upper atmosphere, or by conducting layers, the effects of which vary considerably with the constantly changing atmospheric conditions.

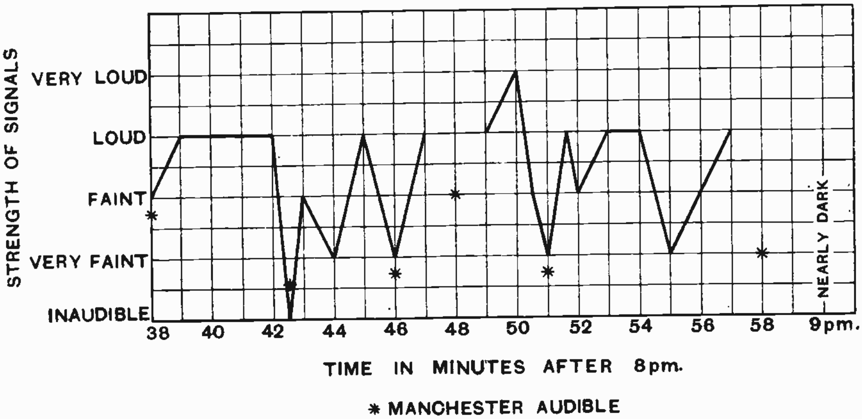
The object of the present article though, is not to discuss fading from a theoretical standpoint, but rather to describe certain observations recently made by the writer and to suggest the carrying out of similar observations by others interested in the phenomenon of fading.

Since the advent of the warmer weather and the longer days, there has been a very noticeable increase in the fading of the Bournemouth broadcasting station as received by the writer at a receiving station situated one hundred and seventy miles north of Bournemouth.

In order to get a thorough understanding as to what was happening, observations were made of this Bournemouth fading on three successive nights. The entries made in the observation book for the first of these three nights were summarised in the curve reproduced in Fig. 1.

The receiver used in making these and subsequent observations was a three-valve receiver, a detector valve followed by two low-frequency amplifying valves. A loudspeaker was used and this was placed at a distance of twelve feet from the observer. Keeping a careful watch on the movements of the seconds hand on a small wrist watch, an estimation of signal strength was made at the end of each minute and also at the half-minute when necessary. The observations were made aurally according to the scale given on the left of Fig. 1. It is scarcely necessary to say that aural observations of this kind cannot be compared with instrumental observations, but, where instrumental observations are not possible, aural observations of signal strength are not to be despised.

The first important point to notice with regard to the curve in Fig. 1 is that the times 9.18½, 9.23, 9.26, and 9.29½, when signal strength was at a minimum, are separated by time intervals of 4½, 3 and 3½ minutes. This irregularity in the intervals of time between successive fadings was noticeable in all subsequent observations.



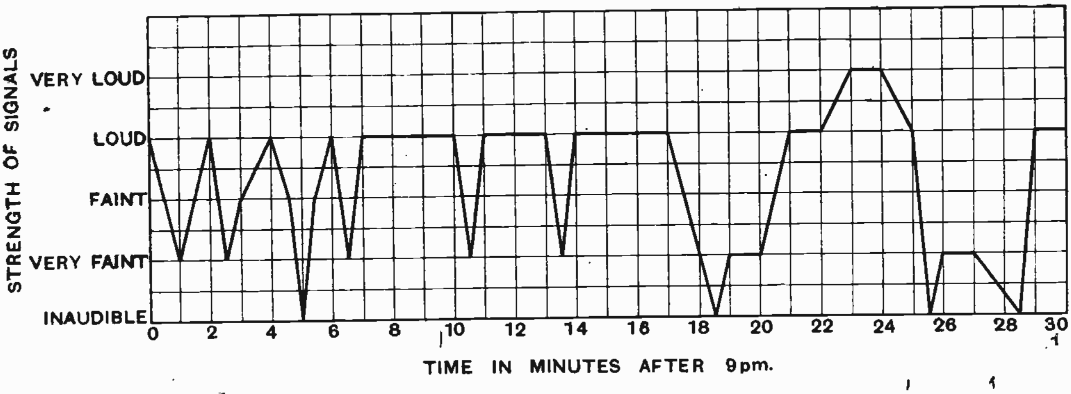


Fig. 2.

A second important point which may be noticed with regard to the observations illustrated in Fig. 1 is that the duration of minimum signal strength is much shorter than the duration of maximum signal strength.

The next set of observations refers to the night following that on which the first set of observations was taken. The observations on this second occasion were taken before and after dark.

For the first twenty minutes of this second set of observations, a note was made when Manchester was audible in the loud-speaker. As already stated, Bournemouth is one hundred and seventy miles to the south of the writer's receiving station. Manchester is forty miles to the north-west. The times at which Bournemouth was so faint as to allow Manchester to become audible are indicated by an asterisk in Fig. 2, the figure in which the second set of observations is illustrated in the form of a diagram.

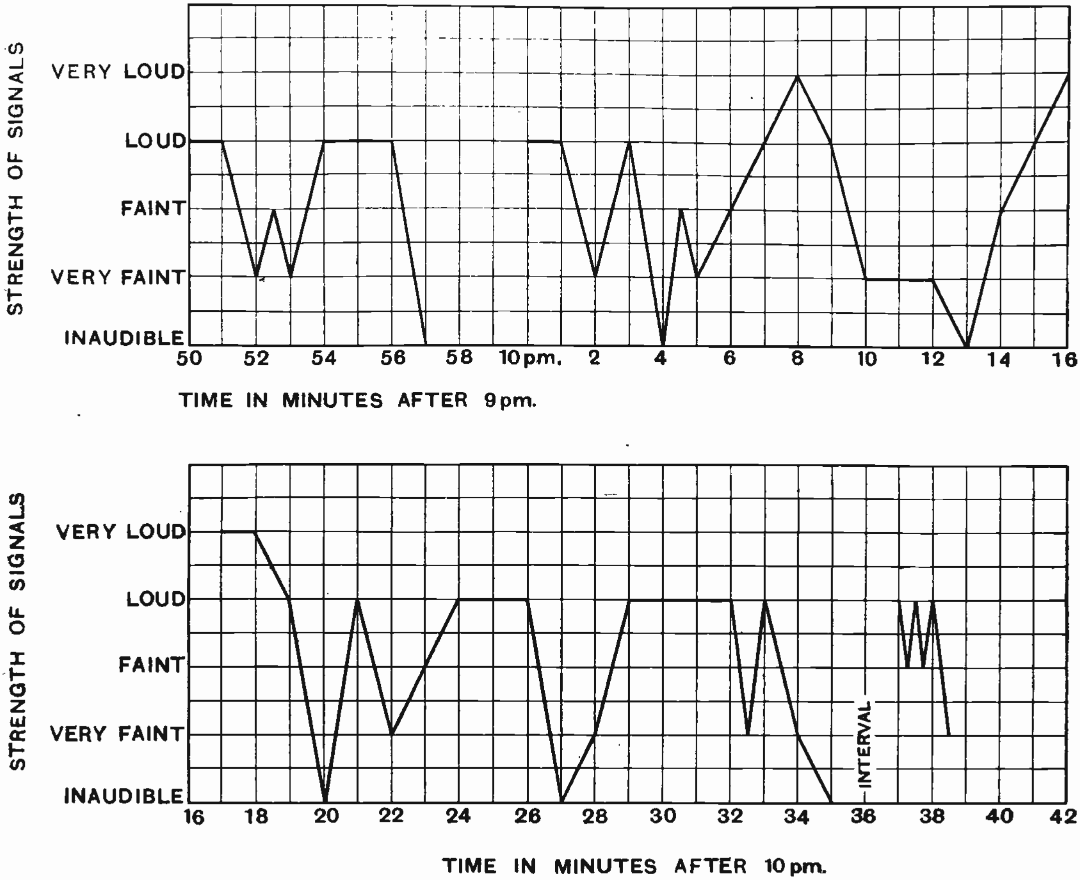


Fig. 3.

In the second set of observations, the times of minimum signal strength were: $8.42\frac{1}{2}$, 8.44, 8.46, ? , 8.51, 8.52, 8.55, ? , 9.01, $9.02\frac{1}{2}$, 9.05, $9.06\frac{1}{2}$, $9.10\frac{1}{2}$, $9.13\frac{1}{2}$, $9.18\frac{1}{2}$, ? , $9.25\frac{1}{2}$, $9.28\frac{1}{2}$, the question mark indicating that one period of fading may have been missed owing to an interval in the Bournemouth programme or owing to interference.

Taking the time interval between well-marked successive occasions of fading, we get the following time intervals in minutes: $1\frac{1}{2}$, 2, 1, 3, $1\frac{1}{2}$, $2\frac{1}{2}$, $1\frac{1}{2}$, 4, 3, 5, 3. The only real feature of these time intervals is their irregularity.

Practically every case of fading in this second set of observations took place quite suddenly. The return to better signal strength was also rapid in most cases.

The third set of observations, taken on the third of the three successive nights, are illustrated in Fig. 3. In this set of observations, the time intervals in minutes between successive occasions were: 1, 4, 2, 1, 5, 3, 1, 6, 2, 5, $5\frac{1}{2}$, $1\frac{1}{2}$, 1, a few seconds, $1\frac{1}{2}$.

Irregularity is again the chief feature of the observations. The comparatively long periods of strong signals are also noticeable.

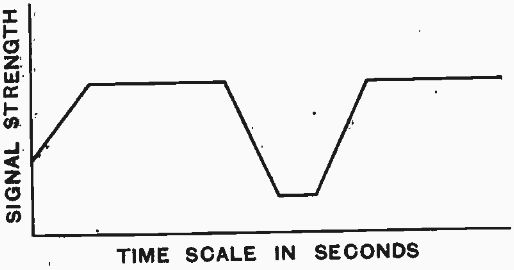


Fig. 4.

The three sets of observations now described were taken on three successive nights when conditions were presumably normal. If there is one thing above all others these observations show, it is that fading takes place in a most irregular manner. Probably the best way of representing such observations in a general sort of way, is by means of a diagram similar to that shown in Fig. 4, *i.e.*, loud signals followed by quick fading, with a short period of minimum signal strength and a rapid recovery to loud signals again.

In conclusion, the writer would like to emphasise the fact that fading is an irregular phenomenon, and that the worst thing an investigator can do is to start off with the preconceived notion that fading is connected with some definite numerical quantity such as wavelength or transmitting power.

Among the Experimental Transmitters.

THE Technische Hoogeschool, Kanaalweg, 2b Delft, Holland, operates under the call-sign NPA9. The laboratory contains various transmitters working on different wavelengths and these are distinguished by different suffixes, *e.g.*, PA9a, PA9b, etc. Reports and correspondence will be welcomed and should be addressed to the Radio Laboratory at the above address.

Mr. E. J. Simmonds (G2OD), Gerrards Cross, has been carrying out tests on a 23-metre wavelength with Egypt and succeeded in establishing communication by telephony with an experimenter in that country on 15th and 16th February with an input of only 4 to 5 watts. He sent, by speech, a difficult combination of figures, input powers, etc., all of which were perfectly received by the Egyptian operator and repeated back on telegraphy. Mr. Simmonds was using an Osram T250 transmitting valve and the total absence of distortion was specially remarked on. The strength of his signals was given as R9. Mr. Simmonds believes that this is the first time a 23-metre wavelength has been used successfully for long-distance telephony on such input and the results are the more surprising because, during the same period, his 45-metre set with an input of over 100 watts failed to convey intelligible speech to the same station.

Mr. C. H. Targett (G6PG), 21, High Street, Dartford, who has been experimenting with an underground aerial, was in communication, on 22nd February, with P3GB, G. de Bianchi, at Funchal, Madeira. He was transmitting on a wavelength of 44.8 metres with an input of 8 watts, using 230 volts H.T. from D.C. mains, M.O. DE5 valve and a Hartley circuit. The aerial is 70 ft. long, of which 50 ft. is buried to a depth of from 18 to 24 in. Signals were reported R5 on o.v.1. receiver.

Capt. Duncan Sinclair (G2OC) "Morven," Shepperton-on-Thames, continues working on 23 metres but is unable to obtain many answers. Some excellent tests have been conducted with various European stations but, though several American stations have been heard at good strength on about 30 metres, no long-distance reports have yet been received. G2OC is very anxious, for special reasons, to work with America, Canada, and South Africa. Regular tests are made every Sunday at 10.00-10.30 G.M.T. with N PC2 and, during the afternoon, from 14.00 G.M.T. onwards. Reports will be very welcome.

Amateur transmitters in Madeira have adopted the International prefix "P" on account of the geographical position of the island in relation to Portugal. Their call-signs will begin with the figure "3" to distinguish them from those in Lisbon which have "1" as their first component. It is understood that Portugal and Madeira will adopt the system, already in use in America, Australia, New Zealand and other countries, of indicating the district in which the station is located by the initial figure or letter of the call-sign.

We understand from Mr. C. A. Jamblin (G6BT), the Hon. Organiser of the Transmitter and Relay section, that the Radio Society of Great Britain has received several hundred QSL cards from abroad for British amateurs which, so far, have not been claimed. Transmitters who are expecting such cards are asked to forward stamped and addressed envelopes to Mr. C. A. Jamblin, 82, York Road, Bury St. Edmunds, Suffolk, who will forward any cards that may be awaiting them or, if there are none, will file the envelope for future use. Envelopes should not be smaller than 6 in. by 4½ in., preferably of the thin foreign variety, and should have the addressees call-sign clearly marked on the left-hand top corner.

The Lorenz High-Frequency System for Radio Transmission.

By F. W. Gillard, A.M.I.C.E.

[R421

THE possibility of generating radio frequency currents by means of alternators has intrigued many talented engineers, and while the design and operation of alternator systems has hitherto been extremely difficult, it may be that this very difficulty has been the cause of some of the attempts.

The three best known alternator systems are :—

(1) *The Goldschmidt,* an alternator-transformer.—The machine generates a medium frequency, while windings on both stator and rotor multiply this up to the required radio frequency. It will be seen that high voltages and losses are concentrated in the machine itself. Efficiency of Goldschmidt machine at Tuckerton 54 per cent. measured on motor input to antenna* kW.

(2) *The Alexanderson.*—This is a true radio-frequency alternator, generating in its own windings the output at the frequency desired. It, of course, has many of its losses, etc., concentrated in the machine itself. The 200kW. set described† is driven by a 600 h.p. induction motor, giving (apparently) an efficiency of 44.7 per cent.

(3) *The Telefunken.*—This is a system of an alternator of moderate frequency, from 5,000 to 8,000 cycles, with frequency doublers and triplers in cascade sufficient to attain the frequency required.

The efficiency of Nauen‡ at 12,600 metres, measured from motor terminals to antenna kW. = 66 per cent. at full load of 620 kW. motor input. At λ = 6,300 metres, 53 per cent.

As is well-known, many different schemes of frequency doubling and tripling have been devised and perfected. The main interest in the invention under notice is that in a single transformer and without exciting coils for D.C. current, it is possible to achieve radio frequency output at one step. With this brief introduction we propose to describe in moderate detail a complete installation, consisting of an alternator of moderate frequency (5,000 to 8,000) and its frequency changer and circuits, the work of Dr. Karl Schmidt, of the Lorenz Co.

The Alternator.

The machine is of the inductor type and of constant reluctance. Figs. 1 and 2 are respectively a part end elevation and part cross section of rotor and stator. On the shaft *A* is mounted a cast-steel rotor *B*, having slots and teeth *C*. The stator frame

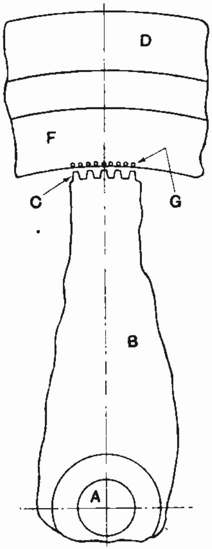


Fig. 1.

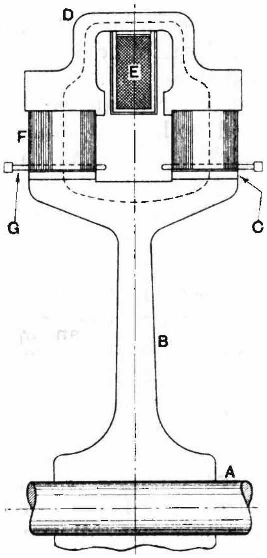


Fig. 2.

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* Eccles, *Handbook of Wireless Telegraphy.*

† Bucher, *General Electric Review,* Oct., 1920.

‡ Ing. Felix Linke, *Zeit. des Vereinse D.E.,* 20th Nov., 1920.

D is also of cast steel, cored out to the shape shown to accommodate the field winding *E*. The portion of the stator in magnetic proximity to the rotor is provided with laminations *F*, which support the A.C. windings *G* laid zigzag as shown. The two sections of the stator are wired separately and may be connected in series or parallel. Also if the two halves of stator and rotor are arranged separately, the output from each half can be utilised at separate radio frequencies for separate transmission.

The machine generates a medium frequency, 5,000 to 8,000 cycles per second, at speeds up to 3,000 r.p.m., at a low-tension. The usual figure is 500V with the midpoint earthed. The insulation is therefore not difficult.

The field coil *E* is wound and mounted in the stator circumferentially as shown. This gives a magnetic circuit as shown by the dotted lines. The reluctance of the magnetic circuit is constant, but as the teeth of the rotor pass the corresponding conductors of the armature, local variations of flux take place, so generating an alternating E.M.F. The iron losses through eddy currents and hysteresis are obviously very small. The rotating parts are therefore seen to be without windings and of robust construction. The circumferential speed never exceeds 115 metres per second, a value of known safety.

Adequate cooling can be provided by air, water or oil. The grooves between the rotor teeth are also arranged to cool the field coil, as a fan. The efficiency of this machine may be taken as comparable to an ordinary 50 cycle alternator in powers of 50kW. and upwards, while its development for small powers of ½kW., etc., is remarkable.*

The motor for driving the alternator is usually an ordinary high speed compound wound interpolar machine. It is preferably slightly under-compounded, so that speed may fall *slightly* with load. Referring now to Fig. 9, the field winding *SC* is in series with two rheostats R_1 and R_2. Of these, one, R_2, is arranged as a speed control rheostat. This speed control gear forms the last item of the motor alternator unit, and is shown in Fig. 3. It consists of a hollow disc *A* keyed on to the shaft of the alternator. This disc carries two fixed contacts *B*, four clips *C*, and two springs *D*, each carrying another contact *E*. On the shaft are two insulated slip rings *F*, each connected to one of a pair of contacts, the other pair being spare and of great use to ensure balance. Each fixed contact *B* is adjustable in its clip by a threaded portion. The action is as follows: With the set running at speed the spring moves out by centrifugal force. When the spring is at the topmost position of its travel, the centrifugal force is lessened by the amount due to the mass of the contact and a portion of the spring. At the bottom position, the two forces are additive. Therefore between two speeds, the first at which contact of the contacts just begins and the second at which contact becomes continuous, the contacts touch for a greater or less portion of the time of each revolution. These two speeds can be adjusted by varying the position of contact *B* in relation to contact *E*. When the contacts *B* and *E* are closed they operate a small relay which in turn shorts the rheostat R_2 and so increases the field of the motor. The correct adjustment of R_1 and R_2 contacts *B* and *E* will hold the speed constant with key up and down to 1/100 per cent.

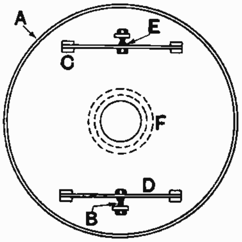

Fig. 3.

In the case of large units, the relay is used to control small auxiliary machines, which in turn act on the driving motor.

The Frequency Changer.

This may be aptly termed the "soul of the system." It has long been known that an alternating current of frequency *n* could be transformed to a frequency of *2n* or *3n* with good efficiency and wave form by means of static frequency multipliers. But

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* G. W. O. Howe, *Electrician*, 8th May, 1925.

doubling or tripling is the limit* of this type of apparatus in a single step. But the frequency can be raised any odd number of times by the Lorenz method up to a limit where the efficiency becomes too low for practical results.

Fig. 4 shows a section of one type of this transformer, in which *AA'* are soft iron cores, consisting of very fine soft iron wire enamel insulated, and wound on circular bobbins of insulating material *D*; *B*, and *C*, H.F. windings of stranded and insulated wire wound in toroid form over the iron, well spaced and insulated from the iron. The two windings are connected in series. The whole transformer, core, windings and insulation is immersed in oil in an iron tank, with suitable terminals for the ends of the windings and sundry taps.

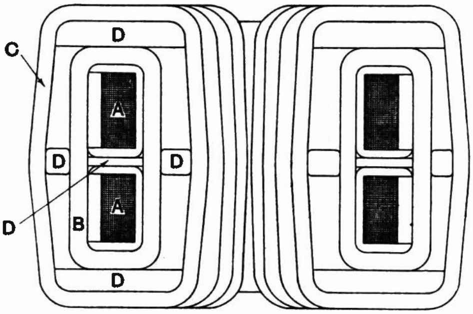

Fig. 4.

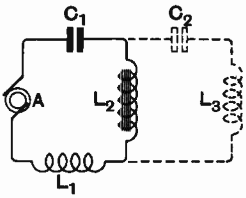

Fig. 5.

Fig. 5 shows a skeleton circuit for purposes of explaining the action of this transformer. If an alternator *A* be connected as shown to an inductance L_1, a condenser C_1 and an iron-cored choke coil L_2 and the values of these inductances and condenser be adjusted to give the circuit resonance with the alternator, a heavy current will flow in AL_1, L_2, C_1. Now suppose that the iron-cored choke L_2 has a magnetic circuit that is easily saturated by the current in AL_1, L_2, C_1 at resonance. We shall then have a set of conditions as shown in Fig. 6 where *I* is the curve of current in the circuit, shown here as a sine wave. *B*, the curve of state of magnetism of iron core, while *E*, Fig. 7, denotes an induced E.M.F. across the coil at each reversal of magnetism *B*. This induced E.M.F. is seen to be in alternate directions and of decided peak form shown in Fig. 7. The impedance of the iron-core coil L_2 is of course negligible when saturated.

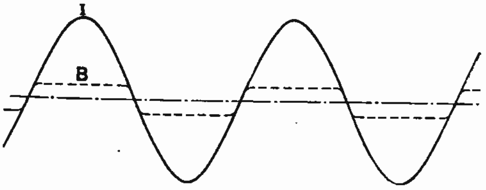

Fig. 6.

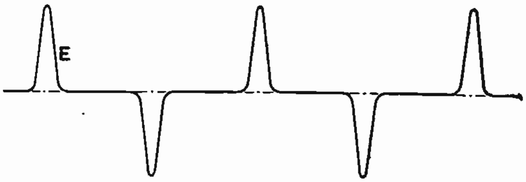

Fig. 7.

Suppose now we connect across L_2 another circuit C_2L_3 and tune this to an odd multiple of the alternator frequency. We shall then have in $L_2C_2L_3$ a series of very slightly damped high frequency currents as shown in Fig. 8. It is thus seen that this amounts to shock excitation of the secondary circuit and is entirely independent of any harmonics the machine may have or may not have.

The efficiency of this transformer may reach 95 per cent. It is of course less when very short waves are required from the secondary. But it should be observed that its losses are almost entirely iron losses.

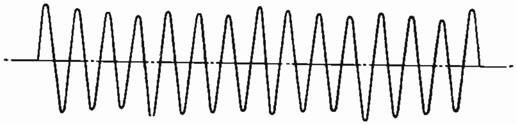

Fig. 8.

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* Eccles, *Handbook of Wireless Telegraphy and Telephony*, gives several methods.

We can now pass to the diagram of a complete transmitting plant as shown in Fig. 9.

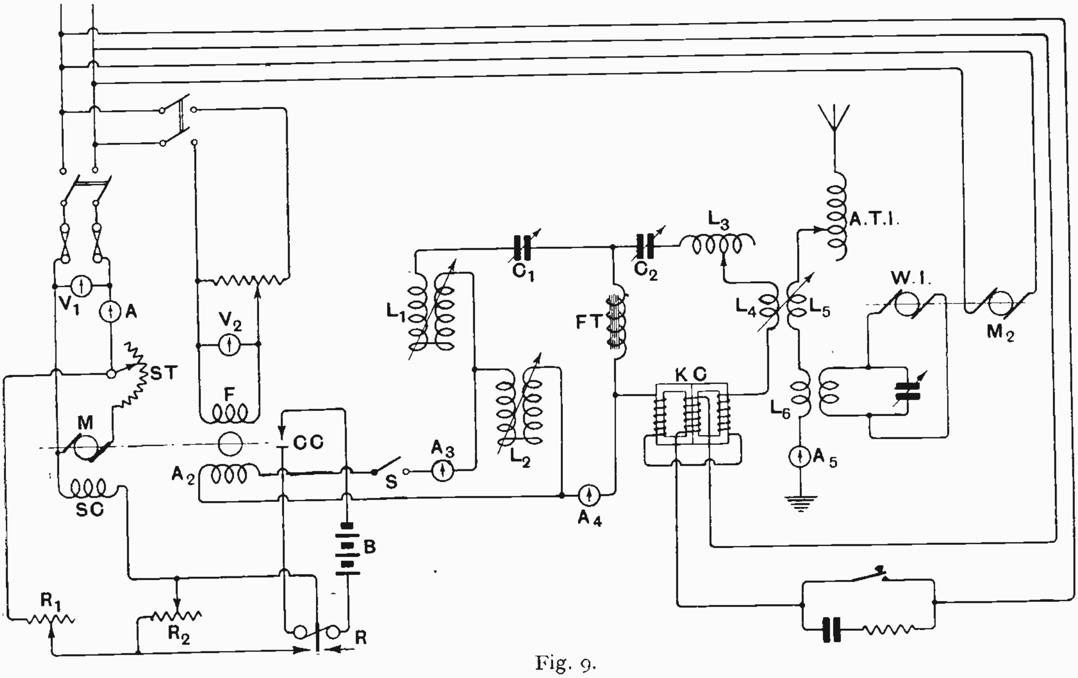

Fig. 9.

M is the motor, complete with D.P. switches, circuit breakers and fuses, ammeter *A*, voltmeter V_1, starter *ST*, shunt field coils *SC*, and field rheostats R_1 and R_2. The contacts *CC* are the speed control contacts on the alternator shaft, fed from the local battery *B*. These contacts and battery operate the relay *R* which in turn short circuits the rheostat R_2.

A_2 is the alternator armature, *F* its field coil, with a voltmeter V_2 across it. The alternator circuit consists of A_2, the armature, a single pole switch *S*, ammeter A_3, variometer inductance L_1, condenser C_1, frequency transformer *FT*, ammeter A_4, and variometer inductance L_2.

The function of the variometer L_2 is of interest. Without this inductance the low frequency current of circuit L_1, C_1, *FT*, L_2 (practically wattless) would traverse the machine. The kW. output of the machine is limited by its K.V.A. capacity. But by inserting L_2 the wattless current does not traverse the machine, which latter only supplies the energy current and so works on a high power factor.*

The high frequency circuit consists of the frequency changer *FT*, condenser C_2, inductance L_3, coupling coil L_4, and iron-cored choke coil *KC*. These two circuits,

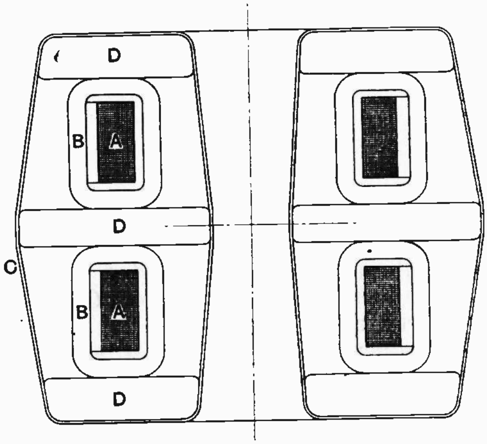

Fig. 10.

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* British Patent No. 194,007.

the alternator circuit and the high frequency circuit carry the currents shown in Figs. 6 and 8 respectively, while the graph of tension across the frequency changer *FT* is shown in Fig. 7.

We can now amplify the particulars of Figs. 6, 7, and 8. These refer to a 40kW. alternator, with 160 teeth on the rotor, giving a frequency of 7,150 at 2,680 r.p.m. The high frequency circuit is tuned to the seventh harmonic giving a high frequency of 50,050, equal to a $\lambda =$ 6,000. Fig. 11 shows the current in the antenna, all these figures being based on actual oscillograph records.

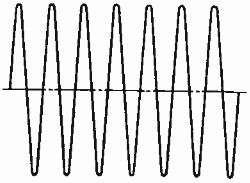

Fig. 11.

The choke coil *KC* is used for keying. A section of one type is shown in Fig. 10. It will be seen to be similar to the frequency changer shown in Fig. 4. But the keying coil has less windings for H.F. current, as it is not desired that the H.F. current should saturate the iron.

There are, as before, two iron cores *A* and *A*, each with its separate H.F. winding *B*, so connected that each winding induces magnetic polarity opposite to the other. Wound as a toroid around both cores and H.F. windings is the D.C. winding *C*.

When current flows in the D.C. winding, the iron is saturated and the impedance of the coil to H.F. currents is negligible. When the D.C. is absent, the impedance is ample to prevent the flow of H.F. current. The opposing polarity of the two iron cores is to prevent any induced H.F. E.M.F. in the D.C. leads.

The keying coil is immersed in oil in an iron tank similar to the frequency changer. It is interesting to note that 200 watts D.C. will key quite perfectly 25kW. in the antenna.

The aerial circuit is quite standard and consists of the inductance *ATI*, coupling coil L_5, variometer L_6, and ammeter A_5, together with the usual German visual wave indicator *WI* consisting of a rotating tube filled with helium and driven by its motor *M*.

For telephony, of course, the keying coil *KC* would be controlled by microphone currents suitably amplified, reminiscent of the Alexanderson magnetic amplifier.

The details given here are for a station of moderate size—25kW. in the antenna—but are correct in principle for the system. It will be seen that losses in the alternator itself are small and that practically all the other losses are concentrated in the iron of the frequency transformer and keying coil. The system has been successfully applied in powers from 200 watts in the antenna to 1,000kW. motor input. This last size gives an overall efficiency, antenna kW. to motor input, of 75-80 per cent.

Inductance Coils Quantitatively Compared.

By A. L. M. Sowerby, B.A., M.Sc. [R240

THE writer has recently commenced an investigation into the high-frequency resistances of different inductance coils, and offers here some preliminary results of his experiments.

The object of the preliminary investigations here detailed was to discover, by means of some careful comparative measurements, the relative high-frequency resistances of a number of coils of different types, both commercial and home-made, and, if possible, to determine whether the "low-loss" coil, of spaced thick wire on a skeleton former, was sufficiently superior to all others to justify the bulk and difficulty of winding that it necessarily involves.

Method.

With the enthusiastic assistance of a friend (Mr. Cedric Vaughan-Spencer) a Moullin voltmeter was set up as in Fig. 1, using anode rectification in order to avoid the heavy damping inseparable from grid rectification. The coils to be compared were connected in turn in its grid circuit, and tuned by the small variable condenser C_1 to the frequency of 2LO, or to that of a local oscillator equipped with a tiny aerial. In either case a small aerial, consisting of a few feet of wire, was used as an energy collector, in order that variations in the amount of energy picked up by the coils direct might be very small compared with the total energy collected. The variations in plate current caused by tuning the coils to be tested to resonance with 2LO or the oscillator were then compared, and the coils arranged in "order of merit" by this means.

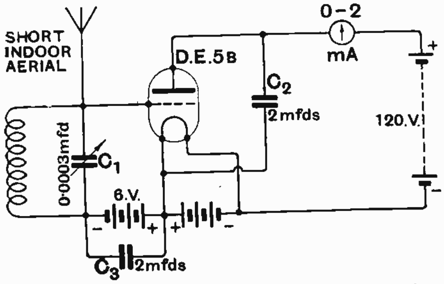

Fig. 1. *Circuit showing how the Moullin Voltmeter was set up.*

All the coils tested were compared, in all the various experiments, with a standard "low-loss" coil, 4½ inches in diameter, wound with 20-gauge bare wire on a skeleton former, the turns being spaced about fourteen to the inch. The inductance of this coil was about 250 microhenries; all coils tested (with the exception of some multi-layer coils) were adjusted to the nearest half turn to tune to 2LO or the local oscillator with the same setting of the tuning condenser C_1, so that the L/C ratio remained sensibly constant throughout the experiments. In measurements of this type it is essential that this precaution be not neglected, as otherwise very misleading results are obtained, the deflection observed at any fixed frequency being greater the greater the inductance of the coil. In both sets of readings, the tubes used as formers for the coils were "waxed cardboard" tubes sold for the purpose, which were used without any further treatment.

In all coils wound on tubes, the turns were as close together as ordinary hand-winding would permit; no wax or shellac was used on the wire.

The first series of readings were taken on 2LO's carrier, at a distance of about 500 yards from that station; only one or two special coils were wound for the experiments, the bulk of the measurements being made on coils that the writer already possessed.

The results, which are of general interest only, are summarised in Table I.

Details of Moullin Voltmeter.

Valve used, DE5b, H.T., 120 volts (accumulator); grid-bias, —6 volts (accumulator); L.T., 6 volts (no rheostat). The whole load in the anode circuit was shunted by a 2-microfarad condenser.

It will be seen that, although no very definite conclusions can be drawn from this series of measurements, the coils of finer wire, although very markedly inferior to the low-loss coil, have a resistance lower than might have been expected, and are, in fact, better than the best multilayer coil, whether commercial or not, that was examined.

TABLE I.

Steady plate current of voltmeter: 675 microamps throughout.

Coil.	C_1 (degrees.)	Anode Current. (μA)	Deflection. (μA)
Standard ..	93	2,600	1,925
4½″ tube, 28 D.S.C.	89	2,150	1,475
4½″ tube, 22 D.S.C.	94	2,350	1,675
4″ tube, 34 D.S.C.	86	1,950	1,275
4½″ tube, 22 D.S.C.	52	2,575	1,900
Best commercial coil tested ..	54	2,000	1,325
Other commercial coils ..	Various	830 to 1,950	155 to 1,275

A further series of experiments was then undertaken, and a number of coils were wound with various gauges of wire to the same inductance value, in order to determine whether, as has recently been stated,* the D/l ratio of the coil plays a greater part in determining the resistance than the gauge of wire used, and the spacing between turns.

For this series of experiments, made at a time when 2LO was silent, the local oscillator, tuned approximately to 365 metres, was used; to swamp direct pick-up on the coil the aerial was retained, and the oscillator was placed some ten feet from the Moullin voltmeter.

The results are shown in Table II, a full description of the coils being given in Table IIA.

Steady plate current, 400 microamps. This was checked repeatedly throughout the whole series of experiments, and there was no variation readable on the 0—2 milliammeter employed.

The readings for the low-loss coil taken as standard are repeated in the table wherever they were checked in the actual experiment; no measurable difference in the readings for the coil were observed during the evening, thus confirming the constancy of the oscillator output, and of the *extremely* loose coupling between it and the voltmeter.

In order to confirm further the reliability of the method employed, experiments were made under widely varying conditions; in all cases the same "order of merit" was obtained, with approximately the same relative differences between the coils.

TABLE II.

Coil.	C_1 (degrees.)	Anode Current at resonance. (μA)	Deflection. (μA)
Standard low loss	91	1,600	1,200
1	89½	1,250	850
2	91	1,060	660
3	91	1,060	660
Standard ..		1,600	1,200
4	92	955	555
5	90½	940	540
Standard ..		1,600	1,200
6	91	1,400	1,000
7	90½	1,225	825
Standard ..		1,600	1,200
8	91	1,225	825
9	90½	1,015	615
Standard ..		1600	1,200
10	90	995	595
11	90	945	545
12	92	830	430
Standard ..		1,600	1,200
4½″ tube, 20-gauge bell-wire ..	90.5	1,525	1,125
Hank - coil of 20-gauge bell-wire	91½	690	290

TABLE IIA.

Coil No.	D/l	Diam. ins.	Length (approx. ins.)	Wire S.W.G.	Turns	D.C. resistance approx (ohms)
		tube		D.S.C.		
1	1.4	3″	2.1	22	66	0.67
2	2.8	3″	1.07	28	58	2.1
3	3.1	3″	0.97	30	57	3.0
4	5.1	3″	0.59	34	52	4.9
5	5.5	3″	0.55	36	50	6.9
				D.C.C.		
6	1.05	3″	2.88	22	70	0.72
7	2.1	3″	1.43	28	61	2.2
				D.S.C.		
8	2.8	4″	1.5	22	46	0.62
9	5.8	4″	0.69	28	40	1.9
10	6.1	4″	0.65	30	39	2.7
11	10.0	4″	0.4	34	35	4.4
12	10.6	4″	0.38	36	34	6.3

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* J. H. Reyner, *Wireless Weekly*, 11th and 18th November, 1925.

It is not claimed that these figures can give absolute values for the resistances of the coils examined, but they do very definitely arrange the coils in " order of merit " and, further, give a very fair numerical idea of their relative high-frequency resistances.

In plotting a curve of wire-diameter against deflection it was discovered that the points did not lie on as smooth a curve as one would like, from which it followed that some unrecognised source of minor error was at work. Breathing on a coil at once revealed the probable cause of the variations; an immediate reduction of the deflection from 825 to 750 microamps followed, a change that showed clearly that any slight difference in the dampness or method of handling of the coils would be enough to account for the irregularities of the curve, indicating that proper precaution would have to be taken in future experiments to make the coils moisture-proof.

Results.

The general direction of the curve, after allowing for all inaccuracies, is nevertheless perfectly unmistakable; the finer the wire the higher the resistance in both series; and if, as has been claimed, there is an optimum D/l ratio, its effect is entirely masked in the present experiments by other far more potent factors.

The author of the article already referred to further states that owing to its favourable D/l ratio, a hank coil has a resistance approximately equal to that of an equivalent solenoid or low-loss coil; reference to the figures obtained by the present writer will show that he was completely unable to confirm this, the resistance of the hank coil being such that the deflection given by it was about one-quarter of that given by the low-loss coil used as standard, or by the corresponding solenoid.

A preliminary glance at the effect of spacing is given by comparison of the two 3-inch coils wound with cotton-covered wire with the corresponding coils wound with silk-covered wire; the slight extra spacing afforded by the thicker covering results in a very marked decrease in resistance.

The writer's further results, which he hopes to communicate later, indicate definitely that the variation here *is* due primarily to the change in the spacing, and not to the difference in dielectric involved in the substitution of cotton for silk.

Conclusion.

It is an indication of the difficulty of such measurements as these, that two independent investigators should come thus to diametrically opposite conclusions; it is to be hoped, however, that with improvements in technique such divergencies will disappear. The writer, however, feels that as he is supported in his results by the whole trend of modern practice, his method is reliable for the comparison of coils with identical inductance values, and he proposes to continue his investigations along the same lines.

The Use of Small Receiving Valves for Transmitting.

By A. G. Wood.

[R344.3

THE writer having recently carried out a number of experiments in transmitting, using receiving valves, an account of the results may be of interest to other experimenters.

For the tests Cossor P1 valves were used. Now a Cossor valve will normally work on about 3½ volts on the filament and 30 to 80 volts on the plate, and using these values very good results are obtainable for receiving. The writer decided to use a valve of this type for transmitting. The principal reason for using receiving valves was, in the first place, financial, but after a few preliminary tests the possibilities were revealed, and further tests were made.

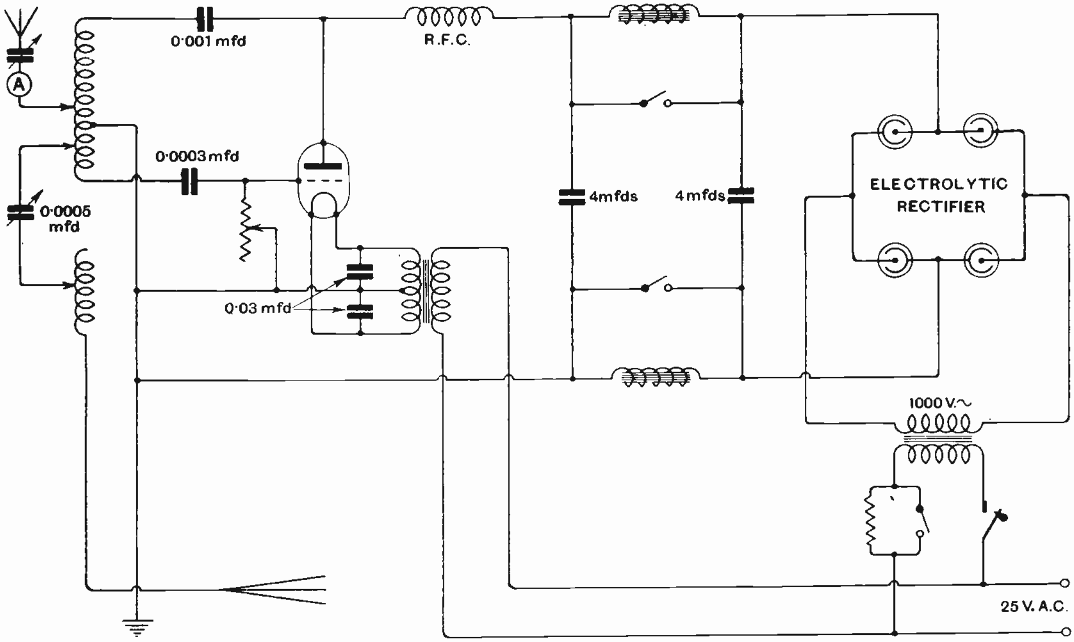

Fig. 1. *The "Hartley" circuit used in the experiments referred to in the article.*

The circuit used, Fig. 1, was the "straight Hartley." This circuit appears particularly adapted for low power valves, as several other circuits were tried without such success. H.T. supply consisted of about 500 volts full-wave rectified A.C., sometimes smoothed and sometimes more or less "raw."

The voltage applied to the filament was at first five and finally six and under these conditions the valve appeared to stand up extremely well. The preliminary tests were carried out using D.C. on the filament; but afterwards A.C. was substituted without any drop in efficiency.

The thermionic flow in a receiving valve operating under normal working conditions is generally in the neighbourhood of two or three milliamps. On this particular circuit the milliammeter registered no less than twenty milliamps. On this load it was possible to work speech without the valve overheating, provided several points were taken into account. In the first place, a grid-leak was used consisting of two electrodes immersed in rainwater. Thus, the value could be adjusted to a nicety by varying the amount of the electrodes immersed. This was very critical, and if it was at all out of adjustment the valve would immediately heat up and "blue." Next, it was absolutely necessary to keep the aerial circuit exactly in tune, otherwise the same effect would be noticed.

The usual procedure for tuning was as follows: Resistance was inserted in the primary of the high tension transformer and both the smoothing chokes in the H.T. side were put into circuit. In addition the filament was somewhat reduced. The power was then switched on and careful adjustments made for best radiation. Having adjusted everything correctly, the filament was increased to the full six volts and the resistance taken out of the H.T. circuit. An immediate increase in radiation was, of course, noticed. The grid-leak had to be readjusted slightly as the power went up. After several tests on speech with the full 10 watts it was decided to ascertain what power could be employed for C.W. or intermittent signalling. The chokes were accordingly taken out of the smoothing circuit, which had the effect of considerably increasing the H.T. volts. Milliamps rose to 35, and still the valve kept cool, provided only key load was taken. The power was then nearly 21 watts. Test calls were made and a report from Copenhagen, about 620 miles away, reported very strong signals.

The next experiment was to parallel two valves of the same make and test results. This was done, and the milliamps were then 50, the power in the plate circuit being 30 watts. Sundry adjustments were carefully made and the milliamps went up to 60 with a corresponding increase in radiation. The power was then a little over 35 watts, both valves remaining cool. By "cool" it is meant that the plates were just dull red.

Although it is of no practical use to give the radiation obtained, since all results differ between experimenters, it may be of interest to a few to know that the aerial current was in the neighbourhood of 1.6 amps on the shorter waves and a little over two amps on the longer. Whilst carrying out the tests on the higher power, the writer accidently moved the aerial series condenser. The result was instantaneous and disastrous. Every condenser in the circuit seemed to spark over and both valves "blued" violently, milliamps rushing up to the neighbourhood of 150. After that, it was necessary to reduce power considerably and let the valves cool off.

However, the last test was running matters to extremes, and there is no reason why an ordinary receiving valve cannot be used on 10 watts speech (*i.e.*, continuous load), provided sufficient precautions are taken and the circuit is properly designed.

Power Loss in Condensers.

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

(*Electrical Department, National Physical Laboratory.*)

[R145·5

IN the last twelve months a large number of variable air condensers of more or less new design have been put on the market, and it is obvious to the most casual observer that the general trend of the modifications made in their construction is towards low power loss. The importance of low power factor for condensers to be used in precision measurements has long been realised, but it is probable that its importance in general radio frequency circuits is only fully realised when small condensers suitable for short-wave work come to be used. Two cases in which power losses were the cause of trouble have recently forced themselves on my attention. First, an oscillating circuit was fitted up, but it refused to oscillate so long as a particular condenser was included in it. On substituting another condenser of the same capacity for this particular one, vigorous oscillations occurred. Subsequent tests proved that the condenser which gave the trouble possessed a large power factor. The second case was that of a precision wavemeter, which although satisfactory when new, showed a gradually decreasing sensitivity in the course of a year or so. Here again the trouble proved to be due to high power factor. Thus it may be worth while to inquire into the cause of power loss in condensers and the means whereby it may be avoided or at any rate reduced.

The Function of a Condenser—Power Factor.

In essence, a condenser consists of a portion of insulating material (generally air, mica, oil or paper) provided with two conducting electrodes (the plates of the condenser), by means of which an electrostatic field may be maintained in the insulating medium or dielectric. When the field is set up by applying an electromotive force to the plates of the condenser, the condenser is charged, the dielectric is said to be electrically polarised and possesses a certain amount of electrical energy. When the potential difference between the plates of the condenser is reduced to zero, the polarisation of the dielectric collapses and the condenser gives out its stored energy to the circuit in which it is connected. Thus when the potential difference between the plates of a condenser is alternating, as in an oscillatory circuit, the condenser is continually storing energy and then giving it back to the circuit. At the same time the charges on the plates of the condenser are continually alternating, and thus the condenser is regarded as carrying current. In a perfect condenser the whole of the energy stored by the condenser when it is charged is given back when it is discharged, and thus when the condenser carries alternating current, energy is merely alternately stored and given back by the condenser, and there is no net loss of power as a result of the passage of current through it. The only perfect dielectric is a vacuum, though air and other gases are very nearly perfect. In the case of all solid and liquid dielectrics, some of the energy stored on charge is not given back on discharge, and thus when the condenser carries alternating current a certain amount of energy is lost every time the condenser is charged and discharged, *i.e.*, there is a continual loss of power, which is dissipated as heat in the dielectric. If the condenser is in a wavemeter this loss of power may cause a serious decrease in sensitivity and in nearly all cases it means a loss of efficiency. Power losses also cause a diminution in the sharpness of tuning and in some cases they are associated with changes in the calibration of the condensers. It is therefore important to be able to estimate this loss in the case of any given condenser and to find a property of the condenser which is a measure of its quality in this respect. The power factor is such a quantity. Let V be the voltage (R.M.S.) applied to a condenser, let f be the frequency, and I

the current through it. Suppose the power dissipated is W. Then the power factor is defined by

$$\text{Power Factor} = \frac{W}{IV} = \theta \text{ say.}$$

$$\text{Thus Power Loss } W = IV\theta$$

If C is the capacity of the condenser, then I is given approximately by

$$I = VC\,2\pi f$$

$$\text{Thus Power Loss}^{*} = W = V^2C \times 2\pi f\theta$$

This gives the energy loss per second, *i.e.*, in each n cycles. The condenser is charged and discharged $2f$ times per second. Thus the loss of energy in each charge and discharge is $V^2C\pi\theta$.

The energy stored by the condenser on charge is $\frac{1}{2}V_0^2C$ where V_0 is the maximum voltage. Thus the ratio of the energy lost in each complete charge and discharge to the total energy stored is

$$\frac{\text{Energy lost per half cycle}}{\text{Energy stored}} \quad \frac{V^2C\pi\theta}{\frac{1}{2}V_0^2C} = \pi\theta$$

$$\text{since} \qquad V^2 \text{ (R.M.S.)} = \frac{V_0^2}{2}$$

This ratio is the *decrement* of the condenser per half cycle, and is another measure of the quality of the condenser as regards power loss. Decrement and power factor are in general independent of voltage and current. For a condenser built up of a given dielectric they are also independent of the capacity (that is to say a small condenser with mica as dielectric will have the same power factor as a large one with the same mica as dielectric, provided there is no loss except that in the mica itself). In many cases power factor does not depend very greatly on the frequency (though this is by no means a universal rule).

Consider now a variable air condenser. The dielectric is mainly air, and for all practical purposes this may be regarded as a perfect dielectric. A certain amount of solid insulating material must, however, be used to support one bank of plates, and in this solid dielectric there will always be a certain amount of power loss. For a given condenser under a given applied voltage the power loss will be in general constant, and not dependent on the setting of the condenser. The total power stored will, however, increase as the capacity increases, and thus the decrement and power factor will increase as the capacity becomes smaller. It is on this account that considerations of power loss become more important with very small condensers.

The Causes of Power Loss.

Power may be dissipated in a condenser carrying current in many ways. For example, when a potential difference is applied to the plates of any actual condenser, there is always a very small leakage current in addition to the true condenser current. In very poor condensers this may be detected by an ordinary direct current insulation test. As an approximation, leakage currents such as are detectable in this way may be taken as obeying Ohm's Law, and thus the power dissipated owing to a conductance G is V^2G, where V is the applied voltage. This is the energy lost per second. Evidently the energy loss per cycle is V^2G/f, where f is the frequency, and the higher the frequency the smaller is the importance of this loss, since the ratio of energy dissipated to energy stored becomes smaller. Thus power loss due to mere leakage such as is detected by ordinary D.C. tests is seldom of importance in radio circuits. Nevertheless it is important to bear it in mind and to see that leakage is reduced to a minimum. It is necessary to emphasise here that the leakage under consideration is only that which can be detected by D.C. tests (by a megger, say). It will be shown later that leakage of another type may exist. This is considered in a separate section. Taking the case of air condensers since these are the most important, leakage is generally due to dust between the plates. If the spacing of the plates is very small or uneven, particles of dust are apt to form conducting bridges between them

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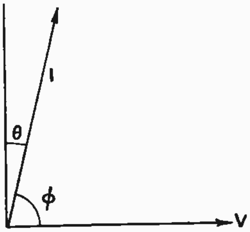

* The power factor is usually represented by *cos* ϕ where ϕ is the angular phase difference between the potential difference and current. If we put $90° - \phi = \theta$, the power factor may also be represented by *sin* θ and in the case of a condenser θ is such a small angle that its sine is approximately equal to the angle itself expressed in radians, so that the power factor is equal to θ.—G.W.O.H.

at different points. Conducting fibres from paper and cardboard packing are often found to be bridging the plates, and it is often quite difficult to remove them. The momentary application of a high voltage will sometimes burn them out and greatly improve the insulation of the condenser. This effect of dust is clearly shown by the following example. Table I gives the results of measurements made on a small variable air condenser.

TABLE I.

Condenser Reading. Degrees.	Capacity. $\mu\mu$F.	Power Factor. θ
0	28	0.0065
20	236	0.0014
40	512	0.0009
60	806	0.0008
80	1 082	0.0012
100	1 305	0.0007

Here the power loss was mainly in the ebonite washers insulating the fixed bank of plates, and thus, generally speaking, the power factor decreases as the capacity increases. At the setting 80, there was, however, a sudden increase in power factor. Examination of the condenser showed that the plates were not flat and that they were dusty. At the setting 80, two of the plates approached each other so closely at one point that it could be seen that dust bridged them. It is evident from the results given that the presence of this dust nearly doubled the power factor at that particular setting.

Under certain circumstances the air dielectric of the condenser may become conducting, *e.g.*, at high voltages ionisation may be caused, especially at the sharp edges of the plates and this will cause a dissipation of power owing to the conductance of the ionised air. In such a case, both the power stored and the power dissipated would increase as the capacity increased, and thus the power factor would probably not decrease as the capacity increased.

At high voltages, or in condensers with very narrow air gaps, a certain amount of power may also be dissipated by mechanical vibrations of the plates. Owing to the electrostatic field there is an attractive force between the plates of a charged condenser. The alternations of this force as the electrostatic field alternates, may cause the plates to vibrate like a telephone diaphragm and thus a certain amount of energy is dissipated in the form of sound waves. At audio frequencies the "singing" of the plates of the condenser is easily heard if the voltage applied to the plates is of the order of 100. The loss of power due to this cause is not usually of any importance in practice, except when one attempts to use condensers of very small air gap for precision measurements, but the existence of this loss, and also that due to dust particles, are sufficiently important to make it essential to have a large air gap (say 2mm. or 3mm. at least) in condensers to be used as standards of power factor.

It is important to remember that the power dissipated in any actual condenser is not entirely dissipated in the dielectric. Current must flow not only through the dielectric, but also through the plates, and through any leads used to connect the terminals to the plates. Thus unless the resistance of these is negligibly small they will add to the power factor of the condenser. It is easy to see that this power loss becomes more important as the frequency increases. For let r be the resistance of the connection between plates and terminals. Let I be the current through the condenser, V the voltage between its terminals and f the frequency. Then

Power dissipated in resistance $r = I^2 r$

$$\therefore \text{Power Factor} = \frac{I^2 r}{IV} = \frac{Ir}{V} = \frac{2\pi f C V r}{V} = 2\pi f C r,$$

C being the capacity of the condenser. Thus a power factor due to this cause increases with the capacity reading and with the frequency.

Dielectric Hysteresis.

The sources of power loss so far considered are all of a comparatively simple nature. The laws governing the actions concerned are fairly well known and it is not difficult to reduce such power losses practically to zero by careful construction of the condenser. There always remains, however, a certain loss of power in the solid insulating material used, and this is by no means well understood. It is much greater with alternating current than the leakage resistance as measured with direct current would lead us to expect. It increases with increase of frequency, and is commonly referred to as dielectric hysteresis, apparently in the belief that it is connected with dielectric polarisation in much the same way that magnetic hysteresis is connected with magnetic polarisation. The general similarity between the laws of magnetic and dielectric actions certainly makes this seem plausible.

The phenomena of magnetic hysteresis are well known. When a magnetic material is taken round a cycle of magnetisation, the magnetic polarisation lags behind the magnetising force, probably owing to the existence of special molecular forces. As a consequence of this a certain amount of energy is lost in every complete cycle of magnetisation, the amount of this energy per cycle being constant for a given quantity of a given material subject to the same degree of magnetisation, and not dependent on the time taken to complete the cycle, *i.e.*, the frequency. Thus, when the magnetising force becomes zero, the magnetisation is not zero and we have the phenomenon of permanent magnetism.

If by the term dielectric hysteresis we understand exactly similar actions in connection with the electric polarisation of insulating materials, then the general trend of modern research on dielectrics suggests very strongly that dielectric hysteresis does not exist. It certainly will not account for the power dissipated by ordinary imperfect condensers.

If the power loss in a given condenser were due to dielectric hysteresis, then it is easy to see that the power factor would be independent of the frequency. For a given voltage the power lost per cycle would be constant, the power stored per cycle would also be constant, and thus the decrement and power factor would be constant. In practice this is not found to be the case, except over a limited range of frequency. Bairsto* found enormous changes of power factor with frequency.

Another important fact is that there appears to be no electrical equivalent of permanent magnetism, which is a consequence of magnetic hysteresis. If the electric force acting on a dielectric is reduced to zero, the electric polarisation also falls to zero eventually, *i.e.*, if a condenser is short-circuited it always loses all its charge, if sufficient time is allowed, whereas a magnet appears to be able to retain its magnetic polarisation indefinitely even when the applied magnetic force is zero.

In short the existence of dielectric hysteresis in the strict sense of the term has never been proved. The only evidence for it is the fact that the power factor of a condenser is sometimes constant over a considerable range of frequency. If, however, the range of frequency is made as large as possible, changes in power factor are always observed. Constancy of power factor over a limited range of frequency is in itself insufficient evidence since this may be due to a number of causes.

Dielectric Viscosity—Absorption.

Realising that the term dielectric hysteresis was insufficient to account for power losses in insulating materials, several workers have made use of the term dielectric viscosity. The idea is that the polarisation of a dielectric is resisted by forces which increase when the rate of polarisation is increased, *i.e.*, they obey laws similar to those which oppose the motion of bodies in a viscous fluid. Work is expended in overcoming these forces and thus arises the power loss. The greater the frequency the greater the loss. Bairsto supposed that the losses due to this cause were proportional to the square of the frequency, *i.e.*, the power loss per cycle and therefore the power factor were proportional to the frequency, though this law does not appear to possess any considerable theoretical or practical foundation, being merely a tentative assumption. On account of these viscous forces the electric polarisation may be regarded as lagging behind the electric force when alternating voltage is applied to a dielectric, and this may be regarded as dielectric hysteresis using the term in a generalised sense.

This dielectric viscosity is really another name for the older term dielectric absorption. When a constant voltage is applied to a condenser there is a sudden rush of current into it (the "instantaneous charge"). This is followed by a current which may be fairly large at first, but which rapidly decreases until finally there is only the constant "leakage current."

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* Bairsto. *Proc. Roy. Soc.* Vol. 96, p. 363, 1920.

We are not here considering the exponential law of charge of a condenser in a circuit of definite resistance, which merely shows how the voltage across the condenser terminals increases. We are considering the case of a constant voltage instantaneously applied to the condenser terminals. If now the condenser is short-circuited, through a galvanometer say, there is first a sudden rush of current in the opposite direction to the charging current. This is the "instantaneous discharge." It does not immediately decrease to zero, but we have a current flowing out of the condenser perhaps for hours or even weeks. The charge carried by this current is regarded as having been "absorbed" by the dielectric during the charge. This absorption current is large at first, but rapidly becomes smaller as time goes on, eventually becoming zero and leaving the condenser completely discharged. These absorption currents occur not only at charge and discharge but whenever the voltage applied to a condenser is changed in any way and in all cases the current is greatest just after the change has been made. It rapidly decreases with time. When the condenser is subject to alternating voltage, this absorption current must be flowing the whole time and the higher the frequency, *i.e.*, the more rapid the changes in voltage, the larger is this current. Further it is not exactly in quadrature with the applied voltage, as the "instantaneous charging current" is, since the current due to any increment of voltage persists after that increment is completed. The result is that the current through the condenser possesses a component (the absorption component) which varies with the frequency, increasing with increasing frequency, and which is not exactly in quadrature with the applied voltage. This means that there is a certain loss of power, and also that the capacity of the condenser varies slightly with the frequency. Current in a dielectric is regarded as rate of change of polarisation. Thus we may explain the above facts by saying that the polarisation of the dielectric possesses an absorption component, which lags behind the applied electric force. The effect is also exactly the same as that which follows from the idea that the polarisation is opposed by a "viscous" force. The resultant polarisation lags behind the applied force, that is to say, we have dielectric hysteresis in the general sense of the term. The experimental laws governing this absorption current and the power loss due to "dielectric viscosity," or "after effect" as it is sometimes called, have been investigated in some detail and in several cases it has been proved that the power losses in dielectrics are entirely due to this cause.

The Fundamental Nature of the Actions.

We have shown that "dielectric power loss," "dielectric hysteresis," "dielectric viscosity" and "absorption" are probably merely different terms for the same fundamental phenomenon. The question now arises: What is the true nature of the phenomenon? A completely satisfactory answer to the question has not yet been given, though a number of possible explanations have been proposed.

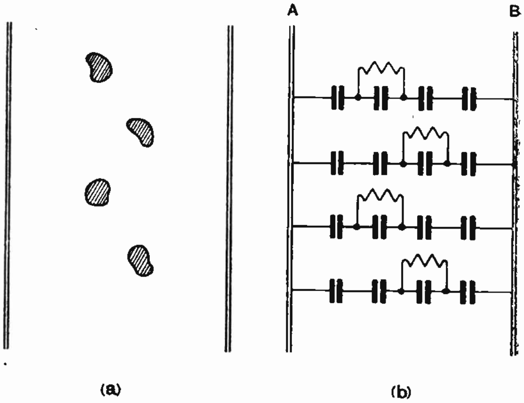

Fig. 1.

Maxwell showed that if we may regard a dielectric as being built up of a number of components with different dielectric constants and resistivities, then the phenomena can be accounted for at least qualitatively. Without going into the mathematics of the question, the actions may be described as follows: Let Fig. 1 (*a*) represent a slab of dielectric. Suppose it is built up of several components, one (unshaded) may be a perfect insulator, the others (shaded) may possess quite considerable leakage conductances. The whole conglomeration may be represented by a system of small condensers and resistances as shown in Fig. 1 (*b*). Consider now the properties of this system :—

1. In the system as drawn in Fig. 1 (*b*) the "insulation resistance" is infinite since

the condensers not shunted are assumed to be perfect, and there is no complete conducting path between the electrodes *A* and *B*.

2. If a constant voltage is suddenly applied to *A* and *B*, then in the first instant, before any current has time to flow in the resistances, the whole system takes an "instantaneous charge" depending only on the component capacities. Each component condenser takes a certain change, the magnitude of which depends on its capacity, and thus there is a definite potential difference across each of these condensers. As a consequence of this P.D. currents begin to flow in the resistances, and as the currents reduce the P.D. producing them, they rapidly decrease. Thus these currents form the "absorption current." They have the effect of increasing the charge on the more perfect condensers. The whole system after a time acquires a charge larger than the instantaneous charge. Hence the apparent dielectric viscosity is explained.

3. If now alternating current is sent through the system, some of this current will pass through the resistances, thereby dissipating power. For a given voltage the amount of current passing through the resistance will depend to a great extent on the frequency and thus we have a power loss, varying with the frequency although the "D.C. leakage current" is zero in the case considered.

Thus according to Maxwell's theory, "dielectric hysteresis loss" is essentially of the same nature as the power dissipated in any conductor. If there were no other source of power loss, then in a perfectly homogeneous insulating material there should be no power loss other than that calculable from D.C. leakage experiments.

A totally different theory has been advanced by von Schweidler.* The electron theory explains the instantaneous charge taken by a dielectric as the displacement of electrons within the molecules of the material, these electrons being bound by elastic forces to the nuclei of the molecule, and thus being capable of vibratory motion of definite frequency about their equilibrium positions. The motion of these electrons is controlled solely by the applied force and these elastic forces; there is no frictional force and thus no power is dissipated by the motion. A perfect dielectric contains only electrons of this class. An imperfect dielectric according to von Schweidler possesses in addition certain electrons or ions which are acted on by frictional forces also, so that if they are displaced from their equilibrium position and then released they do not vibrate, but slowly return to that position. These are the cause of the power loss and absorption phenomena. Some of these electrons (or ions) move extremely slowly, and others relatively quickly under the influence of a given applied force. Those which are capable of very rapid motion very largely determine the power losses at high frequencies.

These two theories are obviously sufficiently wide to cover almost any observed power loss measurements, but the available experimental evidence is quite insufficient to determine to what extent each applies in practice. What we know may be summarised thus:—

All solid insulating materials possess a power-factor which is greater than zero. This power-factor may either increase or decrease with frequency; but over a limited range of frequency it is often constant. This power-factor is in many cases very intimately connected with absorption phenomena. In composite insulating materials such phenomena are certainly due in part to the heterogeneous structure of the material.

Surface Leakage.

In variable air condensers the solid insulating material used is always in the form of pieces of small cross section. The electrical behaviour of such pieces is usually very largely influenced by surface leakage. The nature of this is probably somewhat as follows: The surface of a solid can seldom be regarded as chemically clean. It is nearly always covered with a film of "dirt" of some kind. This may consist of more or less pure water which condenses from the atmosphere, or the material itself may undergo chemical changes under the influence of sunlight, air and moisture. Ebonite is a well-known example of this. The sulphur it contains tends to oxidise and form sulphuric acid at the surface. This surface "dirt,"

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* von Schweidler. *Ann der Physik.* Vol. 24, p. 752, 1907.

however it is formed, is not a good insulator. It may decrease the insulation resistance of the condenser very seriously. The effect on the direct current leakage resistance which has already been considered may however be very small compared with that on the power factor with alternating current. For this " surface leakage " may produce all the phenomena of dielectric viscosity, etc. The moisture which condenses on the surface of the insulator does not spread in a layer of uniform thickness over the whole surface. It tends to collect in small drops which are not in contact with each other. These drops on the surface may be represented by Fig. 1(a), and the system may be represented by the capacities and resistances in Fig. 1(b), and may give rise to " hysteresis losses " as explained above. The water droplets may behave merely as conducting particles connected together by capacities. In this case it is evident that the power dissipated in these conducting particles will be greater the higher the frequency, since the total current flowing is determined by the small capacities and increases with the frequency, and thus the power loss in each drop, which is proportional to the square of the current flowing through it, will increase rapidly with the frequency.

This loss due to surface leakage is particularly important in the case of ebonite exposed to the action of light, and in that of glass and quartz in moist atmospheres. Amber and paraffin wax do not appear to show the effect to any serious extent.

Certain small condensers with quartz insulation used by the writer appeared to show these effects to an enormous extent. It was one day noticed that the value of the capacity was 11$\mu\mu$F higher than it should have been and that the power factor (at telephonic frequency) was 6 per cent. A few days later the capacity was found to be 25$\mu\mu$F higher than the nominal value, and the power factor was 20 per cent. at telephonic frequency. The nominal capacity was 50$\mu\mu$F. These measurements were made at telephonic frequency but it was perfectly obvious that the condensers were useless for work at any frequency and this in spite of the fact that fused quartz was chosen as the best possible insulator. The results were ascribed to surface contamination. The quartz was taken out and thoroughly cleaned with acid and then washed with distilled water. It was then made red hot in a blowpipe flame for at least five minutes and dropped into paraffin wax. The excess of wax was allowed to drain off and the quartz then carefully replaced in the condenser without touching it with the fingers. After this treatment the capacity had returned to its normal value. The power factor was about 0.0001 at telephonic frequency and was too small to be measured at radio frequency. It is not often that " absorption" effects so large as this are observed, but it is obvious that the insulation of very small condensers needs careful attention.

Examples of Poor Power Factors.

Most of the measurements mentioned here were made at telephonic frequency. This is because such measurements are more conveniently and accurately made at telephonic than at radio frequencies. As a rule the power factor of a condenser is of the same order at telephonic and at radio frequencies, and it is the order of the quantity rather than its absolute value which usually matters.

A certain small variable air condenser (300$\mu\mu$F) when included in an oscillating circuit prevented it from oscillating, although other condensers permitted oscillations. This is the condenser referred to at the beginning of this article. Power factor measurements on the poor condenser gave the following results :—

TABLE II.

Scale Reading. Degree.	Capacity $\mu\mu$F.	Power Factor θ	Frequency f.
0	33	0.018	800
86	163	0.0036	—
180	292	0.0021	—

Here the power factor is practically inversely proportional to the capacity reading, which means that the total power loss (which is proportional to the product $C\theta$) is independent of the condenser setting. Thus the power loss is entirely in the solid insulation —probably defective ebonite in this case. This example illustrates the fact that if the power factor of an air condenser is greater than 0.001 at telephonic frequency its performance cannot be regarded as satisfactory.

Some Points in Design.

Provided the air gap of a condenser is not too small, and that there are no high resistances in its plate systems, the whole question in the design of a condenser as far as power losses are concerned, lies in the solid insulation. It is obvious that this must be so arranged that the power losses in it for a given applied voltage are a minimum. It is often stated that the conditions for this are as follows :—

1. The smallest possible amount of solid insulation must be used.
2. It must be placed in as weak an electric field as possible.
3. It must be of as high a quality as possible.

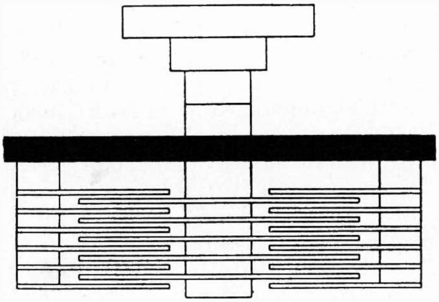

Fig. 2.

A more accurate way of expressing the best conditions is obtained from the following considerations. The power loss in any solid insulating system for a given applied voltage V is given by the equation

$$\text{Loss } W = V^2 C 2\pi f\theta$$

where C is the capacity of the system, θ is its power factor and f is the frequency. Thus for a given voltage and a given frequency the power loss is a minimum when the product $C\theta$ is a minimum. Thus the conditions for minimum power loss are :—

1. The capacity of the solid insulating system must be as small as possible.
2. The power factor of the solid dielectric used must be as small as possible.

Condition 2 determines the material to be used, while 1 determines its size and shape. As to condition 2, good quality fused quartz appears to be the best solid insulator obtainable, though as we have seen, it must be carefully cleaned before being finally assembled. Ordinary glass is not a very good insulator, though special types are obtainable which possess a very low power factor. Ebonite when free from loading material is good, but is apt to deteriorate rapidly under the influence of sunlight. Amber and amberite are very good at low frequencies, though the latter appears to be not very good at radio frequencies, and is not very highly recommended for condenser work. Mica is good but difficult to make up into a suitable form.

It is usually possible to see, by inspection of the condenser, whether condition 1 has been fulfilled. Figures 2, 3, 4, 5, 6 represent typical cases diagrammatically. In Fig. 2 the condenser top is of insulating material (say ebonite) and the fixed bank of plates is suspended from it. Sometimes there is another ebonite plate at the bottom. In Fig. 3 the top is of metal and the fixed bank is insulated by means of three washers (two of which are shown). In Fig. 4 the fixed bank is insulated from the case by pillars. In Fig. 5 these are replaced by short lengths of tube. In Fig. 6 horizontal rods of insulating material support the fixed plates.

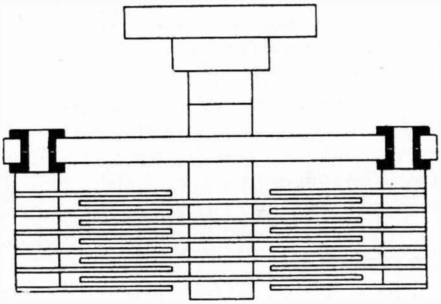

Fig. 3.

It is interesting to note that although in Fig. 3 the actual amount of solid insulating material may be much smaller than that in Figs. 4 and 6 say, the power loss is not necessarily less, since if the washers in Fig. 3 are thin, their capacity may be quite high, probably higher than the rods and pillars in Figs. 4 and 6. The capacity of the tubes in Fig. 5 is smaller than that of the pillars in Fig. 4 and hence we should expect Fig. 5 to be the better arrangement, unless surface leakage should happen to be important. In such a case the extra surface of the tubes would be a disadvantage. The arrangement of Fig. 2 is obviously not good. Comparing it with Fig. 6 for example there is obviously more solid material than is necessary. It is possible however for it to be better than Fig. 3, since the capacity of the insulating top might be lower than that of the washers in Fig. 3. Much would depend on the general design of the plate systems. The arrangements of Figs. 4, 5 and 6 possess the great advantage that the solid insulation is completely enclosed in the condenser and is thus protected from the action of sunlight, moisture, dust, etc. This is especially important in the case of ebonite. Also the condenser is well shielded.

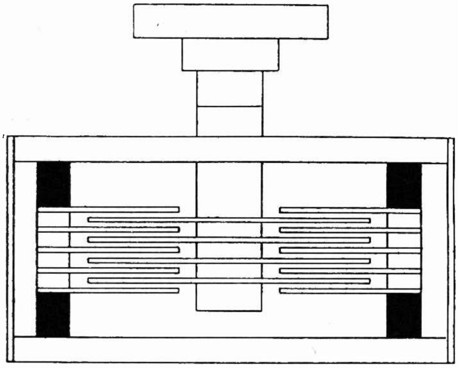

Fig. 4.

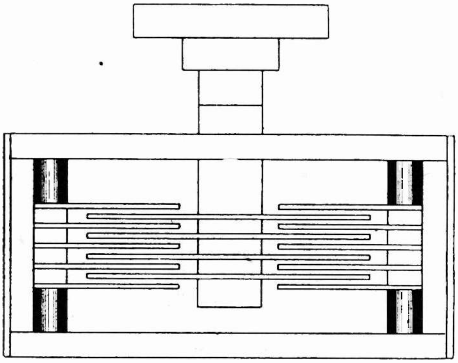

Fig. 5.

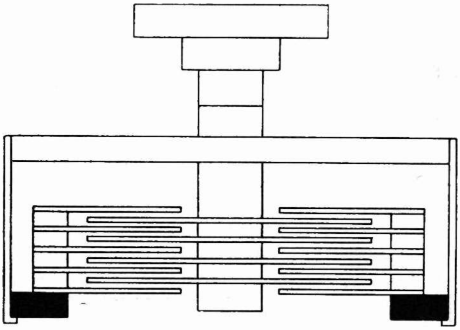

Fig. 6.

The following table illustrates these remarks. It gives the results of power factor measurements made on a series of good quality air condensers of various designs. All the measurements were made at a frequency of about 1 000 cycles.

TABLE III.

Condenser.	Capacity. $\mu\mu$F.	Power Factor.	Insulating System.
A	200	0.0025	Fig. 2 (Ebonite top).
B	200	0.0021	Fig. 2 (Better quality ebonite).
C	200	0.0008	Fig. 2 (As for B but thinner ebonite).
D	200	0.0005	Fig. 3 (Quartz washers).
E	200	0.0001	Fig. 5 (Quartz tubes).

When the readings of these condensers were greater than 200$\mu\mu$F the power factors were correspondingly reduced, the power factor of a well-constructed and well-shielded air condenser being nearly always inversely proportional to the capacity reading.

The Directional Recording of Atmospherics.

Paper read by Mr. R. A. WATSON WATT, B.Sc., before the Wireless
Section, I.E.E., on 3rd March, 1926.

[R114, R125

Abstract.

THE paper is communicated by permission of the Radio Research Board, and describes a simple pen-writing instrument for the continuous-recording of the apparent direction of arrival of atmospherics, citing typical samples of the data obtainable from such recorders.

The work was initiated by the Meteorological Office in 1915, and subsequently developed into a fundamental inquiry into the origin and nature of atmospherics, under the auspices of the Radio Research Board. Observations were made aurally first by means of the standard Bellini-Tosi goniometer and later with a frame aerial, with a view to the ultimate development of a simple and easily operated directional recorder working throughout the 24 hours.

This recorder, as finally developed, is then described. The general arrangements are shown in Fig. 1.*

A teak framing *A* supports a frame antenna *S*, belt driven by a turret clock *C* and carrying a recording-drum on which is inscribed the trace of the oscillograph pen actuated by the output of the multi-stage amplifier *F*, connected to the frame aerial. The frame is tuned to 20,000m. by the tuning condenser *J*, connection to the amplifier being brought *via* mercury slip rings. Detailed constructional diagrams (not reproduced here) are also given of the Recorder, the Abraham-Bloch oscillograph and the girder-syphon pen used in conjunction with it.

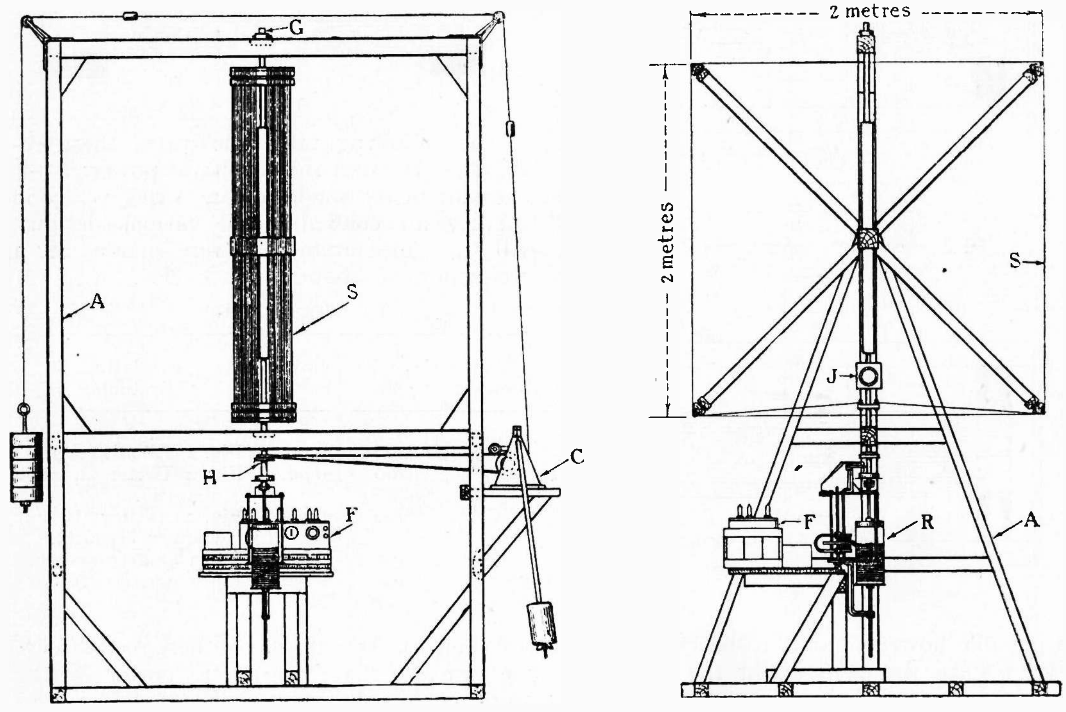

Fig. 1. *Showing general arrangement of the automatic recorder.*

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

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ing 3.75 metres square
The frame aerial is
.4 metre deep, and is
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in the corner members.

The amplifier is provided with five stages of resistance capacity coupling followed by detector and two L.F. stages. Three of the H.F. stages are normally used for recording atmospherics. The anode resistances of 100,000 ohms are wound from 0.04mm. diameter Constantan wire, on slotted ebonite formers, the direction of winding being reversed in alternate slots to reduce the total inductance. Dull emitter triodes (1.8v. filament) are used, a DE6 in the output stage, and DER's elsewhere. Accumulators are used throughout for L.T. and H.T. voltages. The oscillograph in the anode circuit of the output valve is a tetrapolar moving-iron instrument, designed by Abraham & Bloch. A permanent magnet has four laminated radial poles, each carrying a coil, the coils being so connected that the passage of a current rotates the resultant magnetic field to a new direction. A solid soft iron armature follows this rotational displacement, producing torsion of a steel wire control spring. A tongue on the armature shaft carries a pen girder in aluminium, while the girder carries a syphon pen of fine silver tube.

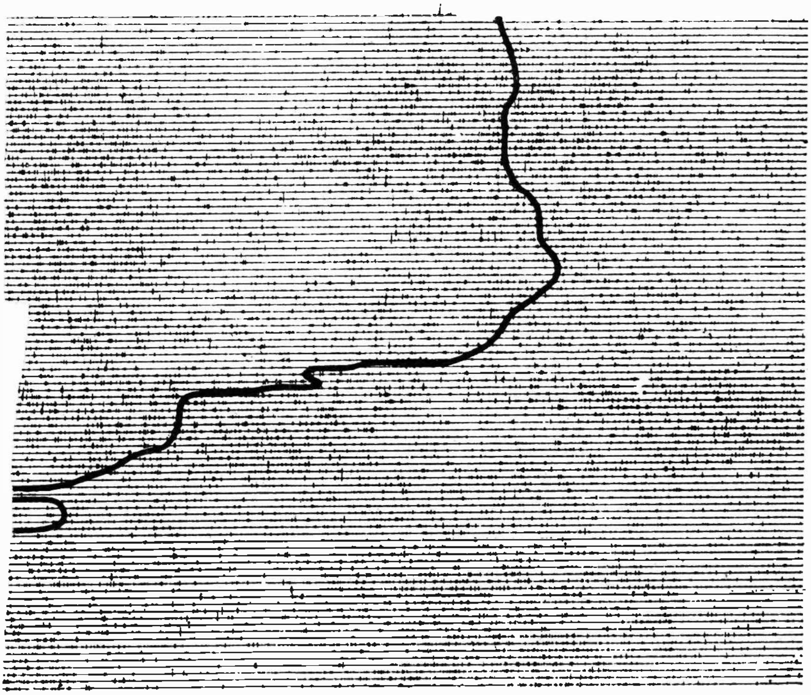

Fig. 7. *Example of record obtained.*

The drum is rotated along with the frame aerial, and carries a chart on which the free end of the syphon pen writes a helical trace. On removal from the drum the trace is resolved into 96 approximately horizontal lines each representing one revolution, or 360° in angle and 15 minutes in time at the normal speed of rotation, *i.e.*, 24 hours per chart.

The arrival of an atmospheric giving sufficient voltage in the amplifier output is marked by a vertical excursion of the pen, transverse to the helical base, the chart on removal having the appearance shown in Fig. 7.

In discussing the defects and advantages of the system, the author indicates the defects to be (1) The instrument is non-discriminating, in that it deals with the average direction of the whole distribution of atmospherics; (2) It is only quantitative within somewhat narrow limits, the lower limit being the comparative insensitivity imposed by the use of a pen-writing oscillograph, the upper limit by saturation, etc.; (3) The amplitude depends on other factors than peak field strength; (4) The record becomes too sparse for interpretation if the total disturbance falls to a low value; (5) It has the normal ambiguity of 180°. Against these it has the advantages of giving fair sampling under relatively invariant conditions throughout the 24 hours; the trace is available for re-examination in case of doubt or fresh line of investigation; it is easily maintained and reliable in operation, and enables data to be collected at widely scattered stations without the provision of specially trained and skilled observers.

For study of the direction of arrival, the charts are examined line by line and the most probable maximum determined by the location of two maxima 180° apart, with minima approximately midway between them. The points so found are joined by a line, as shown in Fig. 7. It is frequently possible to trace double distributions, and separate "grinder" and "click" maxima.

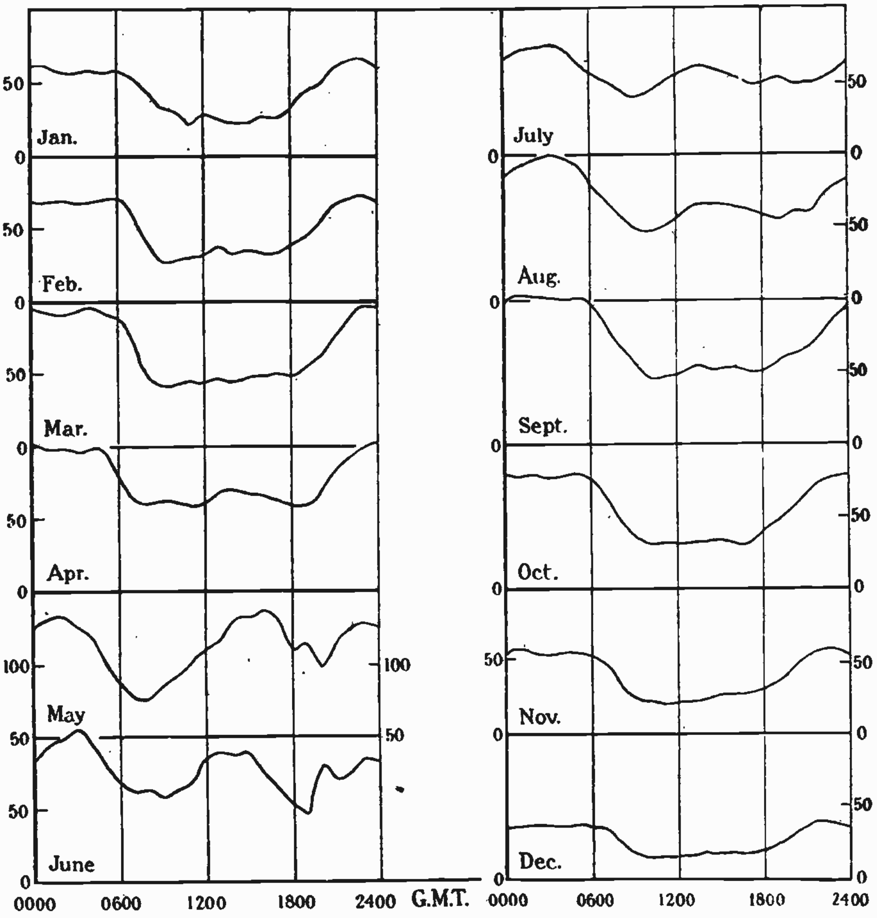

Fig. 9. *A set of chart showing variations.*

The paper then discusses results obtained with the recorder, dealing first with diurnal variation of intensity of disturbance, data for which are available for two and a half years from the first recorder (set up at Aldershot). Results are shown in the curves of Fig. 9, from which it is apparent that there is a principal maximum M_1 in the hours of darkness, a principal minimum N_1 before noon and a secondary minimum in the early evening and subsidiary maximum in the early morning and evening. The times of incidence of these points are plotted in Fig. 10, in which are also shown the mean times of sunrise and sunset, illustrating a close correlation. A table also shows the approximate constancy of the intervals between the times of the various stationary points and the times of the solar phenomena to which they are related.

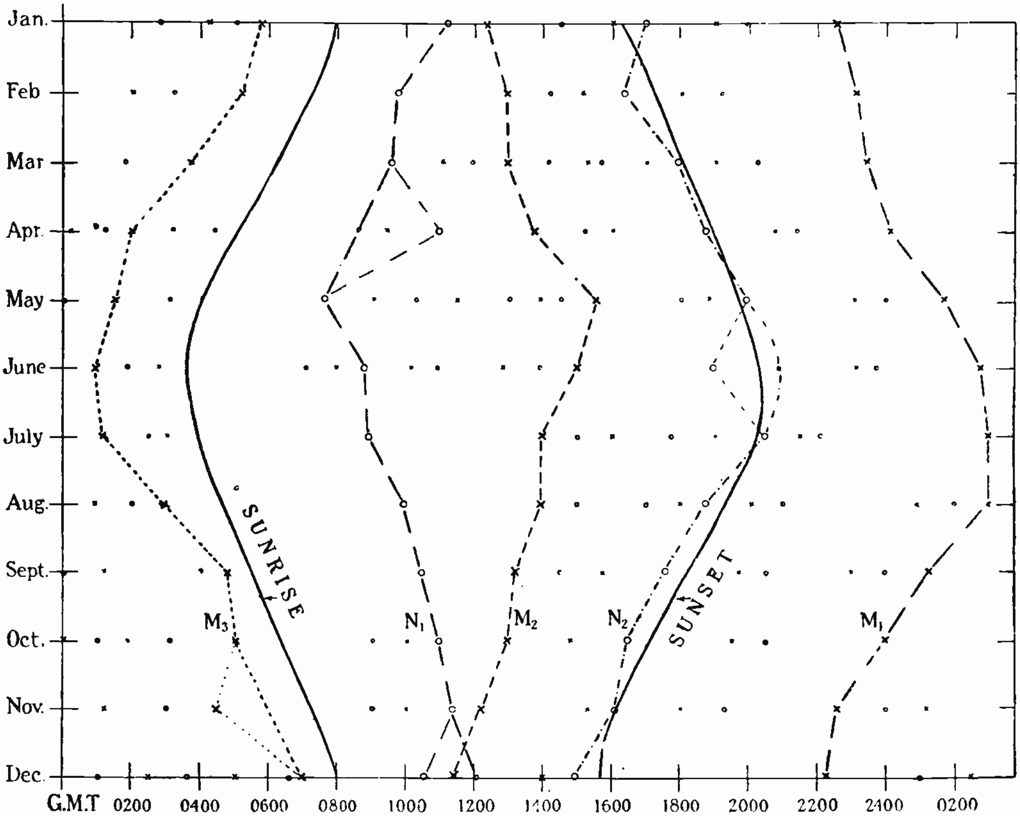

Fig. 10. *Chart showing times of incidence and indicating sunrise and sunset effects.*

In considering the diurnal variation of apparent direction of arrival, the ambiguity of 180° renders difficult the selection of a direction which may be accepted as characteristic of a period. It was finally decided that the principal features of the records were most clearly expressed by the following process: From the line to line curve of direction (as drawn in Fig. 7) were read off the hourly values of apparent direction of arrival for hour periods, centred on hours G.M.T. These were entered on a distribution diagram as Fig. 11, for a month of the recorder at Ditton Park, whither the Station was moved from Aldershot in July, 1924. This shows the number of occasions on which, at any hour, a selected azimuth had been most disturbed. Entries were made, as shown, corresponding to both senses of the 180° ambiguity. The "medians" of the blocks (*i.e.*, the azimuths which had as many observations on one side as on the other), were then selected as the most probable value of the predominant hourly directions for the month. A table of directions so obtained for a recorder at Lerwick is shown for the months September,

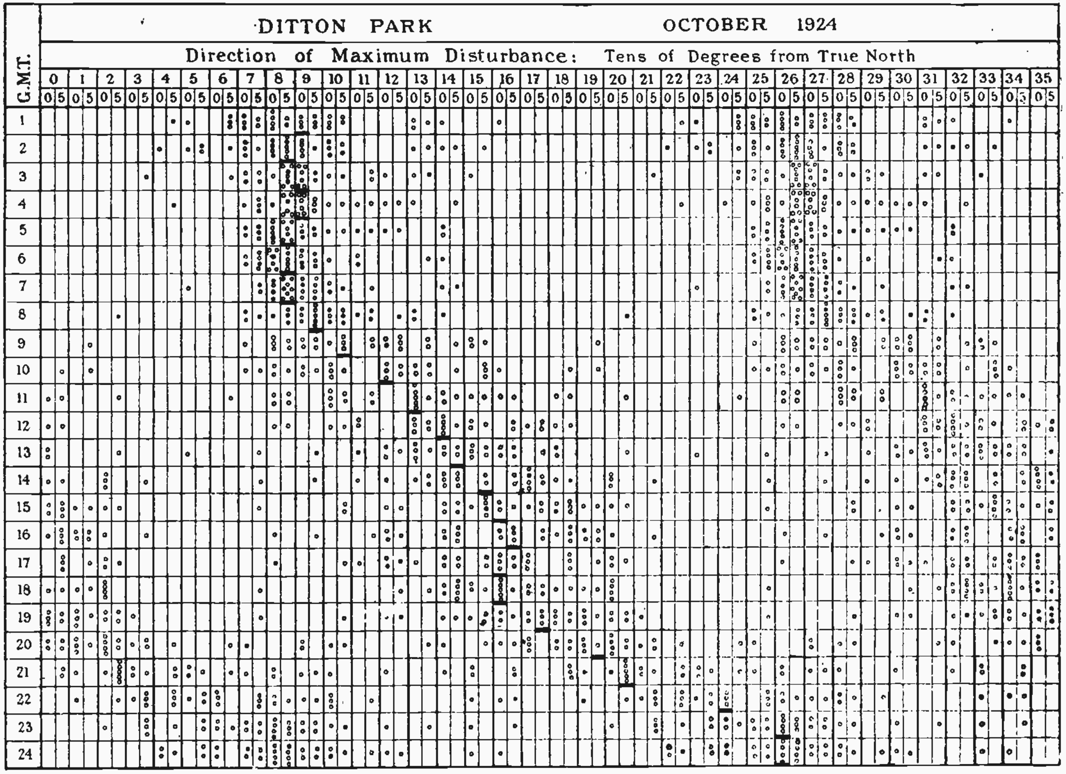

Fig. 11. *Distribution diagram for month of October, 1924.*

1924, to March, 1925. From considerations of this and other data the author suggests the following picture of the variations in the principal stream of atmospherics. Early in the morning atmospherics arriving from the far East, where the sun has already attained some considerable attitude, begin to show themselves. Towards 9 or 10 a.m., G.M.T., they have become the dominant stream arriving from a few degrees south of east about the autumnal equinox and from nearly due south at the winter solstice. In the equinoctial season the cum-solar swing is strongly marked, and in all cases the direction swings through south to a relatively constant S.W. by W. or W.S.W. near midnight. This stream remains the dominant one until 9 a.m., presumably because the American continent produces atmospherics until late in its own evening, while the Pacific Ocean is not an important source. A distribution curve for Bangalore, India, for the month of June is also illustrated showing a cum-solar swing, then in a counter clockwise direction because the sun is then to the north of this station.

Lastly, the author considers the use of a group of those recorders for location of sources of atmospherics. A group of such stations already exists, *i.e.*, at Ditton Park, near Slough (transferred from Aldershot), at Lerwick, Shetland Isles, at Aboukir, Egypt, and at Bangalore, South India. An interesting case of tracing a thunderstorm across Europe by means of the records from Aldershot and Lerwick is quoted. A further example is also quoted from the charts of three recorders. The successive hourly bearings over a period of 12 hours lay almost all along the trough of a shallow depression near Tunis.

A further discussion of such sources is hoped for when the data for the first six months of simultaneous recording have been examined in relation to the available meteorological data.

An Instantaneous Direct-Reading Radiogoniometer. [R114, R125

Paper read by Messrs. R. A. WATSON WATT and J. F. HERD, before the Wireless Section, I.E.E., on 3rd March, 1926.

Abstract.

THIS paper is also communicated by permission of the Radio Research Board, and describes a new system of direction finding in which a cathode ray oscillograph is used as the indicating device to permit the direct and instantaneous reading of direction of either signals or atmospherics.

In the introduction the authors consider the disadvantages of the usual types of D.F. apparatus, especially in the investigation of atmospherics (*cf.* previous abstract). It is pointed out that the usual rotating loop method is only suited for wavetrains sustained for several seconds. The inertia of the moving system prevents the taking of bearings on brief wavetrains or wavetrains of apparent azimuth varying at, say, 1° per second. Applied to the study of atmospherics such a system will merely indicate the mean apparent direction of arrival of the predominant streams. There is a high probability that two physically independent streams may be merged into one stream statistically true but physically fictitious.

The next section describes the new arrangement (see Fig. 2* reproduced) used by the authors, particularly in connection with their work on atmospherics at Ditton Park, near Slough.

Two loop aerials, say, A and B, are considered at right angles and crossing at their centres. A vertical wave front, of maximum vertical electric force E, and making an angle ψ with the plane of A, will produce in A and B E.M.F.s proportional to $E \cos \psi$ and $E \sin \psi$ respectively. The E.M.F.s across each loop condenser will also be in this ratio. If these condensers be joined to the deflector systems of a cathode ray oscillograph, the two fields will recombine to produce a resultant field of strength proportional to E and making an angle ψ with the axis of deflection corresponding to the plates *ns*. Thus the fluorescent spot traces on the screen a line of length linearly related to the E.M.F. which would be induced in a loop similar to A with its plane in the ray direction, and making an angle with the reference axis *ns* equal to the angle between the ray direction and the plane of loop A.

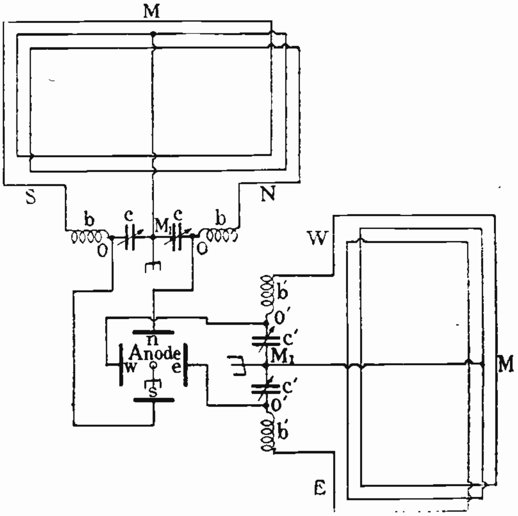

Fig. 2. *General arrangement of cathode-ray direction-finder.*

Generally, for sensitivity comparable to that of commerce, the E.M.F.s will require amplification before application to the deflecting plates of the oscillograph.

Several minor points are to be noted in connection with the oscillograph, one pair of plates (*i.e.*, *ns*) being nearer to the source of the electron beam than the other. The time occupied by an electron in travelling from one pair to the other is 0.0015 microsecond, corresponding to a phase angle of ½° at one

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

million frequency, so that no error is introduced even at the shortest commercial wavelengths. The difference of position also causes an angular error (on the tube screen) reaching a maximum of $2\frac{1}{4}^{c}$ about the 45° points. This error being independent of amplitude or frequency, a permanent scale correction can be applied, or it can be compensated by a method described later. It is pointed out that this error is not inherent to the system but only incidental to the arrangement of the particular tube used.

For work on atmospherics where there is no possibility of even a rough check on the accuracy of the indications, it is desirable to eliminate even remote possibilities of error. The circuits described for the authors' work are consequently designed to satisfy most completely the requirements of symmetry and the minimum of amplification. To eliminate " antenna effect " the loops of Fig. 2 are divided into halves, the mid-points of the horizontal sides being all connected to earth, along with the anode of the oscillograph. The tuning arrangements are split and arranged symmetrically on either side of the central earth lead. The tuning of each half loop is practically independent of that of the other half.

Special oscillograph tubes have been obtained with the four deflector plates separately terminalled, since complete symmetry is not possible with certain commoned connections in the standard pattern.

For strong signals the oscillograph may be connected directly across the condensers as in Fig. 2. For weaker signals the general scheme of amplification is shown in Fig. 3.

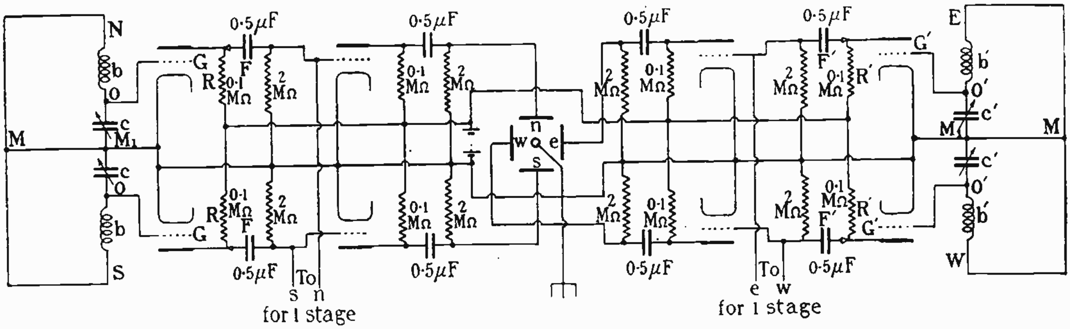

Fig. 3. *Details of circuits.*

The conditions are especially suitable for voltage amplification by resistance-capacity coupling, and symmetry is maintained by the use of the " push-pull " circuits shown. In the installation described the loops each comprise 5 turns, each 1,200 ft. horizontally and some 125 ft. deep. For atmospheric observations each unit is tuned to 10kc. by the coils and condensers. DE5b triodes are used with wire-wound anode resistances of 10^5 ohms, and 300 anode circuit volts giving voltage magnification of 15 per stage. The first stage is tapped in three, so that overall amplifications of 5, 10, 15, 75, 150 and 225 are obtainable. Accuracies of 1° can be attained on any deflections exceeding half the oscillograph scale. The special features are the precautions for symmetry and the large area of loops. This is part of the general policy of quantitative work on atmospherics, to allow measurements to be made with the minimum of amplification. Loops of turns with an area of 30 sq. metres with one pair of vertical limbs coincident, and in combination with normal amplifiers and the standard pattern of oscillograph have already been shown to be practicable.

Tuning and testing arrangements are described. When the whole system is correctly tuned, a signal causes the spot to trace a straight line which makes with the principal axes, angles which are the angles between the direction of the signal and the planes of the aerials. Slight mistune opens out these lines into an ellipse, due to the misphasing of the two fields applied to the tube. The ellipse is quite wide before its major axis begins to depart sensibly from the correct angle. Tuning may thus be performed directly on the signal, or it may be performed on locally generated oscillations of the desired frequency. The loading inductances of Figs. 2 and 3 are arranged as the secondary windings of a crossed-coil transformer, with a rotable primary excited from a screened calibrated oscillator. The primary may first be coupled to one loop alone and this tuned up, then the other loop tuned independently. Finally both may be tuned to identity as tested by the closing of the ellipse. This instrument also permits testing the amplification on each side. These should be identical but the difference in the position of the deflecting plates can be compensated by a slight increase in the amplification of the pair nearer to the screen. This only involves adjustment of the amplification so that equal inputs to the two systems give identical outputs (on the tube screen) so that the compensation is automatically performed in the general adjustment of amplification.

The third section deals with the properties of the system. The device will provide automatic visual and direct reading, capable of operation by a navigator without requiring a knowledge of morse, and it will deal with signal trains of exceedingly short duration. Another important feature is its behaviour with jamming. It will give correct bearings, simultaneously, even in the case of two or three signals. Three types of pattern may be obtained in practice. If two stations are working independently at hand speed, the screen image will be two bright lines, standing out from a background of faint fluorescence. At high speeds the pattern becomes a parallelogram full of fluorescence, whose sides are respectively parallel to the two bearings. Increase in the number of stations merely increases the complexity of the image, but with three high-speed stations the three bearings are still easily read.

The freedom from inertia effects and discrimination in amplitude will throw light on cases and causes of "bad minima," etc.

In Section IV. typical observations on atmospherics are described. On one occasion quoted simultaneous determinations by this direction finder and of the azimuth of visible lightning showed in a large majority of cases agreement within 5°, which was approximately the limit of estimation of the faint distant flashes. More recent observations are discussed and illustrated showing correlation between observations on atmospherics and reported thunderstorms, verified from meteorological sources. These are plotted on a polar diagram and show very complete agreement between the observed thunderstorms and the apparent azimuth of the arrival of atmospherics.

In the last section the authors discuss the application of the arrangement to the navigational beacon problem. C.W. transmission, modulated m per cent. at a frequency f is suggested, where f need only be a fraction of a cycle per second and m can be made large, while both m and f can be given values which become characteristic of a series of beacons. The transmitters could work simultaneously on the same wavelength. A typical screen image might then consist of two lines intersecting at 55°, one varying once in 3 seconds from full to half length, the other once in 5 seconds from full to quarter the length. The navigator would read the bearings and find in his list the stations characterised by $m=50$ and $f=0.33$, and by $m=75$ and $f=0.2$ respectively.

Slides (not reproduced here) were shown illustrating photographs of the parallelograms obtained from the cathode ray oscillograph in the presence of two, and in some cases of three simultaneous signals.

DISCUSSION.

A joint discussion on both papers then followed.

Admiral-of-the-Fleet Sir Henry Jackson, in opening the discussion, congratulated the authors on their papers, and spoke of the energy and work which had gone to bringing matters to such a high state of perfection.

Dr. G. C. Simpson (Director of the Meteorological Office) referred to the origin of the work on atmospherics under that office, and its transfer to the Radio Board. He considered the work of considerable importance in meteorology, apart from its practical applications in radio-telegraphy.

Prof. J. T. MacGregor Morris referred to the excellent work done by the Radio Board, including that of the authors. He offered some practical suggestions for future trial. For recording, he suggested the use of two frames, rotating at right angles to each other, and both writing close together on the paper with differently coloured inks. Regarding the position of the deflecting plates in the cathode ray tube, he pointed out certain difficulties of arranging them to act at the same part of the beam, but offered an alternative solution which should amount to the same effect. He also suggested the use of two oscillographs with quartz ends for photography, working separately to the loops, subsequently recombining their records.

Mr. R. H. Barfield admired the accuracy and detail of the recorder and its application to general use. He inquired whether the author had ever observed a sudden cessation of atmospherics just before sunrise, as had been reported by Capt. Round.

Capt. E. L. Johnston (Airships, Navigation) spoke of the advantage of wireless to navigation. The cathode ray device described more nearly approached the ideal wireless compass than any other device available. It was especially important in aerial navigation.

Mr. M. A. Giblett (Airships, Meteorology) dealt with the application to practice in connection with aircraft meteorology. Such instruments would also be of great use in the airship itself. He reviewed the meteorological effect of "cold fronts" and suggested that the instruments described would be useful for location of such regions dangerous to aerial navigation.

Mr. E. H. Shaughnessy questioned the simultaneous reception of Rugby and Leafield (shown in a slide) if the loops were tuned to 10kc.

Dr. R. L. Smith-Rose dealt with certain points of accuracy of the directional recorder. As regards the cathode ray device, he thought a big step had to be made before it could be put on a ship.

Major G. H. Scott (Airships, Navigation) spoke of the importance of the cathode ray system on airships, and inquired as to progress in the matter of smaller loops with the object of its use on airships.

Mr. R. A. Watson Watt replied briefly to the discussion. Particularly in reply to Mr. Barfield, he stated that although records showed a drop about sunrise he had not encountered the total cessation of atmospherics described. In reply to Mr. Shaughnessy he pointed out that with the slide shown the aerial was tuned to between Rugby and Leafield, which accounted for the reception of both. In reply to Major Scott, there was, he said, every assurance of the possibility of developing loops that could be accommodated in R33.

In moving a vote of thanks to the authors, the Chairman (Major B. Binyon) expressed his belief that the cathode ray device, although still in need of development for general use, was on sound principles.

The Upper Layer.

Discussion at the Royal Society.

[R113.4

The meeting of the Royal Society on Thursday, 4th March, was devoted to a discussion on "The Electrical State of the Upper Atmosphere."

THE discussion was opened by Sir Ernest Rutherford, the President of the Society, who broadly reviewed the subject, referring to the effects as observed in the case of wireless waves, and the evidence available from observation of the fall of meteors, etc. He also spoke of the comparatively recent revelation of a very penetrating radiation which increased in intensity with height above the earth.

The discussion was then continued by Prof. S. Chapman, who dealt with the subject, particularly from the view point of auroral manifestations. Prof. C. T. R. Wilson followed with information from the point of view of the thundercloud, etc. Admiral-of-the-Fleet Sir Henry Jackson introduced the subject from the standpoint of radio-telegraphic investigation, referring to recent long distance work on very short wavelengths Prof. E. V. Appleton continued the discussion on this aspect with reference to other recent measurements of down-coming wave, etc. Dr. R. L. Smith-Rose and Mr. R. H. Barfield then contributed a short abstract of D.F. measurements which had just been published as a Royal Society Paper. Prof. W. H. Eccles finally concluded the wireless evidence by a discussion of long distance transmission. The formal discussion was then concluded by Mr. G. M. B. Dobson, who dealt with observations on falling meteors, and the evidence available from this source of a change of atmospheric conditions at about 50 kilometres height.

A general open discussion then followed, opened by Dr. G. C. Simpson, in which the following speakers joined: Prof. F. A. Lindemann, Dr. C. Chree, Sir A. Schuster and Mr. L. B. Turner.

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.

Part III.

[R201

Calibration of Moullin Voltmeter.

In the last section of this series of articles we concluded by describing an attachment for a microammeter whereby it was converted into a Moullin voltmeter. The calibration of the instrument, *i.e.*, the interpretation of its readings in terms of A.C. volts, will now be considered. Two methods of doing this will be described, one for those who are fortunate enough to have a domestic alternating current supply, and the other for those who are dependent upon D.C. mains or batteries.

Alternating Current Method.

It is here assumed that the reader is equipped with an A.C. supply. If any doubt exists upon this point, an "Osglim" neon lamp should be plugged into the nearest lamp-holder. If both electrodes are brightly illuminated the supply is A.C., whilst if the glow is confined to one electrode only, then the supply is direct. The A.C. supply will, in all probability, be either 100 volts or 220 volts. Either voltage is too high for our present purpose, and it is necessary to "step-down," by means of a transformer, to the neighbourhood of 4 volts. Many experimenters have such a transformer for the purpose of accumulator charging, but a "bell transformer" may be purchased for a few shillings by those who have not. These transformers are intended for working electric bells from A.C. mains, and supply current up to about 1A at an E.M.F. of about 6 volts, R.M.S. They are very useful for a variety of purposes.

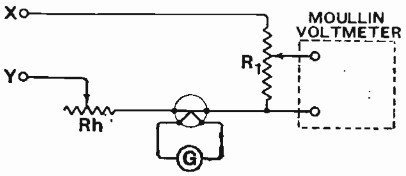

Fig. 32. *Circuit for calibration of Moullin voltmeter.*

The usual method of calibrating a Moullin voltmeter is shown in Fig. 32. The A.C. supply is connected to the terminals X and Y, Rh is a rheostat, R_1 is a straight wire of accurately known resistance having a variable tapping, and G is a galvanometer connected to the main circuit by a "vacuum thermo-junction." By this means G records the current I flowing through R_1, and the value of R_1 being known, the voltage across it is given by the equation: $V = IR$ (see Equation (1*b*), *E.W. & W.E.*, Feb., 1926, p 69). Any known fraction of this voltage may be applied to the Moullin voltmeter by altering the position of the contact on R_1. Unfortunately, we are not in a position to apply the method in the above form because we have not got the necessary vacuum junction. In the absence of the special glass-blowing and pumping facilities which would be necessary in order to make one, we must employ some other means of applying a known alternating voltage across the resistance R_1. In any case, however, we require this resistance: it may take the very convenient form of construction shown in Fig. 33. It consists essentially of a length of resistance wire, exactly a metre long, stretched upon a graduated paper scale of the same length. The two ends of the instrument are identical and constructional details of one of them are shown in the Figure.

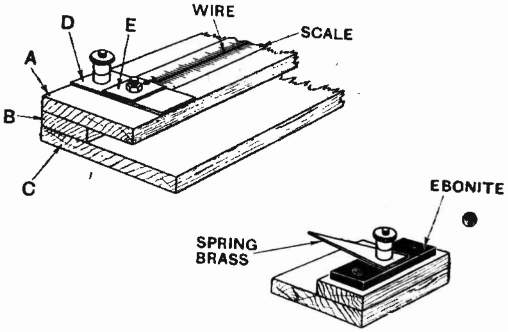

Fig. 33. *Details.*

The three pieces of wood (A, B and C) are all 3 feet 7 inches long, and of the following widths respectively: $A = 2\frac{1}{4}$ inches, $B = 1\frac{1}{2}$ inches, and $C = 3\frac{1}{2}$ inches. These are screwed together in the manner shown. A paper scale, one metre long (obtainable from Messrs. F. E. Becker & Co., Hatton Wall, London, E.C.1, price 5d.) is gummed to the upper surface of A, and two strips of sheet brass D, each provided with a terminal, are let into the wood at the two ends of the scale. The ends of the resistance wire must make contact with these strips. This may be done by direct soldering, but a better plan, which allows the wire to be changed for another of a different gauge, is to provide each of the strips with a 6 B.A. bolt. A square washer of sheet brass E is then held in firm contact with each of the strips by a nut. Matters are so arranged that the two opposite edges of the washers coincide exactly with the ends of the scale. A length of No. 36 S.W.G. bare "Eureka" wire is then stretched over the paper scale and soldered to the brass washers at its two ends.

The construction of the sliding contact is also shown in Fig. 33. The triangular pointer of spring brass is secured to a rectangular piece of ebonite by means of a terminal, and the actual contact with the resistance wire is made by means of a stout "Eureka" wire soldered to the underside of the pointer.

Readers who have found difficulty in obtaining supplies of spring strip brass will be glad to know that it can be obtained from any large printers in a form known as "brass rule." It is used by the compositors for setting up unusually long "lines" which often occur in type, and is a most useful adjunct to the wireless workshop. Previous examples of its use are shown in Figs. 10, 20 and 30 (see February and March issues).

The advantage of the foregoing method of construction lies in the fact that the sliding pointer makes continual contact with the metre wire. This is not the case with the "metre-wire bridge" commonly used.

In page 150 of our last article (*E.W. & W.E.*, March, 1926) it was stated that the Moullin voltmeter there described could be used for voltages not exceeding 4 volts in peak value or 2.8 volts R.M.S. It remains, then, for us to see how to apply an accurately known voltage of, say, 3 volts R.M.S. across the ends of the metre wire. For this purpose we shall use a novel application of the triode, the principle of which is shown in Fig. 34.

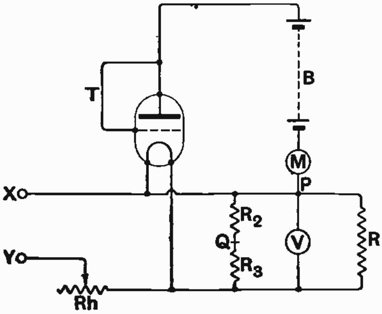

Fig. 34. *Circuit for application of known voltage across resistance wire R_1.*

If the grid and anode of a triode T are connected together, then for any given voltage across the ends of the filament as shown by the voltmeter V, there is a certain "saturation value" of the anode current registered by the milliammeter M, *i.e.*, a certain value that cannot be exceeded however great be the voltage of the battery B. It is evident, therefore, that the reading of M is, under these circumstances, a measure of the voltage applied across the ends of the metre wire resistance R_1, for if this voltage increases so does the brightness of the valve filament and a greater emission of electrons takes place. The readings of M are, however, not quite independent of the direction of the current through the filament. This is because the anode current itself flows through the filament on its way to the negative end of the H.T. battery. When Y is positive and X is negative, the filament is assisted by the anode current, whilst when X is positive and Y is negative it is opposed by the anode current. Thus in the former case the filament is brighter than in the latter, and a larger reading is shown by M for the same voltage across R_1. The discrepancy between the two cases can, however, be considerably reduced by connecting the lower terminal of the milliammeter M to Q instead of P, where Q is the junction of two 1,000-ohm resistance coils R_2 and R_3 made in the same way as those contained in the 10,000 ohm variable resistance (Fig. 9, p. 72, Feb. issue). By so doing, the reading of the milliammeter is not greatly altered by a reversal in the polarity of X and Y.* That is to say, the reading of M is approximately the same whether we apply a direct voltage to X and Y or an alternating voltage of the same R.M.S. value.

The practical application of the above principle to our present task is performed by means of the circuit shown in Fig. 35. *Rh* is a filament rheostat capable of rather fine adjustment, T is a "bright-emitting" 4-volt "R" valve, B is an H.T. battery of 50 volts or more, R_2 and R_3 are 1,000 ohm resistance coils, R_4 is the 10,000 ohm variable resistance (Fig. 9) set at its maximum, R_1 is the metre-wire resistance, M is the micro-ammeter shunted 0 to 1.2mA, and *abcdef* is the mercury cup switch (see Fig. 7). In the left-hand position of the switch M measures the anode current of T, whilst in its right-hand position it serves as a voltmeter with a range of 0 to 12 volts. (When M is in the right-hand position for greater accuracy *ad* is shorted by the "dimming" resistance of the same value as M.)

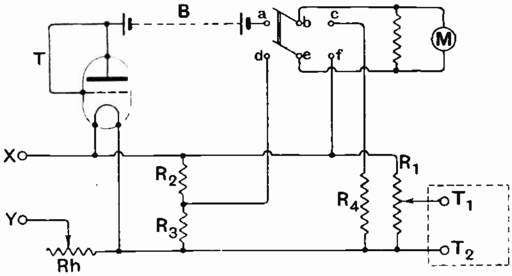

Fig. 35. *Details of calibration method described.*

The calibration of the Moullin voltmeter involves the following operations :—

1. X and Y are connected to a 4-volt accumulator and, with the switch in its right-hand position, b connected to c and e to f, *Rh* is turned until M indicates exactly 3 volts.

2. The switch is thrown to its left-hand position, a to b and d to e connected, and the reading I of the meter is noted.

3. The accumulator is removed from X and Y and replaced by the secondary of a transformer yielding A.C. at about 4 volts.

4. R*h* is adjusted until M once more shows the reading I. The voltage across R_1 is now exactly 3 volts R.M S.

5. The microammeter is removed from the circuit and hooked upon the Moullin attachment (Fig. 30). The L.T. terminals of the latter are connected to a 6-volt accumulator. An H.T. battery also is coupled to its H.T. terminals and adjusted so that the microammeter shows 8μA when the input terminals T_1 and T_2 are shorted. In the instrument shown in Fig. 30, this required exactly 28 volts, but it is usually necessary to adjust the H.T. battery to finer limits than are provided by its tappings, by means of a potentiometer connected across one of its cells (or across an extra cell or two connected in series with it).

6. The input terminals T_1 and T_2 of the Moullin voltmeter are connected respectively to the sliding contact of the metre wire resistance and to its "zero" end.

7. The sliding contact is moved successively to positions "50 mm.," "100 mm.," "150 mm." and so on up to "1,000 mm." Seeing that the total voltage across R_1 is exactly 3 volts R.M.S., these positions correspond respectively to an applied voltage across T_1 and T_2 of 0.15 volt, 0.45 volt and so on up to 3 volts. At each position of the sliding contact, the corresponding reading of the microammeter is taken.

The calibration curve of the Moullin voltmeter is obtained by plotting these readings against the applied voltages. As before, the use of the instrument may be facilitated by the construction of a "supplementary scale," like that shown in Fig. 24. (Fig. 24, by the way, is exactly the size required for the Unipivot instrument recommended.)

Direct Current Method.

The method of calibration given above, although very convenient for those who are furnished with A.C. mains, is of no service at all to those who are dependent upon accumulators or D.C. mains for their supply

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* In our experiments the highest values for the reading of M for the D.C. calibration were found to give results in very close agreement with A.C. calibration. It is to be noted, however, that a considerable change of current in the anode circuit indicates a very small comparative change in the filament circuit. In some early experiments, for example, where no compensation was applied and the lower D.C. calibration curve was taken as correct, an error of less than 2 per cent. in the A.C. calibration in the extreme case was observed.

of current. Lest it should be assumed that such experimenters have no use for an A.C. voltmeter, it must be explained that, although the instrument has been described under the heading of " A.C. measurements," yet its special utility lies in the measurement of high frequency voltages met with in all wireless practice. In fact, we assume that the calibration obtained with a low frequency alternating voltage is valid for a high frequency voltage also. It is but a step from this to assume that the " characteristic " of a valve as obtained with direct current is equally applicable to voltages which are varying very rapidly. Indeed, if we consider any alternating voltage for an instant of time it is *for that instant* a direct voltage, and will correspond at that instant to a definite anode current as shown by the D.C. characteristic curve. Seeing, then, that we can " integrate " the values of the alternating voltage during all the innumerable successive instants which go to make up a complete cycle, then it should be possible to obtain the mean value of the anode current during the cycle from the D.C. characteristic of the valve. We shall show, therefore, a method which does not appear to have been used previously for such a purpose, whereby a Moullin voltmeter can, by a method of approximate integration, be calibrated for alternating voltages provided that the calibration for direct voltages has first been made. The calculation is certainly laborious, but it presents no especial difficulty, and the result is of considerable accuracy.

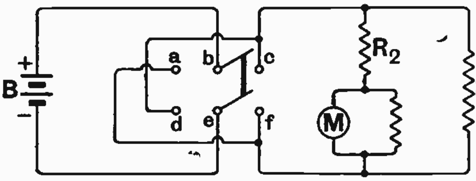


Fig. 36*a*. *Circuit for calibration of Moullin voltmeter by D.C. method.*

The Moullin voltmeter must first be calibrated for direct voltages in the following manner :—

The circuit of Fig. 36*a* is first assembled. B is a 4-volt accumulator, *abcdef* the mercury cup switch (Fig. 7) arranged as a reversing switch, R_1 the " metre-wire " resistance, R_2 the 10,000 ohm resistance (Fig. 9), and M the microammeter shunted to read 0 to 1.2mA. R_2 and M together constitute a voltmeter reading 0 to 12 volts, and enabling the voltage V across R_1 to be measured. The circuit is next modified to that shown in Fig. 36*b*. The L.T. terminals of the Moullin voltmeter are connected to a 6-volt accumulator, and the H.T. battery adjusted as described above so that the microammeter M shows 8A when the input terminals T_1 and T_2 are shorted.

Now we require to find the current in the microammeter corresponding to various known voltages between T_1 and T_2. If the contact X is at the extreme upper end of R_1 opposite to the 1,000 mm. mark on the scale, then this voltage is that already measured, viz. : V. As X is moved downwards, however, the voltage across T_1 and T_2 decreases until when X is at the extreme lower end of R_1, opposite the zero mark of the scale, it has become zero. If it is at any intermediate position, say at 400 mm., then the voltage across T_1 and T_2 is $\frac{400}{1,000} \times V$. Commencing with the switch in the left-hand position, a to b and d to e connected, and, therefore, T_2 positive to T_1, the voltage across these terminals is varied from zero upwards. The current in M being read at each alteration. For voltages over about 2 volts it will be found necessary to shunt the microammeter for a range of 0 to 1.2mA. Finally, the above procedure is repeated with the switch in the right-hand position, b to c and e to f connected, *i.e.*, with T_2 negative to T_1.

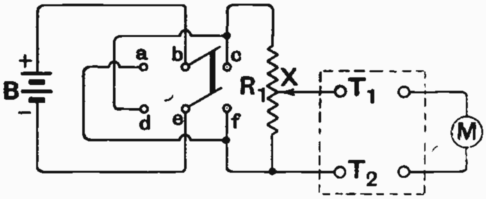


Fig. 36*b*. *Second circuit for D.C. calibration.*

The data is now complete for plotting the D.C. characteristic of the voltmeter. This should be plotted so that the curve can be read with at least as great an accuracy as were the voltage and anode current.

We have now obtained the ordinary input

voltage-anode current characteristic of the biased valve. These two quantities may be assumed to follow the law :—

$$i = \phi(V) \quad \ldots \quad \ldots \quad (13)$$

where i is the anode current and V is the voltage applied to the terminals of the meter. But in an alternating voltage of the simple harmonic type which we are considering we have

$$V = E \sin\theta \quad \ldots \quad \ldots \quad (14)$$

where V=voltage at any instant,

E=maximum or "peak" voltage, and

θ=phase angle at the instant considered.

From this we find that

$$\bar{i} = \frac{\int_0^{360} \phi(E \sin\theta) \cdot d\theta}{360} \quad \ldots \quad (15)$$

where $\bar{i}$ is the average anode current shown by the microammeter, and

$$\left[\int_0^{360} \phi(E \sin\theta) \cdot d\theta\right]$$

is the area of the current-phase-angle graph ; θ being the phase-angle in degrees.

Volts :	1	2	3	4	5	6	7	8	9	10
Av. *sin.*										
0-5	.044	.087	.121	.174	.212	.241	.285	.348	.362	.44
5-10	.131	.26	.392	.522	.653	.784	.914	1.04	1.18	1.31
10-15	.217	.433	.65	.866	1.08	1.3	1.52	1.73	1.95	2.17
15-20	.3	.6	.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0
20-25	.383	.765	1.15	1.53	1.91	2.3	2.68	3.06	3.5	3.83
25-30	.462	.923	1.39	1.85	2.31	2.77	3.23	3.69	4.16	4.62
30-35	.536	1.07	1.61	2.15	2.68	3.22	3.75	4.29	4.83	5.36
35-40	.61	1.22	1.83	2.44	3.05	3.66	4.27	4.88	5.49	6.1
40-45	.675	1.35	2.02	2.8	3.37	4.05	4.72	5.6	6.07	6.75
45-50	.737	1.47	2.21	2.95	3.68	4.42	5.16	5.89	6.63	7.37
50-55	.793	1.59	2.38	3.17	3.96	4.76	5.55	6.34	7.13	7.93
55-60	.843	1.69	2.53	3.37	4.22	5.06	5.90	6.75	7.59	8.43
60-65	.887	1.77	2.66	3.55	4.44	5.32	6.21	7.09	7.98	8.87
65-70	.923	1.85	2.77	3.69	4.62	5.54	6.46	7.39	8.31	9.23
70-75	.953	1.9	2.86	3.81	4.77	5.72	6.67	7.63	8.58	9.53
75-80	.976	1.95	2.93	3.9	4.88	5.86	6.83	7.81	8.78	9.76
80-85	.99	1.98	2.97	3.96	4.95	5.94	6.93	7.92	8.91	9.9
85-90	1.0	2.0	3.0	4.0	5.0	5.99	6.99	7.99	8.99	9.99

Value for .1, .2 volts, etc., are obtained by dividing by 10.

Fig. 37.—*Table of average sines for intervals of five degrees.*

It remains for us to obtain the value of the expression (15). Suppose, for instance, that we wish to find the current shown by the microammeter for an alternating voltage whose peak value is 1 volt. We must split up the voltage cycle into a number of equal parts, say 72 parts, each of 5°. Now the average sine between 0° and 5° may be found from tables to be 0.044. The average value of the current in the cycle of voltage from 0° to 5° may, therefore, be found by looking up the current on the D.C. characteristic corresponding to +0.044 volts on the biased grid. Let this value be i_1. This current i_1 has been flowing for an interval of 5° so that the product of the current and the angle during which it flowed is $5i_1$. This is the area of the first 5° of the current-phase angle graph. By a similar process we obtain $5i_2$ between 5° and 10°, where i_1 is the current corresponding to + 0.131 volt—the average sine between 5° and 10°. The total area over the first *quarter* of the cycle is thus

$$5(i_1 + i_2 + i_3 \ldots\ldots\ldots i_{18})$$

The second quarter of the cycle is, of course, a repetition of this in the reverse order, so that the total area for the first *half* of the cycle is

$$5[2(8_1 + i_2 + i_3 \ldots\ldots\ldots i_{18})]$$

Considering now the third quarter of the cycle, we repeat the process given above, but to find i_{37}, i_{38}, etc., we observe the current on the D.C. characteristic corresponding to — 0.044 volt, — 0.131 volt, etc. The last quarter of the cycle is, as before, a repetition of the third quarter.

Thus for the whole cycle we have a total area of

$$5[2(i_1+i_2+i_3\ .\ .\ i_{18})+2(i_{37}+i_{38}+i_{39}\ .\ .\ i_{54})]$$

but the total interval is 360°, so the average current i is found by dividing the above expression by 360 ; it thus becomes

$$\tfrac{1}{72}[2(i_1+i_2+i_3\ .\ .\ i_{18})+2(i_{37}+i_{38}+i_{39}\ .\ .\ i_{54})]$$

This is the reading of the microammeter corresponding to a peak voltage of 1 volt. For a peak voltage of 2 volts the average sines must be multiplied by 2 in order to obtain the values of the voltages on the D.C. characteristic for which the anode currents are to be taken. In the same way, for the voltages of 3, 4, 0.1, etc., the average sines must be multiplied by 3, 4, 0.1, etc., respectively. In this way the A.C. calibration curve of the Moullin voltmeter is built up point by point. This calibration curve is, however, the relationship of " peak " voltage to meter reading, but the R.M.S. of the voltage is, of course, 0.707 × the peak value.

To make the above operation less laborious we have worked out a table of average sines for intervals of 5° (Fig. 37). It may be pointed out that the calculation may be made much shorter and not much less accurate if intervals of 10° or 15° are taken.

ERRATA.

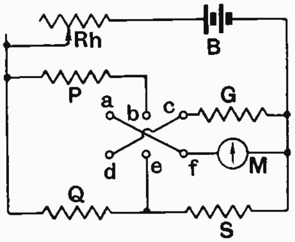
February Issue.

- Page 65, 2nd column, line 6, *for* " bushes " *read* " brushes."
- Page 68, 2nd column, line 12, *for* " ever " *read* " even."
- Page 73, Fig. 11, there should be no connection between b and c. P should be jointed to b, but not to c. See revised diagram.
- Page 76, Appendix 4th line, I_1 = current flowing *through* P when, etc.
- Page 76, Appendix 6th line, I_2 = current flowing *through* Q when, etc.
- Page 104, 2nd column, last line but 5, *for* μA *read* mA

March Issue.

- Page 130, 2nd column, line 4, *insert* " times " *before* " as big as."

An Experimenter's Wireless Laboratory.



Revised diagram of Fig. 11, *page* 73, *February issue.*

N.A.R.M.A.T. WIRELESS EXHIBITION.

An autumn wireless exhibition, which will be open to the trade as a whole, is to be promoted by the National Association of Radio Manufacturers and Traders.

The exhibition will be held in the New Hall, Olympia, from 4th to 18th September next, and it is hoped that sufficient support will be forthcoming to make the display thoroughly representative of the British Radio Industry.

Long-Distance Work.

By Hugh N. Ryan (5BV). **[R545·009.2**

IT was unfortunately not possible to include the customary "Long-distance" article in last month's issue, so this article will cover two months' work instead of the usual one.

As a natural result of last month's non-appearance, reports for this month have been rather scarce, but in any case it is to be feared that very little interesting work has been done during the two months, as far as ordinary DX is concerned, though I believe that the "weather condition" observers are still steadily at work, and obtaining excellent results. As these results must be derived from prolonged periods of observation, it is evident that they can only be published at intervals of several months, if the reports are to be at all interesting, so as I gave a full report of all the most important work in this direction in the February issue, I will not deal with its further developments until more time for observation has elapsed.

The general impression gained from a survey of recent DX work is that the volume of it is falling off very greatly, and that for the most part the better-known and more powerful stations are working much less, while low-powered stations are handling the bulk of the work. This is probably because those of the "hi-pwr" men who were attracted to the work more by the "itch for distance" than by scientific zeal, have given it up now that no DX records remain to be made, while the more scientific among them are now engaged in observation and research work which does not manifest itself so much "on the air." Nevertheless, much work is still to be heard.

2SZ has recently been more than usually busy with other work, and has therefore not been on the air a great deal, but his crystal-controlled transmitter continues to give excellent results.

The doings of 6LJ are wrapped in mystery. His usual report has not turned up, nor has he been heard on the air, but he is said to be deeply immersed in signal-strength curves and weather charts, and some interesting results are expected.

6QB has left short waves for the 200-metre band and uses phone exclusively.

There is plenty to be done on the longer waves, though they seem to be inhabited chiefly by the talk-cum-gramophone people. 6QB has got to Russia and Palestine with very low power on 160 metres, and 6OG (Bristol) is working the United States on 90 metres with only 12 watts.

5HS has worked Australia and Indo-China with 50 watts, though he has difficulty in working Americans. He has also done some very useful low-power work in Europe.

6VP has been one of our most active stations this month. He has altered his aerial system with very good results, and the 1,000 miles which I mentioned as his range last month has now grown to 3,000. He remains one of the few stations one hears with a real D.C. note.

Messrs. Studley, of Harrow, have logged one of the stations in Samoa (NPU) and Panama (PT1). They also head a New Zealander (2BR) who was only using 14 watts input.

5AX has just put up a Hertz aerial, and though his power is still very small his range has increased very greatly.

5QV is getting ready for a change of QRA, but has a temporary rig-up in action, with a Hertz aerial, which is working very well, over most of the world.

6BT has been inactive most of the month, but has worked Malta, while 6JV is working Eastern U.S.A. with 35 watts.

2KK has only been doing receiving work, and has logged a large number of stations, especially South Americans.

2XY recently logged stations in every U.S. district in one night, and his own signals have now been heard in Australia.

6CI is continuing his tests on very low power, his input at present being 0.8 watt, and would welcome reports from stations hearing his signals. His best ranges so far, with this power, have been 215 miles key and 110 miles phone.

A Scottish station has reported for the first time for many months. 6BQ (Glasgow) reports that his portable 10-watt transmitter has been heard in Australia. This must be one of the first Scottish stations to reach the Antipodes, unless the others are too modest to report their successes.

Messrs. O'Dwyer, of Dublin, have stations in most parts of the world in their month's log, including stations in Honolulu and India. One Australian was heard early in the afternoon.

An attempt is being made to form a Saorstat Eireann section of the International Amateur Radio Union. It is certain that such a section is needed, and all Southern Irish amateurs interested are asked to write at once to 115, Anglesea Road, Ballsbridge, Dublin.

The Belgian amateurs have been very active recently, their most interesting achievement being the extra-short-wave work of W2, who has put strong signals into Spain on a wavelength of six metres. As far as I know this is the first long-range work ever done on this wave. S4 has rescued his gear from the flood (mentioned in the last report), and is now working again. He and S2 are both using Hertz aerials, and are both QSO regularly with the U.S.A. Several of the Belgians are doing very well on low powers, E9 having reached South Africa with 20 watts, while G6 has worked Porto Rico on 15 watts and K5 Morocco on half a watt. B2 and D4 are in touch with Brazil, and P2 is, as usual, handling a lot of traffic with U.S.A. Danish 7EC is now living in Belgium, and may soon have a station there.

The Danish amateurs have been doing very useful work in helping a steamship line to equip three of its boats with short wave sets, to communicate with another station on land. The ships ply between Denmark and South America, U.S.A., and Iceland respectively, and have three-letter calls beginning with OY— or OZ—. Reports on the signals from these ships will be welcomed by Danish 7ZM.

Will all those who send me reports please note that I must have them in future by the 6th of each month at the latest, instead of the 10th as hitherto. Reports of low-power DX and reports from foreign stations are especially welcome.

Mathematical Articles.

We have received many letters from our readers suggesting that we should publish articles which would help those whose mathematical training has been limited, to acquire sufficient knowledge of the subject to understand and appreciate, to a greater extent, the mathematical treatment which necessarily enters into so many of our articles. We sympathise very sincerely with those who labour under this disability; it is very disheartening to get interested in an article and then come suddenly on an unintelligible piece of mathematics which makes any further interest impossible.

We are pleased, therefore, to be able to say that we have made arrangements for the immediate commencement of a series of articles which will deal with just those branches of mathematics which are most important to the radio engineer. The subject will be dealt with in as simple and practical a manner as possible, special emphasis being laid throughout upon wireless applications. As in some cases our correspondents have mentioned that it was their inability to follow Mr. Colebrook's articles which caused them specially to regret their lack of mathematics, we are very pleased to be able to say that Mr. Colebrook has undertaken to prepare the series of articles, which we trust will not only enable many of our readers to add to their knowledge of mathematics, but will also enable them to apply more confidently the mathematical knowledge that they already possess to the problems which they meet in their reading and in their experimental work.—Eds.

How Far is that Station ?

By H. E. Adshead, B.A. [R081

IT is sometimes of interest to know exactly how far away and in what direction a certain station lies. Perhaps one is trying a few directional experiments with a frame aerial, or following an aeroplane conversing with Croydon. Maps do not assist us much because the two places seldom come on the same sheet. When we turn to a Mercator projection of the world—the usual one with parallel lines of longitude—the apparent directions are quite erroneous. Ask a Londoner to indicate the direction of New York, and he might point towards Cornwall, whereas the line passes N.W. more or less through Chester ! One would hardly think from Mercator that the shortest way from San Francisco to the Philippine Islands was all round the coast and down the side of Japan, not " straight across " the Pacific.

To work out the bearing (direction) and distance by spherical trigonometry sounds complicated, but I am attempting to make this quite easy. I have set out a special skeleton (filled in with the figures of a worked example) which reduces it to its simplest form, and nothing more than the ability to look up a few straightforward logarithms is required. Rule half-a-dozen horizontal lines and write out all the words there shown, leaving blanks for your own angles and logs, then about twenty minutes with a book of tables will solve the problem. E. and O.E. ! The most likely pitfall is to forget to carry 6's when dealing with minutes of angle and to carry 10's instead.

It is advisable to make just a rough earth diagram to see what one is about. In order to form a spherical triangle on the earth with the two places, we run their lines of longitude up to the nearest pole, and then we have the triangle shown black, the third side which we calculate being the distance required. The angle at the pole is called *D. long.*, or difference of longitude, and it is obviously equal to this if both places are on the *same* side of Greenwich meridian, and equal to their *sum* if on *opposite* sides. Latitude is measured in degrees from the equator, but it is the other part we want, the degrees from the pole, so we subtract the latitude from 90°, and this is called the *co-latitude*. Should one of the places be below the equator, its distance from the pole would be latitude + 90° instead. Try this with a sketch.

Suppose now I have listened to an aeroplane speaking as far as Abbeville (the pilot says where he is) on one valve. How far is that ? The latitude and longitude of each station is obtained from a good atlas or map. We then work out the initial data so :—

	Long.	Lat.	Co-lat.
Abbeville	1° 50′E	50° 08′N	39° 52′
Author ...	0 26′E	51° 57′N	38° 03′

D. Long. = 1° 24′
½ D. Long. = 0° 42′

I will leave this to the reader as a problem. The distance comes to 120 geographical miles, and bearing 153° 24′. I take instead the American broadcasting station KDKA Pittsburg, and Cambridge, England. The distance comes out in degrees, and we remember that 1° = 60 geographical miles, and 1 geographical mile = 6,087.1 feet. One gets two angles for bearings ; which is which ? I have merely called them *A* and *B* so as to refer to them. In any triangle we can see, though Euclid made us prove it, that the greatest angle is opposite the greatest side, and since KDKA is farther from the pole than Cambridge, therefore 68° 35′ will be the angle opposite it, and the bearing required. The results can be checked by comparing them with the " *Wireless World* " *True Bearing Map of the World*. It should be noted, however, that the scales are given wrongly, and are more nearly 1 in. = 1,040 miles, 1.5cm. = 990km. The earth is shown as a 24 in. circle, and 1 in. = 1,000 miles would make its circumference 900 miles short.

It is intended in my skeleton that all the logs on one line shall refer to the angle at the beginning, and that all the logs belonging to the same angle be filled in while the book is open at that page. When looking up *tan* ½ (*A* + *B*) enter the sine of it under the distance column at the same time. A few readers may be puzzled as to why adding half the sum to half the difference of two quantities, gives the larger one, and subtracting them, the smaller; but it is so, try it with a few examples.

Five-figure logarithms will give an answer accurate enough. Perhaps the best five-figure tables are those of M'Aulay, published by Macmillan. The type setting is good and they are fully complete. For seven-figure logs there is the usual Chambers, but some German tables are better set out.

I suggest the reader should work this problem out again for himself, without referring to my figures.

Mathematical readers may like to see the appropriate formulæ set out according to the usual notation. These are:—

$$\tan\tfrac{1}{2}(A+B)=\cot\tfrac{1}{2}C\,.\,\cos\tfrac{1}{2}(a-b)/\cos\tfrac{1}{2}(a+b)$$

$$\tan\tfrac{1}{2}(A-B)=\cot\tfrac{1}{2}C\,.\,\sin\tfrac{1}{2}(a-b)/\sin\tfrac{1}{2}(a+b)$$

$$\tan\tfrac{1}{2}c=\sin\tfrac{1}{2}(A+B)\,.\,\tan\tfrac{1}{2}(a-b)/\sin\tfrac{1}{2}(A-B)$$

Some may ask, why not employ secants and cosecants? In the first place many tables do not give them. Secondly, they do not, for angles near 0° and 90°, give accurate results. Test this on the Abbeville example which is rather interesting on this account. It is not necessary to enter into explanations here. The positions of two B.B.C. stations are: Daventry 1°9′W; 52°15′N, London 0°9′W; 51°39′N, the latter being on the roof of Messrs. Selfridge's Store.

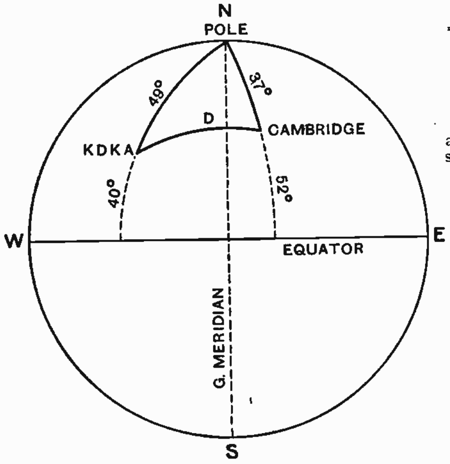
DISTANCE APART OF TWO PLACES ON THE EARTH BY LATITUDE AND LONGITUDE.

MODEL SOLUTION.

Example:	Long.	Lat.	Co-lat.
1. CAMBRIDGE	0° 08′E	52° 12′N	37° 48′
2. KDKA	79° 56′W	40° 27′N	49° 33′

D. Long. = 80° 04′
½ D. Long. = 40° 02′

		DATA.	
Co-lat. (2)	49° 33′		
Co-lat. (1)	37° 48′	½ D. Long.	40° 02′
Diff.	11° 45′	½ Diff.	5° 52′
Sum	87° 21′	½ Sum	43° 40′



For $\frac{1}{2}(A+B)$.

log cot	10.07567
log cos	9.99772
add	20.07339
log cos	9.85936
subtr.	10.21403
= *log tan* ½(A + B) =	58′ 35′
	58° 35′
	10° 00′
adding	68° 35′ = A
subtra.	48° 35′ = B

For $\frac{1}{2}(A-B)$.

log cot	10.07567
log sin	9.00951
	19.08518
log sin	9.83914
	9.24604
= *log tan* ½(A—B) =	10° 00′

For DISTANCE.

log sin ½(A + B)	9.93115
log tan	9.01179
	18.94294
log sin ½(A—B)	9.23967
	9.70327
= *log tan* ½d =	26° 48′
d =	53° 36′
=	3,216 minutes or geographical miles.

$3{,}216 \times \frac{6087}{5280} =$ **3,708 statute miles.**

The greatest angle is opposite the greatest side, therefore the bearing of **KDKA is A, 68° 35′ W. of North.**

NOTE.—

1 geo. mile = 6,087.1 ft. (1855.32 m.);

1 stat. mile = 5,280 ft.;

ratio $\frac{6{,}087}{5{,}280} = 1.153$, *log* 1.153 = 0.06177.

From the World's Wireless Journals.

Abstracts of Technical Articles.

R100.—GENERAL PRINCIPLES AND THEORY.

R112.6.—HORIZONTAL RECEPTION.—R. S. Kruse (*Q.S.T.*, Feb., 1926).

An account of work with horizontal aerials, introduced with special reference to experiments by Dr. G. W. Pickard. Pickard has used a Hertzian rod antenna, with the receiving apparatus at its centre, the whole mounted on top of a wooden tower 18 ft. high, the Hertzian rod being mounted so that it can be rotated or swung into any position.

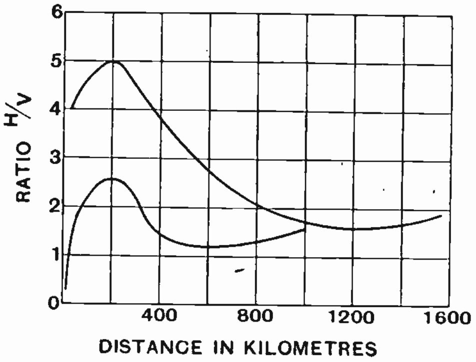


Fig. 1.

Pickard is quoted as stating that wavelengths of the broadcasting band or of greater length are always found to be vertical by day with no measurable trace of horizontal. At night there is a horizontal component amounting to 5 or 10 per cent. of the vertical. With waves of 80, 40 or 20 metres it is found that the greater part of the wave arrives horizontally polarised, the ratios for 80 metres being two-thirds horizontal and one-third vertical, for 40 metres four-fifths horizontal and one-fifth vertical. The results are summed up as follows :

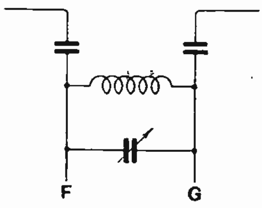


Fig. 2.

The ratio of the horizontal to the vertical electric forces in the wave front depends upon three factors: frequency, distance and time of day. This ratio is not, save in the immediate vicinity of the transmitter, in any way dependent upon the polarisation of the wave at its origin. The curves of Fig. 1 are given as showing results on 80 and 40 metres.

The article also gives a general discussion of the Hertzian di-pole in transmission and reception. Further work on the use of horizontal aerials is described and several typical circuits used are illustrated, that of Fig. 2 being favoured, each of the small condensers being about $5\mu\mu F$.

R113.—SOME STUDIES IN RADIO BROADCAST.—R. Brown, D. K. Martin and R. K. Potter (*Electrician*, 12th Feb., 1926).

An abstract of a Paper read before the Institute of Radio Engineers, dealing with an investigation of transmission made round New York City, and in continuation of previous work by the same writers. It was observed that there were points relatively near New York City where quality distortion was marked at night and in one case detectable in day time. Experiments are described for the investigation of this phenomenon, and it is stated that the carrier and side bands do not fade together as a unit. The carrier may pass through a zero value with still considerable amplitude in the side-band frequencies. Fading is therefore a function of frequency as well as of time. Simple wave interference is the most likely explanation. The effect of frequency differences in fading is then considered theoretically, and curves are given for simultaneous fading on 610 and 610.5kc. 610 and 609.5kc., and 610.5 and 609.5kc. The last shows that maxima and minima of the two frequencies are opposed fairly regularly over the 33 minutes of record shown. Experiments are then described when transmitter frequency was changed in steps over an adjustable range. Results show that within the 2,280 cycle band covered by the data there is approximately one complete cycle of selective fading, the main frequency difference between the successive minima being approximately 2,200 cycles. After considering the shadow effect —*e.g.*, of tall buildings—the paper then describes measurements of fading with spacing. Receivers were spaced 1-16 wavelength apart (*a*) along the line of transmission and (*b*) across the line of transmission. Result curves are shown, the latter revealing closer parallelism than the former. Simultaneous fading results are also given for a vertical aerial and for two loops at right angles to each other in a horizontal plane. These show that a high amplitude of signal may be coming in on both loops while the vertical aerial signal is very small.

Selective fading and its effect on received distortion is then considered theoretically, and it is shown that one side band may fade out completely but that the other will still bring in the signal so long as the carrier is not also lost. The authors conclude that the best form of transmission is single side-band with carrier suppression, and its replacement at the receiver, although the application of this to broadcast transmission and reception would not seem practicable on economic grounds.

R113.—Notes on Wireless Matters.—L. B. Turner (*Electrician*, 12th Feb., 1926).

A continuation of the review of progress in 1925. The magneto ionic theory of propagation is reviewed, along with recent contributions to the literature of the subject. Experiment and theory both point to a critical wavelength of 210 metres at which great absorption should occur in the upper atmosphere. At long distances much better ranges should be obtainable with longer or with shorter waves than this critical value. Other work on propagation is referred to, including that of Appleton and Barnett (abstracted in *E.W.& W.E.*, February, 1926) showing definitely that signal rays do arrive from above as well as horizontally. Reference is also made to the extensive data on signal strength measurements given in the Marconi Research Staff's recent I.E.E. paper (abstracted in *E.W.& W.E.*, December, 1925). The transmission formula deduced is compared with the original Austin-Cohen formula. The present state of knowledge about the upper atmosphere in relation to wireless is then summarised.

R114.—La Prévision du Temps et la Variation Diurne des Atmospheriques.—R. Bureau (*Comptes Rendus*, 4th Jan., 1926.)

The writer distinguishes three chief types of diurnal variation of atmospherics :—

(1) A regular variation characterised by a very marked maximum during the night and an equally marked minimum during the day, with a sharp decrease about sunrise and an increase, generally less abrupt, about sunset.

(2) A regular variation characterised by a total absence of atmospherics in the morning, their marked appearance about 11 or 12, with a maximum about 3 p.m., and their disappearance about 9 p.m.

(3) Irregular variation, appearance and disappearance without regard to the time of day or night. These are correlated with meteorological phenomena. The first originate in anticyclones, the second in "pseudo polar fronts," and include the type of atmospheric known as "grinders." The third is produced by disturbances on a cold front (edge of a depression). The first type is more noticeable in winter, the second type is not so prevalent in moderate latitudes (*e.g.*, France) except in summer, and is more prominent in tropical regions.

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

R149.—La Conductibilité des Colloides Metalliques et ses Applications Electrochimiques.—H. André (*Onde Elec.*, Jan., 1926).

An article dealing with colloidal materials, and their use in electrotechnics, especially in wireless. The general properties and history of colloids are first dealt with. Organic colloids have proved unstable, but metallic, especially silver, colloids have proved stable and satisfactory electrically. The conduction through a cell with electrodes dipping into a colloid are considered, and the author draws a parallel between the action and the electronic emission from a thermionic valve. The rectifying action of a colloidal cell is then considered, and various applications illustrated. These include the use of one cell as a simple rectifier for accumulator charging, etc., and the use of two cells with a centre tapped transformer for full wave rectification, and an arrangement of four cells to give full wave rectification without a transformer. The arrangement of a number of colloidal cells in series or in parallel is also discussed. The author then deals with applications to wireless technique, and illustrates a cell for this purpose in which the cathode is somewhat after the form of the electrode of a Wehnelt interrupter. This works as a wireless detector without any auxiliary voltage and with a sensitivity equal to any "contact apparatus." It is also stated that with suitable electrodes and correct concentration of acid, these cells can be used for the generations of high frequency oscillations. By suitable adjustment from a potentiometer the arrangement can also be used to give amplification with rectification of H.F. currents. The author concludes by comparing the cases of thermionic emission and cold (colloidal) emission, and suggests that the development of the colloidal cell may enable it completely or partially to replace thermionic valves for wireless reception.

R200.—MEASUREMENTS AND STANDARDS.

R201.—An Experimenter's Wireless Laboratory.—L. A. Sayce and J. Taylor (*E.W.& W.E.*, Feb., 1926).

R220.—A Simple Method of Measuring the Capacity and High Frequency Loss of a Condenser.—L. A. Sayce (*Journ. Scien. Insts.*, Jan., 1926).

The method employs a triode oscillator A with a "backed off" galvanometer in its anode circuit. Coupled to A is a closed oscillatory circuit B, containing inductance L, condenser C_1 and resistance R. It is known that, as the coupling between B and A is tightened, B commences to be forced into resonance with A over a short range of C_1, during which the galvanometer drops to a minimum. In the method described the coupling used is that at which the "forcing" just commences. The method is then as follows : (1) R being kept at a value R', near to its maximum, the coupling is adjusted to the point where the "forcing" effect just commences, when B is tuned with C_1 at the value C_1'; (2) Cx, an unknown and imperfect condenser, is then joined in parallel with C_1, and the latter reduced in value until an ill-defined null point indicates approximate resonance; (3) R is then reduced to a new value R'' when "forcing" again just commences. (4) C_1 is finally readjusted to a new value C_1'' at which exact resonance is again shown. It is then evident that the total capacity and total losses in B are identical in (1) and (4), so that the capacity of Cx is $C_1'—C_1''$, and its H.F. losses are $R'—R''$. The losses of C_1 should be negligible and R should be of constant inductance and capacity.

R261.—An Application of the Diode to the Measurement of A.C. Voltages.—J. Taylor (*Journ. Scien. Insts.*, Jan., 1926).

A description of a new form of valve-voltmeter, using a three-electrode valve with its anode and grid connected together to form a diode. The arrangement is shown in Fig. 1, where *R* is of the order of 1 megohm.

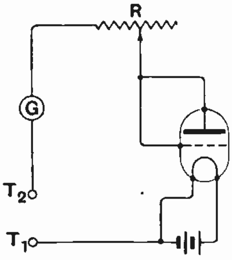


Fig. 1.

The author first considers the case of an ideal valve, *i.e.*, one having unilateral conductivity, following a linear law. It is shown that if an A.C. voltage of *average value* $\overline{V}$ is applied to terminals T_1 and T_2, the *average* current will be half that produced by a D.C. voltage of $\overline{V}$. Expressions are then deduced for the same cases with a diode following Langmuir's "three halves power" law, showing that the ratio is still very nearly half. With the conditions quoted and a potential of only 8 volts, the ratio of D.C. to A.C. would be 2.01 instead of 2, the error decreasing with increase of the voltage measured.

For calibration T_1 and T_2 are first short-circuited and a small back voltage introduced to neutralise any small zero-voltage current. A known steady voltage, say 50 volts, is then applied and *R* adjusted to give, say, 100 galvanometer divisions (2 divisions per volt). If the instrument is then used on A.C. supply the galvanometer will give a deflection of one division per volt (average volts). Since R.M.S. voltage is directly proportional to average voltage, the galvanometer may be made to read R.M.S. value directly by suitable adjustment of *R*.

Frequent calibration is stated not to be necessary, and the calibration is altered little if at all when one valve is substituted for another of a similar type. Results are given for measurements from 100 down to 10 volts for three different valves. These show very good agreement.

R281.—Sur un Nouvel Isolant Electrique.—
A. Samuel (*Comptes Rendus*, 18th Jan., 1926).

A description of a new insulating material, to which the name *thiolite* is given. It is derived from formic-aldehyde and creosol, and is produced (after treatment described) in the form of a white powder. The powder melts at a temperature of 80 deg., and can be further heated and moulded as a solid insulator. It sets very hard and is quite insoluble in any solvent. It is non-fusible and non-inflammable, and does not re-soften with heat. It is also non-hygroscopic and resists chemical action. Samples produced at the beginning of the research four years ago, show no sign of change. Its resistivity is quoted at 3×10^8 megohms per centimetre cube and its specific inductive capacity at 4.5. Its dielectric losses at high frequency are very low.

R300.—APPARATUS AND EQUIPMENT.

R342.—The Performance of Amplifiers.—
H. A. Thomas (*J.I.E.E.*, Feb., 1926).

A detailed abstract of this paper appeared in *E.W.& W.E.* for January, 1926.

The first section of the paper deals with the measurement of voltage amplification. For H.F. measurements a known H.F. voltage (obtained by means of an oscillator and Dye transformer) is modulated 100 per cent. at 1,000 cycles and applied to the amplifier input. The output is measured by a vibration galvanometer. For L.F. amplifiers the 1,000 cycle oscillator is used. Results are shown for H.F. transformer-coupled amplifiers and for resistance-capacity coupling. The second section of the paper deals with the input impedance of the amplifier, *i.e.*, the effect which the connection of the amplifier has upon the oscillatory input circuit. Expressions are given for both cases, with or without reaction, and it is shown that the effect due to reaction can be expressed in terms of the known theoretical conditions. The last section of the paper deals with distortion in audio-frequency amplifiers. For the lower audible frequencies, 130-300 cycles, an Einthoven galvanometer was used for the measurement of distortion. For 1,000 cycles input a cathode ray oscillograph was employed. Cases of severe distortion are illustrated and analysed. The discussion which followed the reading of the paper is also given.

R350.—A.C. Relays.—H. P. Westman (*Q.S.T.*, Feb., 1926).

The article gives a description of a type of relay designed by the author for use on the A.C. supply to a transmitter. One relay is used to break the main power leads, and another as an aerial change-over switch. Constructional details and diagrams are given, with a photograph of the completed relay.

R360.—Short Wave, Plug-in Coil, Receiver Design.—F. J. Marco (*Q.S.T.*, Feb., 1926).

The receiver described uses plug-in coils for grid and reaction circuits. The coils are mounted together and terminalled on four plugs, the plugs of the grid coil being spaced widely apart. An aperiodic aerial coupler is hinge-mounted on the base which carries the tuned coils. Three sizes of coil are described, for a total range of 15 to 130 metres. The coils are of spaced solenoidal winding on a skeleton former of 3 inches diameter. Coil *A* has 19 grid and 6 reaction turns, *B* 8 grid and 4 reaction, *C* 3 grid and 2 reaction turns. The grid

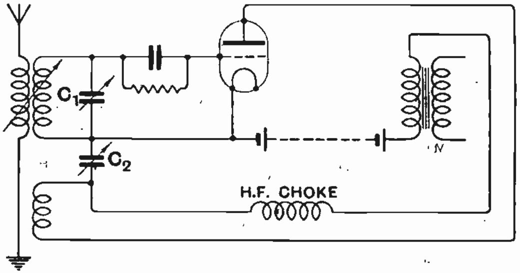


Fig. 1.

coils are of bare No. 18 copper wire, spaced its own diameter. The reaction coils are of small size (not stated) cotton-covered wire slipped inside the main inductance and glued in place at the filament end of the grid coil. The position of the reaction coil being fixed, reaction control is provided by the variable condenser C_2 of Fig. 1, where C_1 is of $140\mu\mu F$ and C_2 of $200\text{-}250\mu\mu F$ total. Calibration curves are given for the three coils described, the reaction control having only a very slight effect on the tuning.

R341.6 and R386.—BATTERY SUBSTITUTES.—R. S. Kruse (*Q.S.T.*, Feb., 1926).

An article describing extensive tests on various (American) commercial rectifier and filter devices for use with A.C. mains for H.T. supply to receiving sets. Thirty-two devices were tested, 19 being already on the market. These 19 are stated to be unquestionably the best of the assortment, although the relative merits of the various makes are not stated. The rectifiers tested fall into three classes: Gaseous tubes, with cold electrodes (*e.g.*, Epom, Raytheon, as recently referred to in abstracts in these columns); Electrolytic; Kenetron or thermionic diode; Kenetron plus gaseous tube; and one completely sealed but probably electrolytic. Tests were made with the following types of receiving set: A regenerative detector with two stages of high grade transformer L.F. amplification; a crystal detector with resistance-capacity L.F. amplifier; a supersonic heterodyne without L.F. amplification; two H.F. stages with detector and two L.F. stages; two H.F. stages with detector and three L.F. resistance-capacity stages. Some of the devices tested were not found suitable for the supply of complete receivers within the above classes. It is stated that the radio frequency amplifier was apparently most sensitive to remaining hum in the supply, and that it was possible to feed the L.F. system with some devices which were quite unsatisfactory for the whole set. Types and details of filters are discussed, and the article well illustrated with diagrams and photographs of many of the substitutes tested.

R351.218.—THE PIEZO-ELECTRIC EFFECT AND ITS APPLICATION TO WIRELESS.—C. W. Goyder (*E.W. & W.E.*, Feb., 1926).

R375.—SUR LA DÉTECTION ET LA STABILITÉ DE CERTAINS DÉTECTEURS.—H. Pelabon (*Comptes Rendus*, 11th Jan., 1926).

A note on imperfect contact detectors of the general form metal-dielectric-metal. Reference is made to a previous note in which the same author described the use of a metal plate with a powder of a metalloid and a metallic point. It is now shown that all dielectrics more or less give the same behaviour as a metalloid and that a sphere of 1 to 3 cm. in diameter may replace the point. Air alone as a dielectric is unstable, and the use of an insulating ring of about 1 mm. thickness is recommended, the sphere being compressed until detection is obtained. Powdered insulating materials (*e.g.*, sulphur, ebonite, glass, mica, etc.) may replace the ring, and excellent results are stated to have been obtained with silicon. The use of a very thin sheet of mica is also described, the sphere being compressed until a puncture is made in the mica. A thin coating of gum may also be similarly used.

R375.—SUR LE MÉCANISME DE LA DÉTECTION.—H. Pelabon (*Comptes Rendus*, 15th Feb., 1926).

A discussion of the theory of the rectifier arrangements described in the previous abstract. The role of the dielectric is twofold—it opposes the approach of the conductors and acts approximately as a restorer after the manner of a Branly coherer. Under a voltage, the two conductors are attracted, and the dielectric exercises an opposing force separating the conductors on the cessation of the voltage. A like state of vibration has been observed by other experiments (quoted). The distance e between the conductors thus varies between $e—a$ and $e + a$. When the sphere is at the closer distance of $e—a$ it is alternately electrically positive and negative. During the negative periods the surface density of negative electricity can attain sufficient value to permit some electrons to leap the very small space separating the conductors.

R351.218 and R384.—CALIBRATING YOUR WAVEMETER FROM A QUARTZ CRYSTAL.—J. M. Clayton (*Q.S.T.*, Feb., 1926).

An article describing the practical use of an oscillating Piezo-electric (quartz) crystal as a frequency standard for the calibration of another circuit. The crystal oscillating circuits are first discussed; the arrangement illustrated provides for the connection of the quartz between grid and anode or between grid and filament, the latter being preferred. An auxiliary generator, in the form of a Hartley oscillator, is then described, with the method of tuning it to the fundamental of the quartz drive. The wavemeter is then to be loosely coupled to the auxiliary generator and tuned for maximum drop in the auxiliary generator milliammeter. The crystal oscillator remaining untouched, the auxiliary drive is then tuned (by reduction of the condenser) to the second harmonic of the quartz drive, and the wavemeter tuned to this as before and so on throughout the available range of harmonics. Points should be recorded as obtained on squared paper so that any error may be detected at once. This refers particularly to the accidental selection of a "fractional harmonic," but the author later describes how these can deliberately be chosen to obtain a greater number of points. The article concludes with a list of sources (in America) from which quartz oscillators can be obtained.

R386.—ESSAI SUR LA THÉORIE DES FILTRES ELECTRIQUES.—P. David (*Onde Elec.*, Jan., 1926).

A lengthy treatise on the theory and practice of filters. First is considered the simple case of the reduction of current due to a circuit whose impedance is a function of frequency. If the ratio $\frac{\text{current without filter}}{\text{current with filter}} = \varepsilon^{\alpha}$, the reduction of current is said to be "α Napiers," and the Napier is defined as the reduction experienced by a current which is reduced to $1/\varepsilon$ of its initial value.

Treatment is then developed for a simple filter of negligible resistance, built up from consideration of the links of a filter chain. The conditions for filtration are stated and the expressions are used to show graphically the limits of frequency which will be passed. The treatment is applied first to the particular case of a low-pass filter, then to the cases of high pass and band pass filters. The effect of ohmic resistance is next considered, and expressions given for the modification of impedance due to its presence. The alteration in the case of a low pass filter is particularly illustrated. The latter part of the article considers the linking up of units of a filter chain, the units not necessarily being identical.

R386.—Filtering the Synchronous Rectifier.—C. Hoover (*Q.S.T.*, Feb., 1926).

A description of the author's experiments on filtering the output of a rotating synchronous rectifier for transmitter supply from A.C. mains. The filter finally used has two effective capacities each of 1μF across the output, the first condenser having a series resistance of 6,000 ohms. A choke of 50 henries is inserted in one lead, and of 1 henry in the other.

R400.—SYSTEMS OF WORKING.

R401.24.—A Portable Transmitter.—A. H. Waynick (*Q.S.T.*, Jan., 1926).

A description, with photographs, of a small transmitter for 40-80 meters. The transmitter panel measures only 6½ by 11 inches. The circuit used is the Reinartz Sending Circuit, shown in Fig. 1. The following dimensions are quoted :—

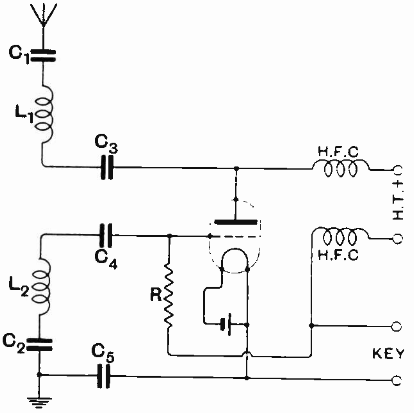


Fig. 1.

C_1 and C_2	.00025μF variable.
C_3 and C_4	.002μF mica.
C_5	.00025μF mica.
L_1 and L_2	15 turns Lorenz coil, 3 in., diameter for 40 meters, or 30 turns for 80 metres.
R	Variable grid leak.
R.F.C.	Radio frequency chokes, each of 90 turns, No. 28 enamelled wire on 1½ inch tube ; the coils wound in opposite directions to each other.

The circuit shown is said to be very adaptable to aerials of various characteristics.

R500.—APPLICATIONS AND USES.

537.1.—Reviews of Progress—Electrophysics. Prof. A. O. Rankine (*J.I.E.E.*, Jan., 1926.)

A review of the present position of knowledge on the fundamental electrical structure of matter, dealing with the atom, electrons, protons, etc., X-rays, ionisation potentials, photo-electricity conduction in gases and in metals, and magnetism.

R800.—NON-WIRELESS SUBJECTS.

R621.313.355.—Entretiers d'une Oscillation Libre non sinusoidale par Résonance de l'un de ses Harmoniques.—J. Fallon and A. Mandiut (*Comptes Rendus*, 1st Feb., 1926).

The article first considers the transient effect in an oscillatory circuit of frequency *m* when an oscillatory or alternating E.M.F. of frequency ω is impressed on it. It is pointed out that the transient term quickly becomes negligible, but if it is desired to obtain across the circuit condenser a voltage of frequency *m*, it is necessary that ω should be a harmonic of *m*. If the circuit has a magnetic—*e.g.*, iron—core and the transient term is sufficient to saturate it, the current wave is altered and the voltage across the condenser includes a fundamental of frequency *m* accompanied by a series of harmonics. This is capable of use as a frequency de-multiplier, *i.e.*, of giving an output frequency which is a sub-multiple of the input. The method used is by the connection of a suitable transformer across the condenser. It is stated that the arrangement has been used to obtain a frequency of 16⅔ cycles from a supply of 50 cycles.

R621.313.355.—Sur la Reversibilité des Multiplicateurs de fréquence à Noyon de Fer.—A. Blondel (*Comptes Rendus*, 1st Feb., 1926).

A theoretical consideration of the process described in the preceding abstract (Fallon and Mandiut). The fundamental equation for a frequency multiplication is considered, and it is shown that from this the reversibility of the process is to be expected. It is pointed out that the de-multiplier will tend to be less stable than the frequency multiplier, and that stability will be helped by an increase of load on the output 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.

The Beverage Aerial.

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

SIR,—I notice your correspondent, Mr. Kaye E. Weedon, in the February issue, makes inquiries with regard to the Beverage Aerial.[*] The Beverage Aerial is described and forms the subject of the United States Patent No. 1,381,089, granted to Mr. H. H. Beverage. A very excellent article by the inventor will also be found in the November, 1922, issue of *Q.S.T.*, on page 7. The aerial consists of a single horizontal wire of length equal to the wavelength to be received or of length equal to an integral multiple of the wavelength. The far end of the wire is earthed through a resistance equal to the surge impedance of the wire. An aerial suitable for 200-metre reception will be 650 ft. long and the surge impedance of such a wire is 550 ohms, assuming length stated and height 10 ft. from the ground. There are one or two effects which theory does not consider, so the most suitable resistance is best found by experiment, and in the case given above will be in between 200—600 ohms. The near end of the aerial is taken to earth through an inductance in the usual manner. For 200 metres this inductance should have a value of approximately 100μH. The receiver is then coupled on to this inductance. The aerial has no very special virtue except that its directional properties are enormous, which, of course, results in the reduction of static and interference. Unfortunately, it is impossible to erect such an aerial in the back garden as Mr. Weedon mentions!

DALLAS BOWER.

Brighton, Sussex.

Rejectors and Absorbers.

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

SIR,—I have read with interest Professor Howe's article on Rejectors and Absorbers in your last issue, but feel there is one point which I do not quite understand.

Surely, for a circuit containing LCR in the form of a rejector the resonant angular frequency is given by ω where $\omega = \sqrt{\frac{1}{LC} - \frac{R^2}{L^2}}$.

I think it is correct that at resonance the impedance of a rejector is L/CR ohms, and that the power factor in the external circuit is unity, so that the value of V/I given as $\omega^2L^2/R + j\omega L$ is incorrect as it cannot be of unity power factor due to the presence of the term $j\omega L$.

Admittedly in practice R^2/L^2 is small compared with $1/LC$ so that the assumption that $R^2/L^2 = 0$ does not introduce appreciable error in assuming that the resonant frequency is $1/2\pi\sqrt{LC}$.

The impedance of a rejector circuit can be given by

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

from which at resonance

$$\frac{\omega L}{R^2+\omega^2L^2} = \omega C \quad \text{or} \quad \omega = \sqrt{\frac{1}{LC} - \frac{R^2}{L^2}}$$

and impedance

$$= \frac{R^2\omega^2L^2}{R} = \frac{L}{CR}$$

C. C. INGLIS.

[The statements made by Mr. Inglis are quite correct, and in the case of the rejector circuits it would have been better if I had not used the term resonance for the condition when $x=1$, or had explained more precisely the sense in which I used the term.

I was mainly concerned, however, to show the similarity between these circuits and the absorber circuit of Fig. 1, and to bring this out I considered in each case the condition $\omega^2CL=1$.

I would point out, however, that $\omega = 1/\sqrt{LC}$ is the resonant angular frequency of the rejector circuits themselves, that is, considered as closed circuits in which an E.M.F. is induced, and it was in this sense that I used the term resonance. It is not exactly the frequency, however, for which the rejector circuit, when forming two parallel paths for an external current as in Figs. 2 and 3, acts as a non-inductive resistance. In the case of Fig. 3, this angular frequency is given by the formula

$$\omega = \sqrt{\frac{1}{LC} - \frac{R^2}{L^2}}$$

as stated by Mr. Inglis, whereas in Fig. 2,

$$\omega = \sqrt{\frac{1}{LC - C^2R^2}}$$

G. W. O. H.]

"Wipe Out."

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

SIR,—Mr. Scroggie has evidently misread my letter. I did not intend to convey that the inductance of the oscillator was changed by influence of 2LO.

While the oscillator is oscillating in step with 2LO it is quite possible that the re-radiation is 180° out of phase, which would account for the phenomenon.

S. BROWNING.

Kingstown, Ireland.

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[*] For a very complete description and discussion of the Beverage Antenna, see an article by Beverage, Rice and Kellogg in the *Journ. Amer. Inst. Elec. Engineers*, Vol. 42, 1923. Also a paper read by Busch in the *Jahrbuch des Drahtlosen Telegraphie*, Vol. 21, 1923.

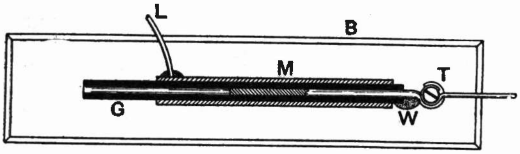
Some Recent Patents.

[R·008

A NEUTRODYNE CONDENSER.

(*Convention date* (*U.S.A.*), *20th February*, 1924.
No. 229,625.)

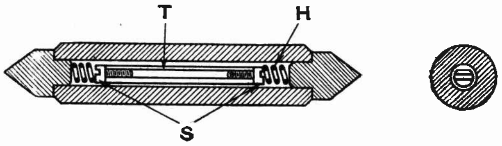
J. F. Dreyer and H. W. Dreyer and the Hazeltine Corporation describe the construction of a neutrodyne condenser in the above British Patent. The accompanying illustration shows that the condenser is a metal tube or piece of foil sliding over a piece of glass tube in which is located a piece of wire. Thus, in one arrangement, the condenser comprises a baseboard *B*, to which is fixed a piece of broad gauge wire *W* held by terminals *T*, around which is a glass tube *G* over which slides a metal tube *M*, to which a wire *L* is attached. Variation of capacity, of course, is obtained by sliding the brass tube along the glass tube, the wire inside the latter only extending about halfway. In another modification two pieces of wire are used projecting from either end of the tube, a metal tube sliding over the tube, capacity variation occurring between the two wires through the metal tube.



GRID-LEAK CONSTRUCTION.

(*Application date*, *12th January*, 1925.
No. 244,284.)

M. Koopman claims the construction of a grid-leak or other similar resistance in the above British Patent, which is illustrated by the accompanying diagram. The grid-leak is made by taking a piece of ebonite or similar insulating tube *T*, and fixing screws *S* at each end. A flat is then preferably filed along the length of the tube and the two screw heads, when graphite is applied by any convenient means, and burnished. The element is then held between two clips connected to a measuring instrument, and more graphite is added or taken away, until the required resistance is obtained.

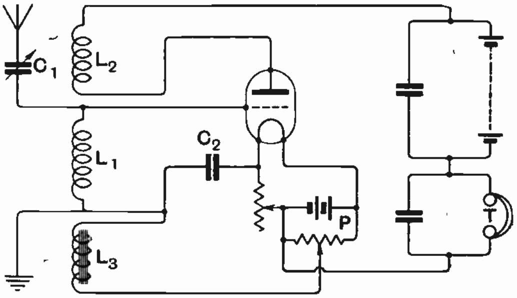


The unit so constructed is then placed in an ebonite or other insulating tube, provided with metal contact points adapted to be held in clips. Connection between the contact points and the resistance element is made by means of helical springs.

ANOTHER SQUEGGER CIRCUIT.

(*Application date*, *1st November*, 1924.
No. 246,592.)

A rather interesting form of squegger circuit, and one which should appeal to experimenters is described by J. Robinson and N. Cox-Walker in the above British Patent. The squegger circuit, it will be remembered, is one in which a valve is provided with tuned high frequency circuits, coupled so as to produce a regenerative effect, the valve further being so adjusted that it will break into oscillation and cease oscillation at some audible frequency, this being known as the "squegger" effect. The accompanying illustration shows the broad idea of the invention. The grid circuit comprises an ordinary tuning coil L_1 and condenser C_1, a reaction coil L_2 being included in the anode circuit, as well as the telephones *T*. The grid circuit contains a grid condenser C_2 and an inductance L_3, the grid potential being regulated by means of the grid potentiometer *P*.

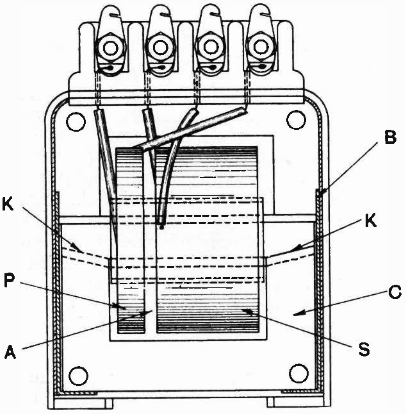


By-pass condensers are shown connected across the high tension battery and telephones. The aerial is tuned to the incoming signals in the usual way, by variation of the condenser C_1, which also controls the frequency of the high frequency oscillations which the valve is generating. With this adjustment a note will be heard in the telephones. On a signal being received, however, the telephone note will vary in frequency, and also probably in character. In operation the position of the reaction coil L_2 and the slider on the potentiometer have to be varied until a suitable squegger note is heard. The inductance L_3 may comprise a winding of about 10,000 turns of No. 42 copper wire, with a closed core of stalloy stampings, the resistance of the inductance being about 2,000 ohms, while the squegger condenser C_2 may be about 0.0003μF. Many modifications of the circuit are shown. For example, the telephones *T* may substitute the iron-cored inductance L_3. The value of the choke L_3 mentioned above is suitable for a high impedance valve. If a lower impedance valve is used, for example, of the order of 5,000 ohms, the inductance L_3 may comprise an air-cored choke, such as a 3,500 turn honeycomb coil. Or again a more compact inductance may comprise 3,000 turns of No. 40 S.W.G. wire on a closed core of stalloy stampings. In another modification the high tension battery is dispensed with, the telephones being connected to the positive side of the low tension battery. Yet another modification consists in including a type of transformer, the primary circuit of which is in the anode circuit, while the secondary circuit comprises the inductance L_3. Those interested in experimenting with squegger circuits would do well to study the specification in detail, as it contains a considerable amount of useful information.

A MODIFIED IGRANIC TRANSFORMER.

(*Application date, 1st September,* 1924.
No. 246,535.)

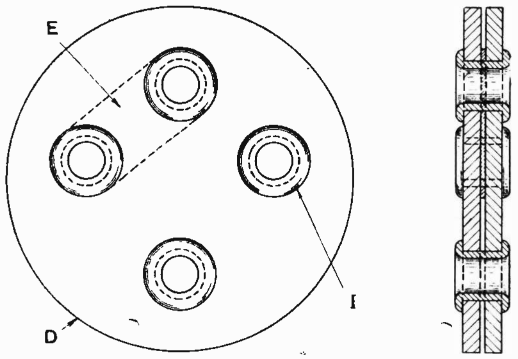
Some modifications of the well-known shrouded type of Igranic transformer are described in British Patent No. 246,535, which has been granted to the Igranic Electrical Company, Limited, A. H. Curtis, S. R. Wright and E. J. Brunning. The modifications are merely constructional details which tend to improve the efficiency of the transformer. It will be remembered that in the early type of transformer the two coils are arranged coaxially on a window type of core. In the accompanying illustration it will be noticed that the coils are still arranged in the same position, but a considerable air gap *A* is left between the primary *P*, and the secondary *S*. This, of course, very materially reduces the capacity between the two windings. Another feature of the invention lies in making the coils comparatively thin in relation to their diameter. The core has also been modified, and it is made in the form of a single rectangle *C* and comprises a number of separate rectangular laminæ, each of which is made discontinuous by a small cut at one point of the magnetic circuit. The core is assembled from the laminæ so that the cuts *K* come at different points in the magnetic circuit. The rectangular laminæ are then opened at the cut and threaded through the core, after which they are closed and pressed together. The edges of the core are further protected from the entrance of dust by providing copper or brass edges *B* which are bent round the ends of the laminæ. Another minor modification is the inclusion of a spring plunger type of terminal.



A DETACHABLE GRID LEAK.

(*Application date, 21st January,* 1925.
No. 246,305.)

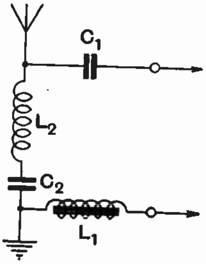
A very novel type of grid leak construction is described in the above British Patent Specification by C. Chapman. The invention consists in mounting a grid resistance element *E* between two discs *D* of ebonite or similar insulating material. The disc carries four sockets in the form of eyelets *I*, which coincide with the normal position of the valve legs, the eyelets serving to hold the two insulating discs together. The resistance element is connected between the grid eyelet and one of the filament eyelets. Thus it will be seen that if the valve legs are pushed through the appropriate eyelets the grid leak will be connected electrically between the grid and one of the filament pins. Simply by removing the discs and turning them over, and replacing them on the valve legs, the leak will then be connected to the other side of the filament.



A DISTURBANCE ELIMINATOR.

(*Application date, 16th February,* 1925.
No. 245,953.)

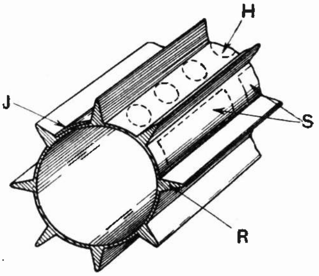
A circuit intended to eliminate disturbances arising from electric light mains, and similar forms of electric interference, is claimed by A. E. R. Trotman in the above British Patent, No. 245,953. The device comprises essentially a radio frequency choke and small capacity condenser, and a low frequency choke and a large capacity condenser, which are arranged as a network, and connected to an ordinary receiver. The accompanying illustration shows the arrangement of the circuit. The novelty of the invention lies not only in the arrangement, but also in the actual values of the components. Thus, in the illustration, the radio frequency condenser C_1 is of the order of 0.0003μF, and acts as a by-pass to radio frequency currents. The specification simply states that the iron-cored low frequency choke L_1 has a resistance of about 750 ohms, but no indication of its inductance is given. Between the aerial and the earth a high frequency choke L_2 is included. This may comprise about 350 turns of No. 42 double silk covered wire on a $1\frac{5}{8}$ inch former. This inductance is in series with a large capacity condenser C_2 of the order of 1 to 3μF. It would seem that the arrangement allows high frequencies to be applied to the set, and substantially tends to eliminate the effect of any low frequency potentials which might be introduced by induction from the aerial or earth leads, or by leakage currents.



A LOW LOSS COIL FORMER.

(*Application date, 9th March,* 1925.
No. 245,634.)

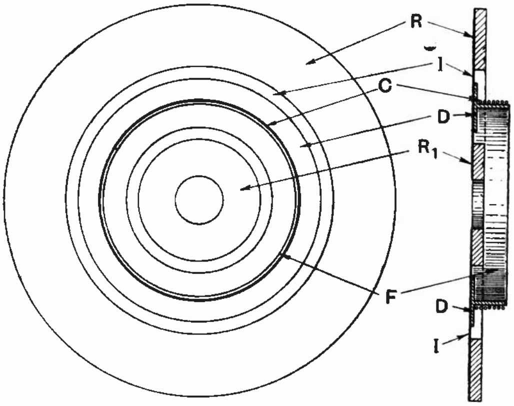
The construction of a low loss coil former is described by Fuller's United Electric Works, Limited, and A. P. Welch in the above British Patent. The accompanying diagram illustrates the type of former which, in effect, is simply a cylinder provided with a number of longitudinal fins or ribs. Actually the former is made out of sheet insulating material provided with a number of V-shaped ribs *R*. The sheet is then rolled into a cylinder, the ends being overlapped as shown at *J*. In order still further to increase the air space and remove as much dielectric material from the field as possible, holes *H*, or slots *S*, may be stamped out of the sheet. The specification also provides for arranging the ribs spirally about the surface of the cylinder.

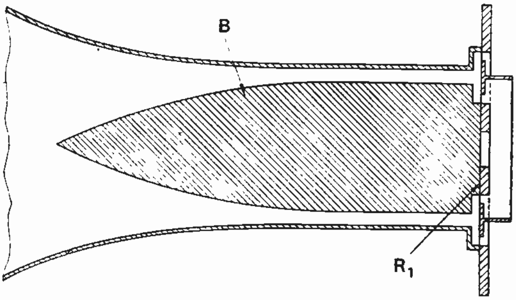


ANOTHER "ROUND" LOUD-SPEAKER.

(*Application date, 5th January,* 1924.
No. 246,096.)

Some very interesting details of the construction of a loud-speaker are described by H. J. Round in the above British Patent, which relates essentially to a loud-speaker having an annular diaphragm. The ring diaphragm *D* is made of non-magnetic material, such as ebonite, and carries a cylindrical flange *F*. This flange is preferably attached to the ring diaphragm *D* by means of a strip of silk provided with a series of cuts to form tongues turned alternately to each side of the uncut portion, the tongues being attached to the flange by means of "Bakelite" varnish. The flange carries a coil *C*, through which the speech currents are passed; the diaphragm *D* is attached to two concentric rings *R* and R_1, by means of some flexible material *I*, such as rubber. The coil *C* carried by the flange *F* is, of course, immersed in a strong magnetic field. The method of communicating the vibrations of the diaphragm to the air in the sound conduit is rather interesting, and is also shown in the accompanying diagram. It will be noticed that the inner ring R_1 has attached to it a device *B* of symmetrical formation, which is shown in cross section. Some interesting points in the specification are that the weight of the conductor in the coil *C* should be of the same order as the weight of the diaphragm, or a little greater. It is also stated that the elastic material supporting the diaphragm should preferably be stretched to such a degree as to communicate to the air system when vibrating at a frequency of the order of 80, but not more than 150. It is stated that it has been found that if the flexible material is left flabby, thereby giving a very low natural frequency, the response



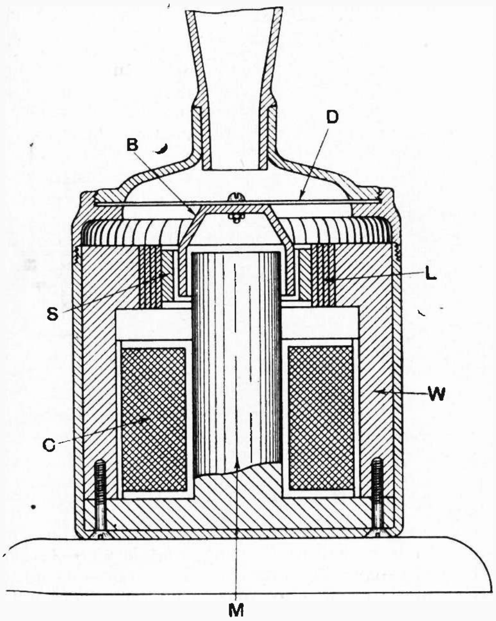


of the diaphragm for the lower musical tones is likely to be such that the diaphragm may touch the pole pieces. The specification is very detailed, and describes several modifications of the diaphragm and construction of the magnetic system.

A DUBILIER LOUD-SPEAKER.

(*Application date, 27th October*, 1924. *No.* 246,556.)

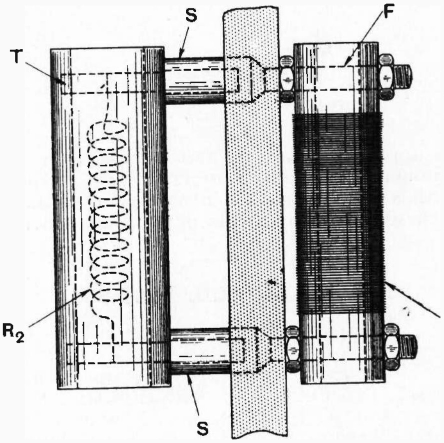
A rather interesting form of coil-driven loud-speaker is described by The Dubilier Condenser Company (1921), Limited and A. Nyman in the above British Patent. The accompanying illustration shows the arrangement of the loud-speaker, in which it will be seen that there is an upright permanent magnet *M* to which are attached cylindrical walls *W* provided with laminated pole pieces *L*. Around the permanent magnet *M* is a coil *C* which is energised from a source of direct current. The diaphragm *D* is fixed to a bell-shaped portion *B* made of aluminium or other light metal. The mouth of the metal bell lies between the end of the permanent magnet and another winding *S* arranged round the laminated pole pieces. Thus it will be seen that the bell-shaped portion *B* is traversed by a relatively strong direct current magnetic field produced by the winding *C*. It will also be seen that if the speech currents are communicated to the stationary winding *S* the bell-shaped portion *B* will also be traversed by alternating currents induced by the speech currents, which will therefore cause the bell-shaped portion to move up and down, thereby imparting vibrations to the diaphragm *D*, which communicates with a sound conduit in the usual manner.



CONTROL OF FILAMENT CURRENTS.

(*Application date, 3rd November*, 1924. *No.* 246,233.)

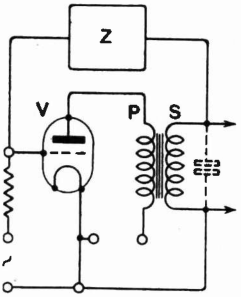
H. Stevens and A. J. Stevens & Company (1914), Limited, describe a method of controlling filament current which is illustrated by the accompanying diagram. The filament circuit of a particular valve has included in it a resistance R_1, which is shown wound on a cylindrical former *F*. The ends of the resistance are connected to two sockets *S*, on the front panel of a receiver. An additional resistance R_2 is mounted in an insulating tube *T* provided with pins which fit into the socket *S*. The resistance, which is permanently included in circuit, is intended to be suitable for use with dull emitter valves, and the resistance in the detachable tube is such that when it is connected in parallel with the fixed resistance it is suitable for use with bright emitter valves.



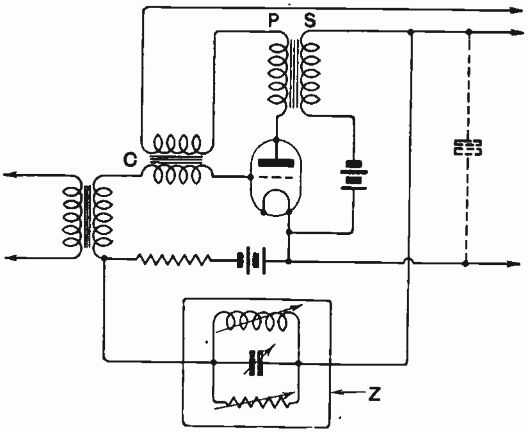
COMPENSATING FOR DISTORTION.

(*Application date, 14th October*, 1924. *No.* 245,839.)

A very interesting method of compensating for distortion in low frequency amplifiers in which the successive valves are coupled by transformers is described by P. W. Willans in the above British Patent. Distortion in low frequency amplifiers may be due to three causes: first, the diminution of impedance of transformer windings at low audible frequencies, secondly, the drop in the impedance of the transformer at high frequencies owing to its self capacities, and finally, magnetic leakage between the primary and secondary windings of the transformers. According to the invention, the distortion is compensated by employing reaction between the output and input circuits of the amplifying valves. The accompanying illustration shows the broad idea of the invention, in which a valve is provided with a transformer having primary windings *P* and secondary windings *S*. The usual filament batteries are omitted from the drawings for the sake of clearness. The transformer is connected so that the primary has its windings in opposite sense to the secondary windings; that is, the ends connected to the anode and the grid are substantially in opposite phase. An impedance is then connected between the grid of the valve and the secondary circuit of the transformer, the impedance being shown at Z. If this impedance is a capacity the result will be to reduce the effective self-capacity of the transformer.



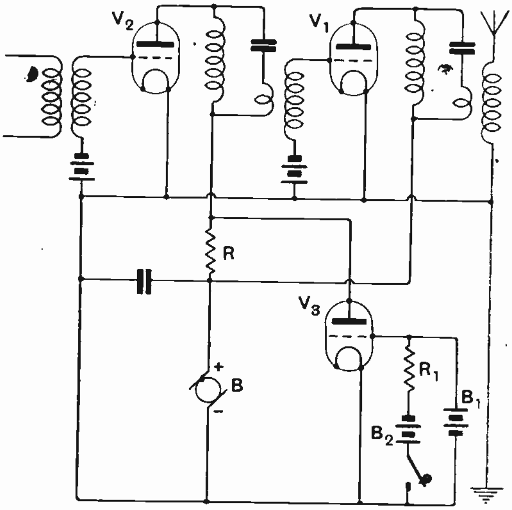
If it be an inductance the result will be to increase the effective self inductance of the transformer, thereby giving more amplification at the lower frequencies. If the impedance is composite, that is, comprising an inductance and a capacity, both the results will be obtained simultaneously. Again, if the impedance is simply a resistance the effect will be to increase the component of amplification in phase. Again a resistance in series with an inductance will compensate the effect of magnetic leakage. The exact nature of the impedance desired has to be found by experiment to suit the conditions of the transformer. The specification describes a number of similar modifications, in which an additional compensating transformer is connected so as to compensate for the effect of magnetic leakage. It is connected in series with the primary of the main transformer, the secondary being connected in the grid circuit of the valve. The illustration also shows an arrangement which will compensate for all forms of distortion likely to occur. The compensating transformer C, the main transformer PS and the compensating impedance Z will readily be recognised. The specification gives no indication of the desired value of the various components, which obviously have to be found by trial.



KEYING TRANSMITTERS.

(*Application date, 13th October, 1924.*
No. 245,829.)

A very interesting method of keying transmitters which should prove useful to the amateur experimenter is claimed in British Patent No. 245,829 by N. E. Davis and W. T. Ditcham. The novelty of the invention lies in including a resistance in the supply lead to an independent drive valve or intermediate amplifier, and keying the transmitter by causing a sufficient voltage to be produced across this resistance which very materially lowers the normal potential of the independent drive so that the output from the last magnifier is either very considerably diminished or reduced to zero. The accompanying diagram illustrates the basic form of the circuit. The valve V_1 represents the last magnifier and the valve V_2 represents an intermediate magnifier, but the scheme may equally well be applied to the independent drive. The source of anode supply is at B, and it will be seen that the anode circuit of the valve V_1 is connected direct to this through the ordinary oscillatory circuit. The anode of the valve V_2, however, is connected through its oscillatory circuit by a resistance R. The valve V_3 has its filament and anode connected across the generator and the top end of the resistance R. The value of the resistance is such that normally the potential applied to the anode of the valve V_2 is sufficient for correct functioning. However, if a positive potential be applied to the grid of the valve V_3 the impedance of the anode filament space will be very considerably lowered. This

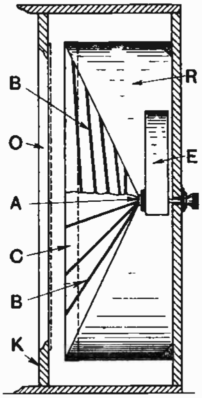


means that there will be a considerable potential drop across the resistance R, sufficient to lower the anode voltage of the valve V_2 to such a point that it ceases to amplify to any appreciable extent, or oscillate, as the case may be. This control is brought about by means of two batteries. The battery B_1 gives the grid a positive potential, and the battery B_2 connected to a resistance R_1 gives the grid a negative potential, the change being brought about by means of the key. The degree of control can be varied as desired merely by altering the value of the resistance R and the grid bias battery of the amplifier valves.

A REINFORCED DIAPHRAGM.

(*Application date*, 24*th October*, 1925. *No.* 245,704.)

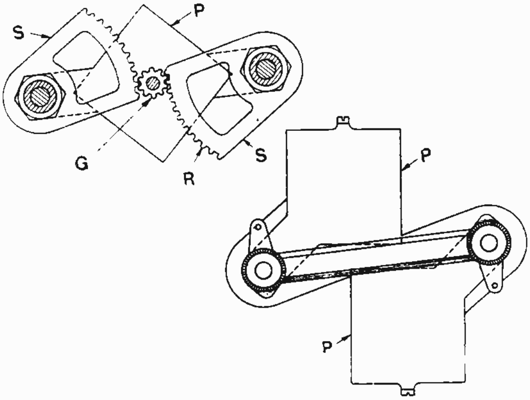
The construction of a loud-speaker diaphragm is claimed in the above British Patent by E. V. Mackintosh and C. French. The novelty of the invention lies in the reinforcing of a conical diaphragm. The diaphragm is composed of some light material of the nature of paper and is made in the form of a cone C, reinforced with strips of bamboo B. The periphery of the cone is rigidly clamped to some material, such as bristol board R, while the apex of the cone A is attached to an electro-magnetic system E. It is stated that the weight of the cone may be of the order of one ounce, and that a 12-inch cone rigidly clamped at the edge will vibrate at a frequency as low as 60 cycles. The conical diaphragm and the driving mechanism is housed within a cabinet or container K provided with an opening O in front of the cone.



THE NEWEY CONDENSER.

(*Application date*, 15*th May*, 1925. *No.* 246,362.)

The Newey square plate condenser is described in the above British Patent by J. G. Newey and C. B. Jerred. The accompanying illustration should be sufficiently clear to illustrate the idea of the invention. It will be noticed that the condenser comprises two sets of square plates P designed to interleave with each other. The operating knob and dial are connected to a pinion G which engages simultaneously with two racks R formed on the end of sectors S. The two sets of plates are naturally insulated from each other. The lower half of the illustration shows the very low minimum capacity which exists in the zero position. It will be seen that on rotating the dial the pinion G will engage with the two sets of racks R, thereby causing the plates to interleave, the increasing area of overlap being substantially in the form of a rectangle.



A SPACED INDUCTANCE.

(*Application date*, 18*th October*, 1924. *No.* 245,537.)

Lord Egerton of Tatton describes the construction of a rather interesting coil former in the above British Patent. The coil is built up upon a cylindrical former F provided with a number of longitudinal V-shaped grooves V. Spacing bars S of triangular cross section are provided with grooves G, and the spacing bars are arranged in the longitudinal grooves V on the cylinder, being held in position by pins P which pass through holes H in the centre of the bars. The inductance is wound over the first layer of spacers, the wire being held in the small grooves G. Another set of spacing bars is then placed over the first set as shown, and the second layer wound on. Two of the pins P are replaced by metallic connectors K, which serve the dual purpose of making connection with the ends of the coil and also holding two sets of spacing bars in position. The specification also provides for the use of slightly different shapes of spacing bars.