EXPERIMENTAL WIRELESS
& The WIRELESS ENGINEER

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A JOURNAL OF RADIO RESEARCH AND PROGRESS

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IN THIS ISSUE

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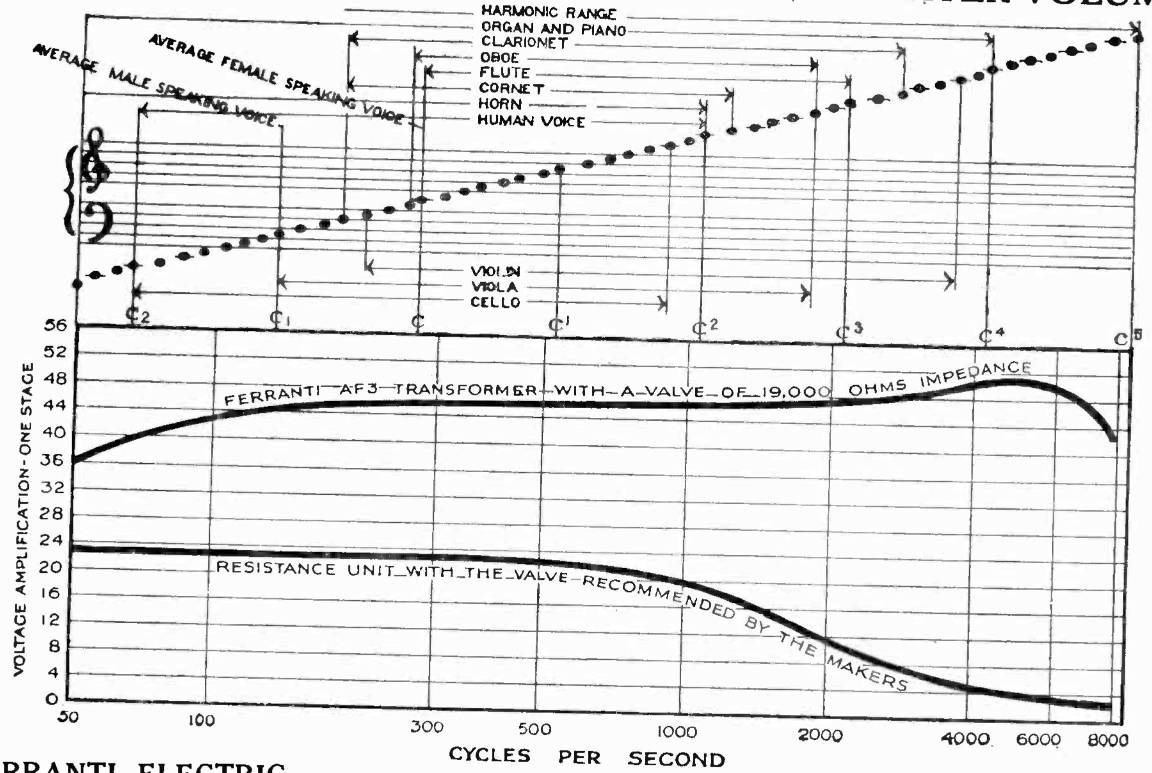

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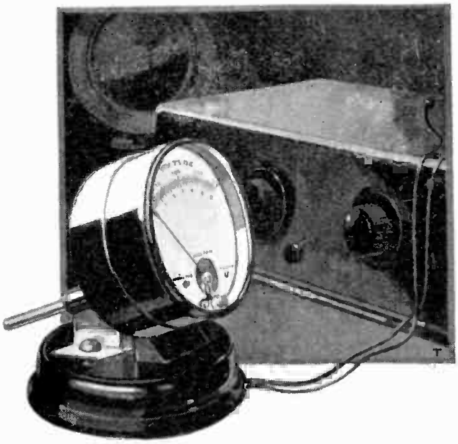

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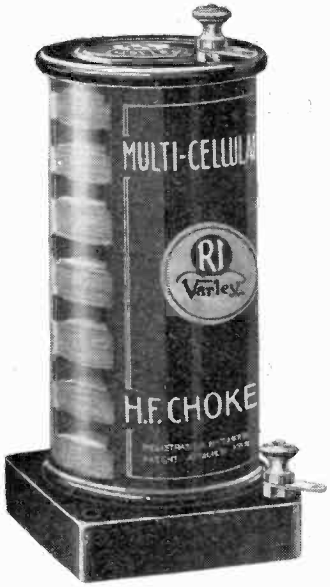

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A Journal of Radio Research and Progress

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EXPERIMENTAL WIRELESS
& The WIRELESS ENGINEER

VOL. IV. AUGUST, 1927. No. 47.

Editorial.

A Simple Indirect Method of Measuring Grid Current.

IN the March number of the *Zeitschrift für Hochfrequenztechnik*, von Ardenne describes a novel method of measuring very small grid currents by means of a galvanometer or micro-ammeter which, used directly, would be too insensitive for the purpose. Grid currents of 10^{-10} to 10^{-9} amperes can be measured by means of an instrument capable of measuring 10^{-7} to 10^{-6} amperes. The method is based upon the fact that if a grid leak of known value is employed the grid current causes a fall of potential along the leak resistance, and thus alters the grid potential by an amount which is determined from the

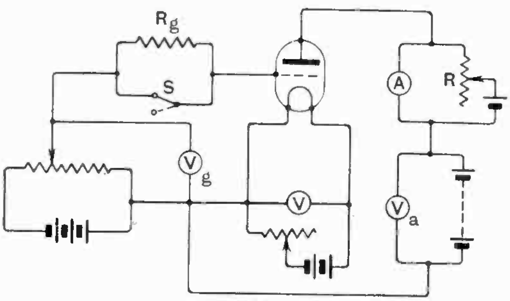

Fig. 1.

change it produces in the anode current. It is thus an application of the valve voltmeter principle to the determination of one of the characteristics of the valve itself. Fig. 1 shows the circuit arrangements; *A* is the micro-ammeter or galvanometer in the anode circuit, the reading of which is normally

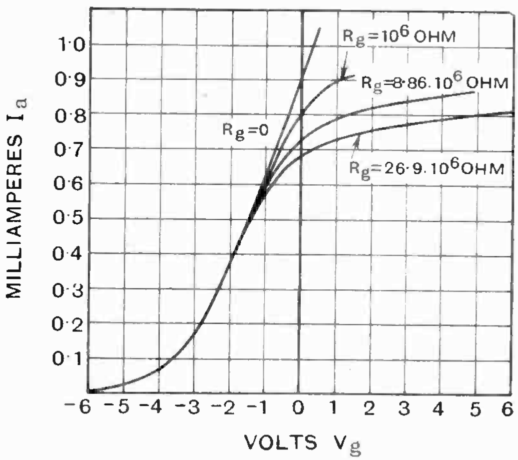

Fig. 2.

adjusted to zero by means of a cell and the resistance *R*. The grid battery is provided with a potential divider, across which the voltmeter V_g is connected. The switch *S* enables the grid resistance R_g to be inserted or short-circuited. So long as no grid current flows, it is immaterial whether R_g is in or out, but if there is any grid current a fall of potential occurs in R_g and the anode current is modified by its insertion. This is clearly shown in Fig. 2, which shows how the anode current varies with V_g for various values of R_g. In Fig. 3 the upper curve is the ordinary characteristic with R_g cut out and the lower curve that with R_g inserted. Since the points A and B represent the same anode current they must also represent the same actual grid voltage; it will be noticed that V_g in Fig. 1 reads the voltage tapped off the grid battery, but not the actual voltage of the grid except when $R_g=0$ or $I_g=0$. The vertical intercept BC in Fig. 3 represents the decrease of anode current caused by the insertion of R_g, which decrease could have been produced without inserting

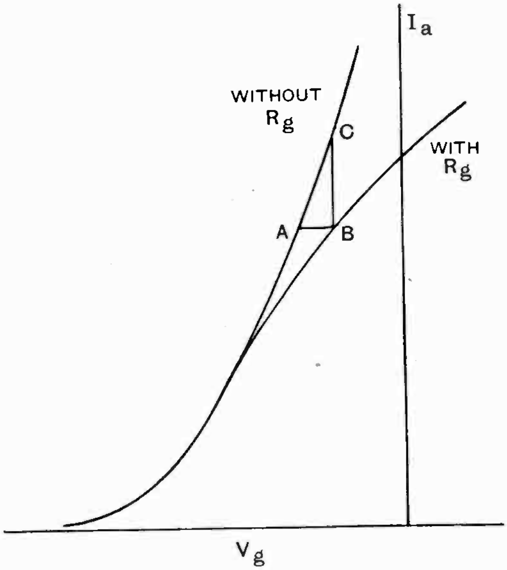

Fig. 3.

R_g by decreasing the grid potential by an amount AB. Hence $BC=\delta I_a$ and $AB=I_gR_g$. Calling the slope of the characteristic S, we have

$$S=\frac{BC}{AB}=\frac{\delta I_a}{I_gR_g}$$

and

$$\frac{\delta I_a}{I_g}=S.R_g$$

This expression gives a measure of the increased sensitivity of the method, since δI_a is what is actually measured instead of I_g. Although it can be theoretically increased indefinitely by increasing R_g, great difficulties due to insulation are introduced if R_g is increased beyond about 50 megohms. This is sufficient, however, to give an increased sensitivity of about 10,000, thus enabling a grid current of about 10^{-10} amperes to be measured by means of a pointer instrument.

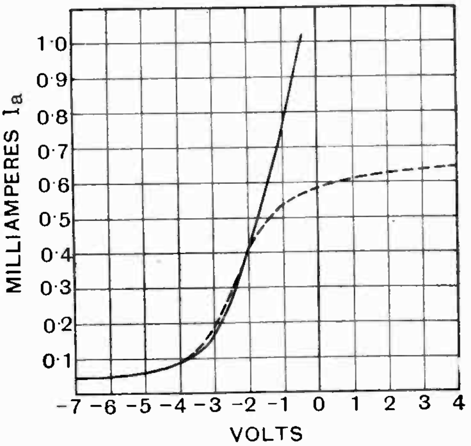

Fig. 4.

To plot the grid current characteristic a number of horizontal lines, such as AB in Fig. 3, are drawn corresponding to the grid voltage at A, the grid current is equal to AB/R_g and this is plotted on the vertical ordinate through the point A. If the valve contains gas it is known that grid current flows in the reverse direction for certain values of negative grid voltage owing to positive gas ions being attracted to the grid.

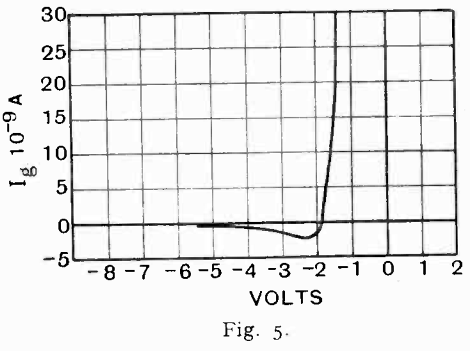

Fig. 5.

This will cause the grid to assume a higher or more positive potential than that indicated on V_g since the fall of potential in R_g is now in the reverse direction. This is seen in Fig. 4, which was obtained from tests on a soft valve; an analysis of these results in the way described above gives the grid characteristic shown in Fig. 5.

Grid Signal Characteristics and other Aids to the Numerical Solution of Grid Rectification Problems.

By W. A. Barclay, M.A.

PART I.

MOST experimenters are familiar with the use of the grid current characteristic of a valve in explaining the complicated theory of grid detection. Apart from this theoretical use, the usual practical function of the grid characteristic as applied to detector valves lies in the approximate determination of initial working conditions. Certain values of leak resistance and grid bias voltage being decided upon in more or less arbitrary fashion, a resistance line of position and slope to correspond is inscribed upon the conventional diagram, and its point of intersection with the characteristic curve noted. The co-ordinates of this point then represent the grid voltage and grid current of the system for initial or pre-signal conditions.

Thus far there is nothing at all questionable in the procedure, so long as the limitations which are tacitly imposed upon the diagram are distinctly understood. Unfortunately many amateurs (and valve manufacturers also) are apt to regard this diagram as conveying in some way an idea of the "detecting efficiency" of the valve. This efficiency, of course, is not only a function of the valve and the circuit in which it operates but depends also upon the magnitude of the signal which it is desired to rectify. The crux of the process of grid rectification lies in the change of mean grid potential due to the impressed signal, which, for simplicity in the argument, we shall assume to be pure C.W. Now, this change of mean grid potential for any signal is, as will be shown hereafter, readily obtainable from the characteristic diagram. Its value, however, is by no means ascertainable by mere inspection, and until it has been derived, the diagram affords no indication of "detecting efficiency." The idea that it is possible to estimate this solely from the "curvature" of the characteristic at the point of intersection with the resistance line is thus seen to be quite fallacious. Apart altogether from the fact that this point has to do with the initial conditions, and not with those under which signals are received, it should be noted that the term "curvature" as thus applied to the characteristic is quite unscientific. The idea in the minds of those who use the word in this connection is not the "curvature" of the mathematicians, but partakes of the nature of a second differential coefficient. The looseness of thought is reflected in the impossibility of exact definition, which, happily, there is no need to attempt.

The theory of grid rectification has been exhaustively dealt with in the pages of this journal, notably in the valuable series of articles by Mr. F. M. Colebrook (*E.W. & W.E.*, November, 1925—February, 1926) to which readers are referred. The writer, however, may be pardoned his impression that the quantitative aspect of the subject has not yet been developed on lines commensurate with its importance, and that from the point of view of the computer anxious for numerical results, the theory of grid detection is not in so satisfactory a state as the corresponding theory of amplification. For this, the complicated mathematics of grid detection is largely to blame: yet, in one view, this analysis can only be justified if, in the end, it smooths the way to an easy arithmetical or graphical procedure in the practical case. To simplify the calculations incidental to the subject has been the aim of the present writer in the following notes. At the outset, as much of the theory of grid detection will be considered as will render intelligible the conception of "grid signal characteristics," after which, abandoning theory, practical methods of obtaining these curves both graphically and arithmetically will be discussed. Thereafter, certain advantages of these methods will be considered, always from the arithmetical standpoint, and graphical and arithmetical processes described which will materially shorten the calculations involved. It should be clearly realised, however, that the author's method of "grid signal characteristics" is applicable to grid characteristics of any form. It is thus eminently suited to the experimental curves met with in practice, which do not, generally, conform to the exponential form over a wide working range of grid voltage.

The theory of grid rectification being presumed familiar to readers, the conventional diagram of Fig. 1 will not require any detailed explanation. The i_g—v_g curve having been experimentally obtained for conditions in the valve, the line VP_o is drawn to show the relation between the current flowing and the P.D. between the two ends of the leak, of which that connected to the filament is held at the fixed potential v, represented by the point V. The pre-signal values of voltage and current are then shown by the co-ordinates of P_o, viz., OM_o and M_oP_o.

The problem of grid detection is, in general, to obtain the position of a point M_s which will represent the average value v_s of grid voltage during reception of a signal which we shall suppose of amplitude E. For the normal detecting circuit, the point M_s will generally be situated to the left of M_o. In Fig. 1 lengths LM_s and M_sN are taken to represent E volts, so that LQ and NR are the extreme limits of current variation. Now, during a sinusoidal variation in grid voltage $E \sin \omega t$ about a mean value represented by the point M_s, there will be a certain average value of current, mathematically determinable, which may be represented by a point P_s on the ordinate upon M_s. The length M_sP_s will, of course, depend upon the magnitude of E as well as upon the shape of the curve, so that for other values of signal amplitude, other positions of P_s will correspond on the same ordinate. If the signal amplitude E is such that the position of P_s happens to lie upon the leak line VP_o produced, it will be apparent that the average current flowing when $E \sin \omega t$ acts about M_s is exactly sufficient to maintain a P.D. represented by M_sV between the ends of the leak. In other words, if P_s lie on the leak line, M_s will represent the average voltage v_s of the grid during reception of a signal of amplitude E, using this particular value of leak and bias voltage. Further, the length M_oM_s will represent the amount of change in mean grid potential due to the reception of the signal, and this, of course, is our ultimate objective.

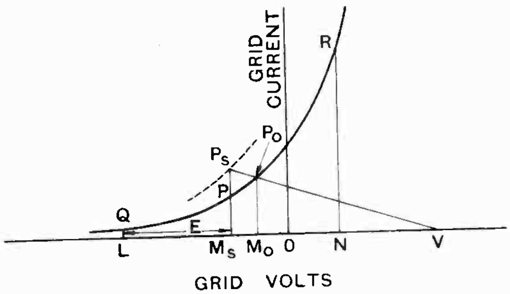

Fig. 1. *Conventional diagram for grid current characteristic.*

We have seen that by mathematical considerations (into which we shall enter presently) it is possible to assign the length of an ordinate M_sP_s which shall represent the average current corresponding to a sinusoidal variation of grid voltage of amplitude E about a mean value v_s. By repeating the same procedure for a different value of mean grid voltage, v_s', we can also obtain the ordinate $M_s'P_s'$ which represents the average current due to a sinusoidal variation of voltage of the same amplitude E about another mean position M_s'. It is clear that a series of ordinates may thus be plotted for different points along the voltage axis. Each such ordinate is derived from the original characteristic by determining mathematically the average grid current due to a sinusoidal variation in grid voltage of constant amplitude E, when the mean value of this signal voltage operates at various points of the voltage axis. To the curve drawn through the points P_s, P_s', etc., may be assigned the name of *the grid signal characteristic for signal amplitude E*. This is the dotted curve shown in Fig. 1. Its intersection with the leak line VP_o occurs at

P_s, and it is seen that, means having been found to draw the grid signal characteristic, the abscissa of its intersection with the leak line determines the mean value v_s of grid voltage during the signal in the same manner as the intersection of this line with the original grid characteristic determined the pre-signal conditions. In passing, it is to be noted that to every value of E there will correspond a separate grid signal characteristic curve. If a series of such curves for various values of E be drawn on the diagram, it becomes a simple matter to read off the variations in grid voltage due to the rectification of C.W. signals of various amplitudes, using any values of leak resistance and fixed bias voltage. This is possible inasmuch as the grid signal characteristics are entirely independent of leak resistance and bias voltage, depending solely upon the original grid characteristic curve and the signal amplitude. The derivation of the grid signal characteristics will now be considered.

Let the ordinary grid current characteristic of a valve as obtained experimentally be represented by the equation

$$i_g = f(v_g)$$

where f is, in general, an unknown function. If, now, the grid be maintained at a mean voltage value v_s, while subject to a sinusoidal variation of amplitude E, we may represent the total extent of the voltage variation by the distance LN, of which the middle point, M_s, represents the voltage v_s, while $LM_s = E$ volts (see Fig. 1). Let the frequency of the E.M.F. be n per second, so that the period of one complete oscillation is $1/n$ second. Let us consider the variation of grid voltage with the time during one complete oscillation. We shall suppose that at time $t=0$, the grid voltage has its minimum value, $v_s - E$, represented by the point L. At the end of a quarter period, or when $t=1/4n$, its value is v_s, represented by M_s. When $t=1/2n$, its value is v_s+E, shown at N. As t increases yet further, the voltage again diminishes, until at $t=1/n$ it is again represented by the point L. A convenient expression for the instantaneous grid voltage will be

$$v_g = v_s - E \cos 2\pi nt \qquad \dots \quad (1)$$

as may be seen by substituting for the above values of t. The corresponding expression for the variation in grid current is at once given by

$$i_g = f(v_s - E \cos 2\pi nt) \qquad \dots \quad (2)$$

As t assumes the values 0, $1/4n$, $1/2n$, $3/4n$, $1/n$, the values of i_g are represented by the ordinates LQ, M_sP, NR, M_sP and LQ. Our problem now is to find the height of an average ordinate, M_sP_s, which shall represent the average value of current, $\bar{i}$, throughout this cycle. As in half a period from $t=0$ the value of i_g passes from minimum to maximum, and in the next half period the cycle is reversed, the average current flowing through each half period is the same. We may therefore proceed to find the average value of i_g during the first half cycle only. This mean value is obtained by integrating equation (2) with respect to time between the limits $t=0$ and $t=1/2n$, and dividing by the amount of the time between these limits, viz., $1/2n$. We have then for the average value of the current,

$$\bar{i} = 2n \int_0^{\frac{1}{2n}} f(v_s - E \cos 2\pi nt).dt \qquad \dots \quad (3)$$

or, changing the variable to θ, the angular phase of the voltage variation at instant t, so that $\theta = 2\pi nt$,

$$\bar{i} = \frac{1}{\pi} \int_0^{\pi} f(v_s - E \cos \theta).d\theta \qquad \dots \quad (4)$$

The insuperable obstacle to the straightforward evaluation of this integral lies, of course, in the unknown nature of the function f. By assuming an exponential form for this function Mr. Colebrook has obtained the value of a similar integral as the sum of an infinite series, and has given tables by means of which it may be accurately computed under this hypothesis. But, as before remarked, the experimental curves obtained in practice rarely conform throughout any wide range of grid voltage to the exponential form, and it will be better, perhaps, to tackle the problem from a new angle, leaving the form of the function unspecified. The most obvious procedure, where the form of the function is unknown, is to have recourse to methods of approximate or "numerical" integration, and the writer applied various formulæ widely used in engineering and actuarial science to the problem of evaluating this integral. The most convenient for the purpose, however, and one which, as will be shown, lends itself admirably to arithmetical processes, was found to be the following, due to Bronwin (*Phil. Mag.*, 34 (1849), p. 262),

$$\int_0^{\pi} f(\cos\theta).d\theta = \frac{\pi}{p}\left\{ f\left(\cos\frac{\pi}{2p}\right) + f\left(\cos\frac{3\pi}{2p}\right) + \ldots + f\left(\cos\frac{\overline{2p-1}.\pi}{2p}\right)\right\}$$

which is rigorously true if f is presumed to be a function whose $2p$th differences are zero.

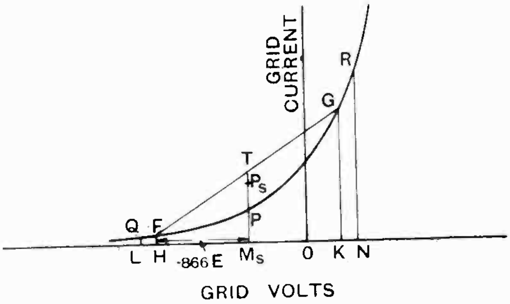

Fig. 2. *Showing the derivation of the point* P_s *on the grid signal characteristic corresponding to signal amplitude* E.

Assuming, then, that the sixth differences of our characteristic function are negligible throughout the voltage range in which we are interested, we may put $p=3$, and write,

$$\int_0^{\pi} f(\cos\theta).\,d\theta = \frac{\pi}{3}\left\{ f\left(\cos\frac{\pi}{6}\right) + f\left(\cos\frac{\pi}{2}\right) + f\left(\cos\frac{5\pi}{6}\right)\right\} \ldots (5)$$

Here, then, is a very simple evaluation of the integral in equation (4). We have,

$$i = \frac{1}{\pi}\int_0^{\pi} f(v_s - E\cos\theta)\cdot d\theta$$

$$= \tfrac{1}{3}\left\{ f\left(v_s - E\cos\frac{\pi}{6}\right) + f\left(v_s - E\cos\frac{\pi}{2}\right) + f\left(v_s - E\cos\frac{5\pi}{6}\right)\right\}$$

$$= \tfrac{1}{3}\{f(v_s - .866E) + f(v_s) + f(v_s + \cdot 866E)\} \ \ldots \ (6)$$

If in Fig. 2 we take the points H and K on either side of M_s and distant from it by $.866E$, and erect ordinates HF and KG to the curve, it is evident that we can substitute the lengths of the three ordinates in equation (6). We have then the remarkable result,

$$i = M_sP_s = \tfrac{1}{3}\{HF + M_sP + KG\} \ \ldots \ (7)$$

A very simple geometrical construction for obtaining the value of the average current thus follows which, for facility of reference, may be termed the "three-ordinate method." On either side of M_s (Fig. 2) at distances equal to $.866E$ erect ordinates HF and KG to the curve. Join FG, and let it meet the ordinate at M_s in T. Then the point P_s is situated above P at two-thirds the distance PT. For

$$M_sT = \tfrac{1}{2}(HF + KG)$$

$$PT = M_sT - M_sP = \tfrac{1}{2}(HF + KG - 2M_sP)$$

By construction

$$PP_s = \tfrac{2}{3}PT = \tfrac{1}{3}(HF + KG - 2M_sP)$$

$$\therefore M_sP_s = M_sP + PP_s = \tfrac{1}{3}(HF + KG + M_sP)$$

The procedure thus indicated to find the point P_s on the ordinate at M_s can, of course, be carried out very easily for any other value of mean voltage v_s, taking care that the extreme ordinates be always situated at the constant distance of $.866E$ volt from the centre ordinate. By this means, the grid signal characteristic curve corresponding to a given signal amplitude E may be plotted out as v_s varies in value. By an extension of the process, the signal characteristics for other values of E may also readily be found.

It may be useful here to outline a graphical adaptation of the three-ordinate process which the writer has found of service in plotting out the grid signal characteristics for various values of E. Let it be required, for example, to plot these curves for every .2 volt difference in E. In Fig. 3 let the voltage axis be divided into steps of $.2 \times .866$ volt, *i.e.*, of .173 volt, starting from any arbitrary position. Then, by applying the three-ordinate method, taking each ordinate in turn as the mean, and using three consecutive ordinates, the grid signal characteristic for $E = .2$ volt is obtained. By applying the method using the next ordinate but one on either side of every mean, we obtain the curve for $E = .4$ volt. Again applying it, using the third ordinate from every mean, we obtain that for E=.6 volt. In the diagram (Fig. 3), chords C_1, C_2, C_3 have been drawn corresponding to these three cases for the particular ordinate at M. The corresponding points P_1, P_2, P_3 are shown at their appropriate positions on this ordinate between the chords and the curve. The dotted curves show the results of the application of the process to other ordinates. The constructional work may be done very rapidly in pencil, the resulting points on the signal characteristics being marked in ink. As large a scale as can conveniently be used is recommended for the work.

The above graphical method is not always,

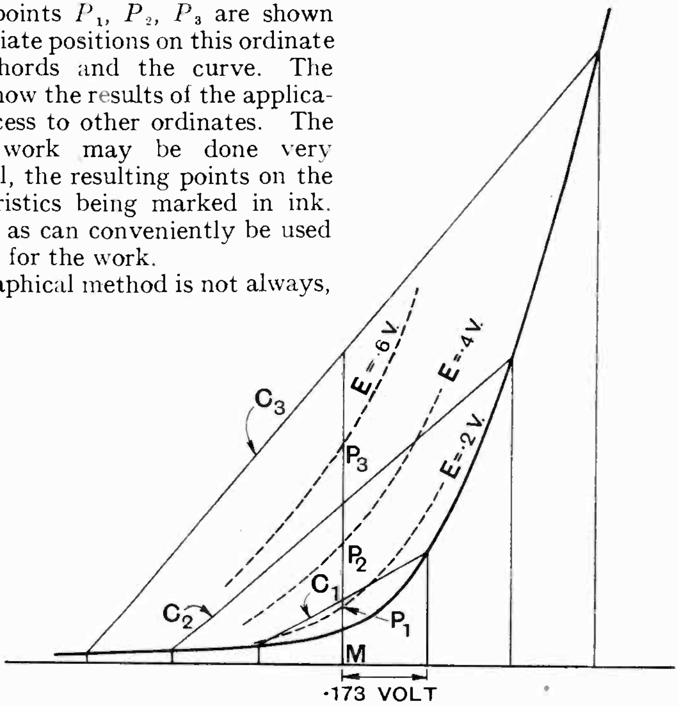

Fig. 3. *Graphical derivation of grid signal characteristic curves.*

however, convenient, and the arithmetical process now to be described may, perhaps, be considered superior to it from the point of view of accuracy. It being required to find the grid signal characteristics at intervals of e volt signal amplitude, set off on the voltage axis steps of .866e volt on either side of the zero point (see Fig. 4). Then the values of grid voltage at these points will be .866pe, where p has a succession of integral values, positive or negative. Let the corresponding values of grid current for these values of p be denoted by i_p. Then we may write

$$i_p = f\,(.866pe) \quad \ldots \quad \ldots \ (8)$$

Suppose, now, that we select some particular value of p which we will call n, so that the particular voltage on the grid is .866ne and the corresponding grid current i_n. Let us consider this voltage .866ne as the mean value of several sinusoidal E.M.Fs. of different amplitudes. If ${}_e\bar{i}_n$ represent the average value of current due to an alternating E.M.F. of amplitude e operating about a mean grid voltage v_s=.866ne, we have, since

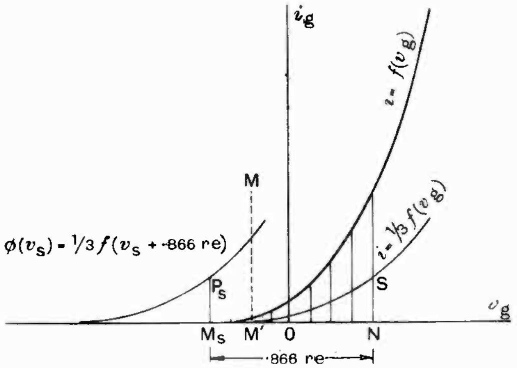

Fig. 4. *Each small division on the* v_g *axis represents* .866e *volts. In this diagram* M_s *is shown four divisions to the left of* 0, *i.e., the value of* n *taken is* −4, *and* $v_s = -4 \times .866e$ *volts. The length* M_sN *occupies eight divisions, i.e.,* $r = 8$, *so that the signal amplitude illustrated is* 8e *volts.*

the consecutive ordinates are situated .866e volt apart, by equation (7),

$$_{e}\bar{i}_n = \tfrac{1}{3}\{i_{n-1} + i_n + i_{n+1}\}$$

Also, if the signal amplitude is 2e, the average current is, similarly,

$$_{2e}\bar{i}_n = \tfrac{1}{3}\{i_{n-2} + i_n + i_{n+2}\}$$

And, generally, the average current due to a signal amplitude of re volts, operating at the value .866ne of mean grid voltage where n and r are any integers, is

$$_{re}\bar{i}_n = \tfrac{1}{3}\{i_{n-r} + i_n + i_{n+r}\} \quad \ldots (9)$$

On the diagram of Fig. 4 we may select any arbitrary ordinate MM', to the left of which all ordinates to the original grid characteristic curve may be considered negligible. If the value of n taken in the last paragraph is such as to cause the position of v_s to lie to the left of MM', *i.e.*, if the current ordinate i_n is negligible, the ordinates i_n and i_{n-r} may be put equal to zero in equation (9), which thus becomes

$$_{re}\bar{i}_n = \tfrac{1}{3} i_{n+r} \quad \ldots \quad \ldots (11)$$

a result of extreme simplicity. Rewriting

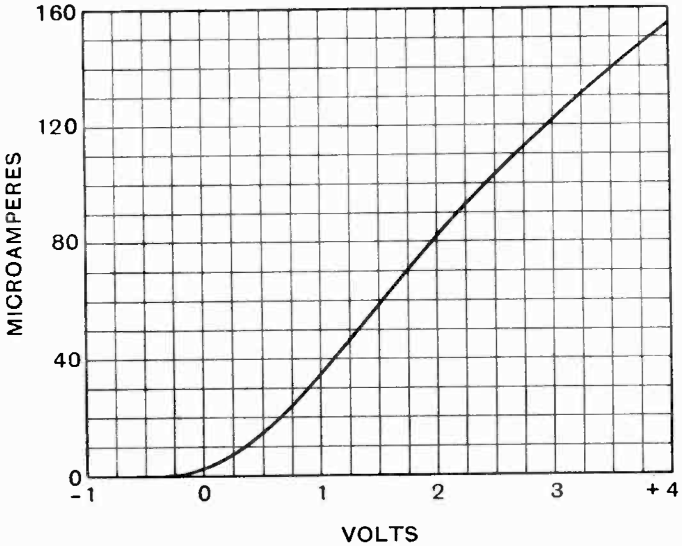

Fig. 5. *Grid current characteristic of Edison Swan D.R.2 valve.*
($v_f = 2$v; $v_a = 60$v.)

In computing these values, much labour will be saved if each of the original current values obtained from the characteristic be divided by 3. The values of $_{re}\bar{i}_n$ as both n and r vary may thus be easily obtained by simple addition. Writing $j_n = \frac{1}{3} i_n$, we have,

$$_{re}\bar{i}_n = j_{n-r} + j_n + j_{n+r} \quad \ldots (10)$$

the values of which may be rapidly set down by inspection from a table of values of j_n.

It will often occur, in carrying out the addition process of the last paragraph, that the values of several of the ordinates dealt with are so small as to be negligible. Owing to this circumstance the task of plotting the grid signal characteristics over a portion of their length may be yet further facilitated.

this equation by means of (8),

$$_{re}\bar{i}_n = \tfrac{1}{3} f\,(.866\,(n+r).e) \quad \ldots (12)$$

it appears that, for any position of mean grid voltage $v_s = .866ne$ situated to the left of MM', a sinusoidal variation of re volts amplitude will cause to flow an average current equal to one-third of the instantaneous current shown by the original grid characteristic at a voltage increased by .866re. In other words, the grid signal characteristic of amplitude re is, for all that part of it situated to the left of the ordinate MM', a replica of the curve obtained by dividing the ordinates of the original grid characteristic by three, the horizontal distance between the two curves being equal to .866re (see Fig. 4).

This may perhaps be more clearly demonstrated by considering the average grid current flowing for signal amplitude re as a function of the mean grid voltage about which the signal operates. If v_s denote this mean voltage, we may write

$$ {}_{re}\bar{i}_n = \phi(v_s) $$
$$ = \phi\,(.866ne) $$

Therefore, from equation (12),

$$ \phi\,(.866ne) = \tfrac{1}{3} f\,(.866\,(n+r).e) $$

i.e., $$ \phi\,(v_s) = \tfrac{1}{3} f\,(v_s + .866re) \quad \ldots \quad \ldots (13) $$

which is the analytical expression of the age. As in all cases the signal characteristics lie to the left of the original curve, it will be seen that the intersections of the leak line with the signal curves will mostly occur at values of grid voltage lying to the left of the line MM'. Thus it happens that, in the great majority of cases, only the signal characteristics to the left of MM' need be drawn, and it is a happy circumstance that it is in this region of the diagram that the curves are easiest to construct.

We shall now derive the grid signal characteristics for a typical case. Fig. 5 shows a grid characteristic curve supplied

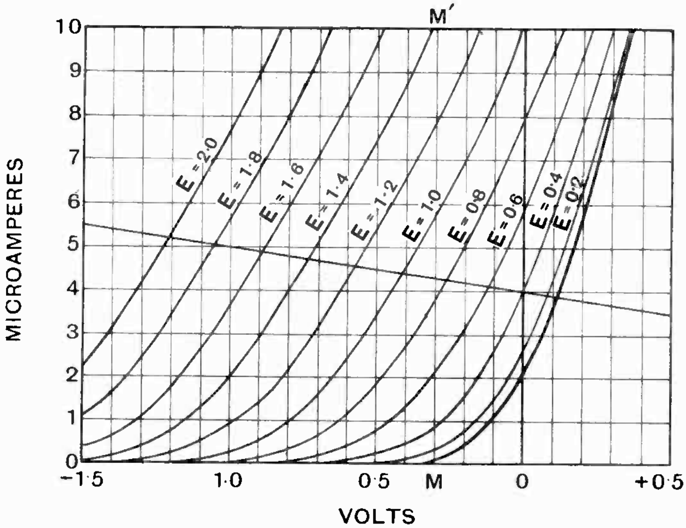

Fig. 6. *Portion of grid signal characteristics of D.R.2 valve. The leak line is that for 1 megohm with fixed positive bias of 4 volts.*

statement made above. It should be carefully noted that equations (11), (12) and (13) are only true for certain values of v_s, viz., those at which ordinates to the original characteristic may be considered as negligible. For values of v_s to the right of MM', the signal characteristics must be plotted from equations (9) or (10).

It will be convenient to recall here the purpose for which the grid signal characteristics are constructed. As we have seen, they are used in conjunction with the leak resistance line to determine the mean value of grid voltage under signal conditions in precisely the same way as the original grid characteristic determined the pre-signal voltage.

by the Edison Swan Company for their D.R.2 valve. Taking $e = .2$ volt, the values of i_n for the values $v_g = .866ne = .173n$ were read off this curve and tabulated as in the annexed table. Corresponding values of ${}_{re}\bar{i}_n$ for various values of r were then computed as shown, and plotted against their particular mean voltage values $.173n$ in Fig. 6. The heavy curve in this figure is the original grid characteristic: the others represent the signal characteristics at intervals of .2 volt up to a signal amplitude of 2 volts. It will be seen that all curves to the left of MM' are similar.

The resistance line corresponding to a leak of 1 megohm at a positive bias of 4 volts is also shown, from which the mean grid voltages for various signal amplitudes with this leak may be read off immediately. For other values of leak and bias voltage, other lines may be drawn as required.

It may be remarked that the writer's choice of a grid current characteristic to illustrate his method was purely fortuitous, and no expression of opinion as to its merits as "detector" is intended to be conveyed. The characteristic is, however, otherwise interesting, departing notably from the exponential form (Fig. 5).

In the next part of this paper it is hoped to deal with further simplifications in method and practical working.

TABLE

Showing derivation of values of $_r\bar{i}_n$ from those of i_n.

n	$v_g = .173n$	i_n	j_n	$_{.2}\bar{i}_n$	$_{.4}\bar{i}_n$	$_{.6}\bar{i}_n$	$_{.8}\bar{i}_n$	$_{1.0}\bar{i}_n$	$_{1.2}\bar{i}_n$	$_{1.4}\bar{i}_n$	$_{1.6}\bar{i}_n$	$_{1.8}\bar{i}_n$	$_{2.0}\bar{i}_n$
—9	—1.56	0	0	0	0	0	0	0	0	0	0.2	0.7	1.7
—8	—1.39	0	0	0	0	0	0	0	0	0.2	0.7	1.7	3.3
—7	—1.21	0	0	0	0	0	0	0	0.2	0.7	1.7	3.3	5.3
—6	—1.04	0	0	0	0	0	0	0.2	0.7	1.7	3.3	5.3	7.3
—5	—0.87	0	0	0	0	0	0.2	0.7	1.7	3.3	5.3	7.3	9.7
—4	—0.69	0	0	0	0	0.2	0.7	1.7	3.3	5.3	7.3	9.7	
—3	—0.52	0	0	0	0.2	0.7	1.7	3.3	5.3	7.3	9.7		
—2	—0.35	0	0	0.2	0.7	1.7	3.3	5.3	7.3	9.7			
—1	—0.17	0.6	0.2	0.9	1.9	3.5	5.5	7.5	9.9				
0	0	2.0	0.7	2.6	4.0	6.0	8.0	10.4					
+1	0.17	5.0	1.7	5.7	7.2	9.0							
+2	0.35	10.0	3.3	10.3									
+3	0.52	16.0	5.3										
+4	0.69	22.0	7.3										
+5	0.87	29.0	9.7										

NOTE.—In the above Table, the values computed for average grid current have an upper limit of 10 microamperes, as no higher values are required to plot the limited region shown in Fig. 6. In general, however, the Table should be extended to utilise a greater portion of the characteristic of Fig. 5 than is here done.

(To be continued.)

Alterations to the Modulating Panel at 2LO.

By E. Green, J. L. Hewitt, and T. G. Petersen.

THE original 2LO station was erected at Marconi House before the British Broadcasting Company was formed, and many investigations were made there by Marconi's Wireless Telegraph Company, Limited. Among these, an interesting investigation by Captain Round, in which one of the authors was assisting, of the conditions obtaining in the Modulating Panel of the station, gives a good example of the value of plate current-plate voltage characteristics in studying the action of valves.

The alterations made to the panel, as a result of the investigation, greatly improved the modulation by enabling a greater depth of modulation to be used over the whole frequency range, more especially at the highest frequencies. These alterations were subsequently embodied in the new 2LO station.

If the H.T. D.C. voltage $= V_0$
and the electrostatic voltmeter reading $= V$
then amplitude of voltage variation $= V \times \sqrt{2}$.

Depth of modulation $= \dfrac{\sqrt{2}\,.\,V}{V_0} \times 100$ per cent.

We shall see later that this would give misleading results at the lowest frequencies, but would be approximately correct for all frequencies above 100 cycles.

At frequencies around 200 to 1,000 cycles, it was possible to modulate quite normally to a depth of 55 per cent. without getting grid current or rectification on the main modulator valves. As the frequency was raised, this possible depth gradually decreased until at a frequency of 5,000 cycles it was only about 30 per cent., and at 10,000, about 20 per cent. If these limits were exceeded, grid currents flowed in the main modulating

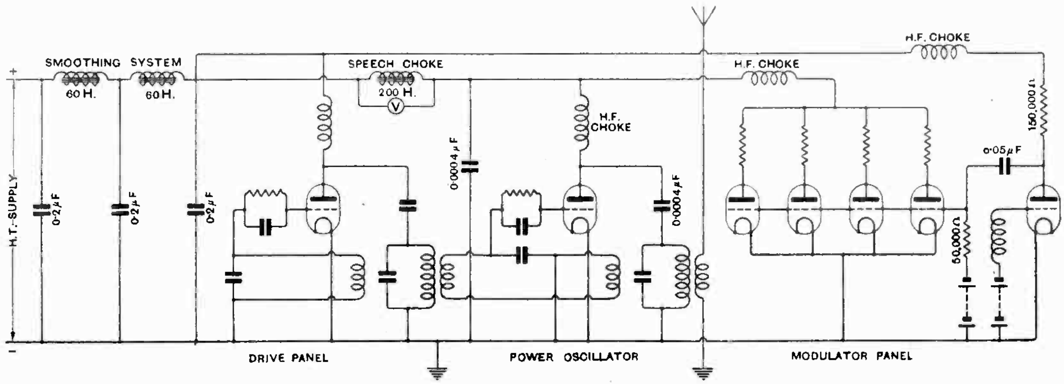

Fig. 1.

valves, and there was also rectification of plate current with consequent distortion.

An ingenious note oscillator was used by means of which a sinusoidal voltage could be applied of definite amplitude, and of any frequency up to 10,000 cycles or more, either to the grid of the sub-modulator valve or directly to the grids of the main modulator valves.

The percentage modulation was measured by means of an electrostatic voltmeter across the speech choke in the anode circuit of the valve.

It was found that this effect was due to the .001μF capacity which was virtually in parallel with the power oscillator, and by changing the main modulator valves, it was possible to obtain equal depth of modulation over the whole frequency range required.

The following is an outline of the investigation, and of the alterations made to the modulator panel as a result.

The schematic diagram of 2LO is shown in Fig. 1. In particular the main modulator panel as it then existed consisted of four M.T.7B valves in parallel, whilst the sub-modulator was one M.T.4B valve. (The

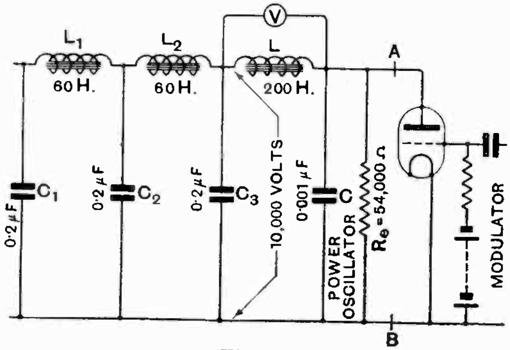

Fig. 2a.

plate-current, plate-voltage characteristics of the four M.T.7B valves are shown in Fig. 4, and those of the M.T.4B in Fig. 5(A.)

H.T. D.C. voltage=9,000.

Feed to power oscillator=167mA.

Total feed to four main modulator valves=160mA.

Feed to sub-modulator valve=10mA.

redraw the power oscillator and main control valves as shown in Fig. 2a. The capacity of 0.001μF in parallel with the 54,000 ohms is made up of the two 0.0004μF condensers that are shown as the blocking and feed condensers of the power oscillator in Fig. 1, and an estimated 0.0002μF due to stray capacity from the H.T. side of the system to earth. The voltmeter across the speech choke is an electrostatic one reading up to 5,000 volts.

As noted before, with no modulation on the set the grid bias on the main modulating valves is adjusted so that they take a total current of 160mA. This is the point o on the characteristic curves of Fig. 4. We require to find the locus of the working point when an alternating voltage is applied to the grids of the main modulating valves. The simplest possible and the ideal solution would occur if the speech choke had an infinitely large inductance, L, and the capacity across the equivalent resistance (54,000 ohms) of the power oscillator were zero. In this case the main modulating valves would be working into the resistance of 54,000 ohms, and the working line would be as shown at $R\,O\,R'$ in Fig. 4. From this it will be seen that the theoretical limit of modulation without grid current would be

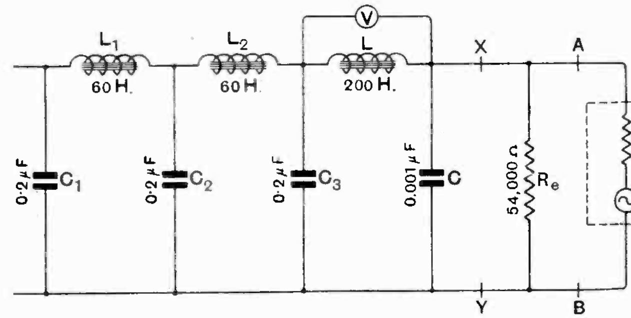

Fig. 2b.

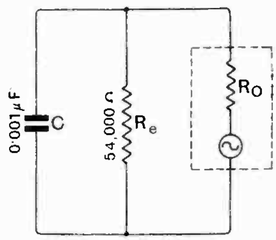

Fig. 2c.

The power oscillator circuit takes a feed proportional to the H.T. voltage. Hence it may be regarded as a resistance

$$=\frac{9{,}000}{0.167}=54{,}000 \text{ ohms},$$

for the comparatively low frequencies at which the power to it is modulated by the main modulator valves. We can now

about 5,000 volts max. = 55 per cent. over the whole frequency range required.

The actual load into which the main modulating valves work is the whole complex circuit to the left of AB in Fig. 2a. It is well known that while working within the limits of the straight part of its characteristics a valve (or valves in parallel) can be replaced (so far as the action on the external circuit is concerned) by an alternator of resistance R_0 and E.M.F. me_g,

where $R_0 = \left(\frac{d\,E_p}{d\,I_p}\right)_{E_g \text{ constant}}$ = slope resistance,

m = amplification factor,

and e_g = alternating grid E.M.F.

This has been done in Fig. 2b and serves to bring out more clearly the nature of the external load. We note the following points :—

1. With some very low frequency modulation, the speech choke "L" and the smoothing system, would be in tune and would form an acceptor circuit across the resistance R_e.

(NOTE.—The equivalent circuit of the whole smoothing system, as measured across the final condenser C_3, Fig. 2a, varies with the frequency. At very low frequencies, *e.g.*, 10 cycles, $1/C_1\omega$ or $1/C_2\omega$ is much greater than $L_1\omega$ or $L_2\omega$, and therefore the equivalent circuit may be regarded as approximately equal to C_1, C_2, C, all in parallel. At high frequencies $L_1\omega$ and $L_2\omega$ are very much greater than $1/C_1\omega$ or $1/C_2\omega$ and the equivalent circuit is therefore approximately equal to the condenser C_3.)

To continue, if we consider C_1, C_2, and C_3 in parallel to be equivalent to the smoothing system, the resonant frequency n mentioned above will occur when

$$L\omega = \frac{1}{(C_1 + C_2 + C_3)\,\omega}$$

Therefore $n = \dfrac{1}{2\pi\sqrt{L(C_1 + C_2 + C_3)}}$

Taking L = 200 henries

and $C_1 = C_2 = C_3 = 0.2\mu\text{F}$

we get :—

$$n = \frac{10^3}{2\pi\sqrt{120}} = 15 \text{ cycles per sec. (approx.)*}$$

With an alternating voltage of this frequency on the grid, we should get a large voltage reading across the speech choke † although there was actually no alternating current flowing through R_e, *i.e.*, no modulation of the current supplied to the power oscillator.

* It has since been found that this resonant frequency is considerably higher, and C_3 has been increased to reduce it.

† There is a corresponding voltage across C_3 which acts on the drive and sub-modulator, giving complex effects.

TABLE OF REACTANCE OF L AND $C_1+C_2+C_3$ AT VARIOUS FREQUENCIES.

Frequency cycles per second.	Reactance of L $\omega = L$	Reactance of $C_1 + C_2 + C_3$ $= \frac{1}{(C_1+C_2+C_3)\omega}$	Reactance of L and $C_1+C_2+C_3$ $= L\omega - \frac{1}{(C_1+C_2+C_3)\omega}$
5	6,280	53,100	— 46,820
10	12,560	26,550	— 13,990
15	18,850	17,700	+ 1,150
20	25,100	13,270	+ 11,830
25	31,400	10,600	+ 20,800
30	37,700	8,840	+ 28,860
40	50,200	6,640	+ 43,560
50	62,750	5,300	+ 57,450
60	75,400	4,420	+ 70,980
80	100,400	3,320	+ 97,080
100	125,600	2,650	+122,950

From the above table we see that as the frequency is increased, a point is soon reached where the reactance

$$\left(L\omega - \frac{1}{(C_1 + C_2 + C_3)\omega}\right)$$

of the path through the speech choke and smoothing condensers becomes large compared with R_e (54,000 ohms) and so most of the modulated current will flow through R_e as required.

During this period the resultant load on the main modulating valves consists of R_e and an inductive reactance in parallel with it. The working line therefore becomes an ellipse traversed in the clockwise direction.

2. As the modulating frequency is further increased the next critical point occurs when the capacity C (0.001μF) resonates with the remainder of the circuit to the left of it, to form a rejector circuit between the points XY (Fig. 2b). This point will occur when

$$L\omega - \frac{1}{C_3\omega} = \frac{1}{C\omega}$$

As $1/C_3\omega$ is very small compared with $L\omega$ in the region of the resonant frequency, the critical point will occur approximately when $L\omega = 1/C\omega$.

If $L = 200$ henries and $C = 0.001\mu F$, we get :—

$$L\omega = \frac{1}{C\omega} \therefore n = \frac{1}{2\pi\sqrt{LC}}$$

$$\therefore n = \frac{10^4}{2\pi\sqrt{20}} = 356 \text{ cycles per sec.}$$

At this frequency practically no alternating current will flow to the left of XY, and the load on the main modulating valves is solely the resistance R_e. Thus the working line on the $E_p\ I_p$ diagram is $A'OC'$, the line drawn for the simple case.

The working line at this frequency (5,000 cycles) and range (5,000 volts) is the ellipse $A'DC'B$ shown in Fig. 4, traversed in the counter-clockwise direction ; while at 10,000 cycles it is the ellipse $EHGF$. The detailed construction of these ellipses is given in Appendix I. It is clear from the figure that such ellipses would result both in grid current and in rectification, and owing to these effects the possible range of modulation at these higher frequencies would be greatly decreased, as found experimentally.

The ellipse for 10,000 cycles and a voltage amplitude of 2,000 is shown dotted in Fig. 4. This represents a modulation of 20 per cent., and would be about the limit for modulation at this frequency under the conditions shown. It could perhaps be increased to 25 per cent. by working at a lower H.T. voltage with correspondingly heavier currents in the main modulator. This would move the ellipse upward and to the left, and so keep it within the limits as to zero grid current and rectification.

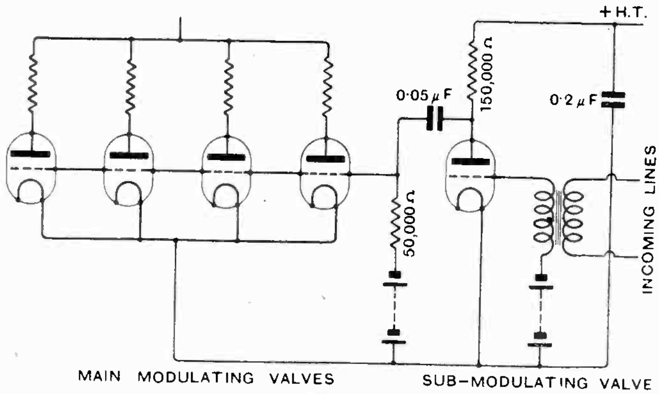

Fig. 3a.

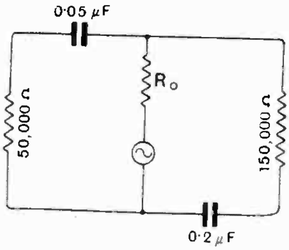

Fig. 3b.

3. At higher modulating frequencies, the capacity effects predominate, and the circuit becomes virtually that of Fig. 2c. The total capacity in parallel with R_e is made up of :—

Blocking and feed condensers	$= 0.0008\mu F$.
Stray capacity	$= 0.0002\mu F$.
Total capacity	$= 0.001\mu F$.

The working line on the $E_p\ I_p$ diagram is again an ellipse, but this time traversed in the counter-clockwise direction. We will now proceed to study this in greater detail.

If we assume a voltage variation of 5,000 at the terminals of R_e we have :—

Maximum value of alternating current through R_e

$$= \frac{5{,}000 \times 1{,}000}{54{,}000} = 92\text{mA}.$$

At 5,000 cycles the maximum current through the capacity of $0.001\mu F$

$$= \frac{5{,}000 \times 2\pi \times 5{,}000 \times 10^3}{10^9} = 157\text{mA}.$$

It should here be pointed out that provided the ellipses are not too pronounced, and keep within the region of straight characteristics and zero grid current, there is no appreciable distortion. There is a phase shift between the modulated current flowing through R_e (the power oscillator) as compared with grid E.M.F. on the main modulating valves, and this phase shift varies with the frequency. The ear, however, takes no account of the phase relationship of the harmonic components of complex sounds, but only of their relative amplitudes. It may be seen from Fig. 4 that the amplitude of grid E.M.F. required to give an amplitude of 5,000 volts across R_e increases only slightly up to a frequency of 10,000 cycles.

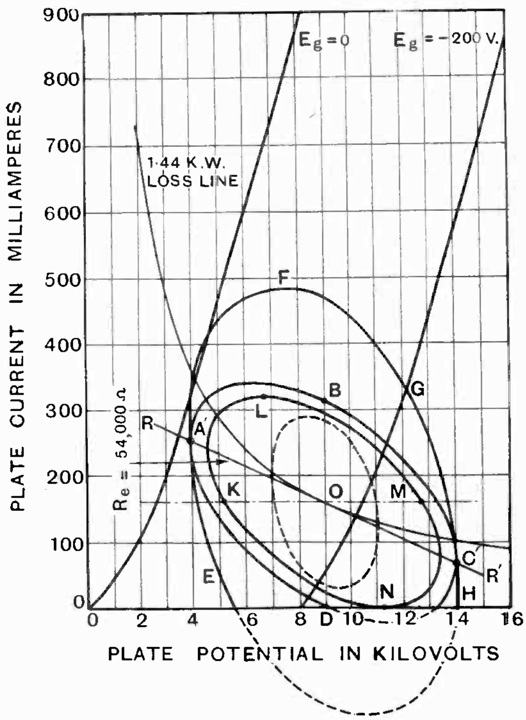

Fig. 4.

It is not possible to reduce the shunt capacity of 0.001μF to any great extent. It was seen that if the working ellipses could be moved up by allowing the control valves to absorb more power, and at the same time the I_p-E_p characteristics were made steeper by using valves of lower slope resistance R_o, it would be possible to maintain a much greater percentage modulation throughout the whole frequency range. Capt. Round therefore designed a new type of main modulating valve (known as the M.T.9A) capable of dissipating 600 watts each at the anode. Four of these were used in parallel and the power dissipated in them adjusted by grid potential to 2.4kW. The E_p-I_p characteristics of the four valves in parallel are given in Fig. 6. The slope resistance R_o for four of these valves in parallel is 2,500 ohms as compared with 7,000 ohms for four M.T.7B's in parallel.

The other adjustments of the set, after the improvements were carried out, were as follows :—

H.T. voltage = 8,000.

Feed to power oscillator = 188mA.

Equivalent resistance of power oscillator

$$R_e = \frac{8,000}{.188} = 42,600 \text{ ohms.}$$

Feed to main modulator valves = 300mA.

Grid potential of modulator valves

= —530 volts.

The working line when R_e only is considered is AOC', and gives a possible range of modulation of 6,000 volts, and this can be maintained up to a frequency of 5,000 cycles, even with 0.001μF shunt capacity. The percentage modulation

$$= \frac{6,000}{8,000} \times 100 = 75 \text{ per cent.}$$

In Fig. 6 are also given the ellipses for a modulation voltage amplitude of 5,000 and frequencies of 5,000 and 8,800 respectively.

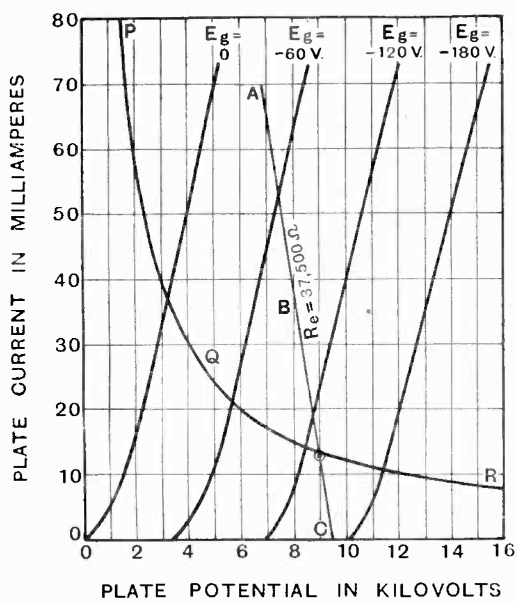

Fig. 5a.

It will be seen that this range of modulation (62½ per cent.) can just be obtained at the higher frequency. This is a striking improvement on the old conditions in which the possible modulation at 8,800 cycles frequency and with 0.001μF shunt capacity would be only about half this value, as can be seen from Fig. 4.

The best value for the H.T. voltage and the point to which the modulating valves

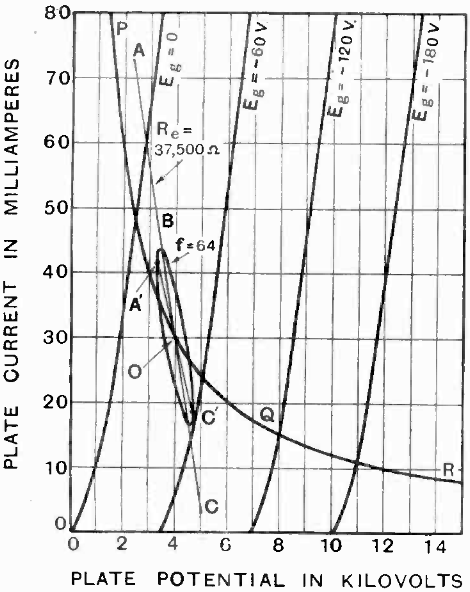

Fig. 5b.

are adjusted by grid potential, can be found by drawing out the various possibilities on the E_p-I_p characteristics.

The conditions to be fulfilled are that the power supplied to the power oscillator should not be more than 1.5kW, and that to the main modulating valves not more than 2.4kW.

In Fig. 7 are shown ellipses worked out for a frequency of 5,000, and modulated voltage amplitude of 5,000 for three values of H.T. voltage, viz., 6,000, 8,000, and 10,000. The conditions of 1.5kW to the oscillator and 2.4kW to the modulator are fulfilled in each case. The former condition implies that the equivalent resistance, R_e, of the power oscillator varies inversely as the square of the H.T. voltage in use, and this affects the slope and shape of the corresponding ellipse. (NOTE.—This variation in R_e can be obtained by alteration in the aerial coupling.)

It will be seen that with the H.T. voltage set at 8,000 the ellipse is most evenly situated between the working limits, and 8,000 volts was therefore the value chosen.

Alterations to Sub-Modulator System.

From Fig. 6 we see that the necessary grid bias on the M.T.9A valves is about 530 volts. This value is therefore the maximum value of grid swing to be provided from the sub-modulating valve system.

A diagrammatic representation of the sub-modulator system is given in Fig 3a. To study its action with alternating currents, we substitute the equivalent alternator and omit the H.T. D.C. and grid battery, and so derive Fig. 3b. From this we see that the external load on the valve consists of two parallel branches, one containing a resistance of 50,000 ohms, and a condenser of 0.05μF in series, and the other a resistance of 150,000 ohms and a condenser of 0.2μF in series. At a frequency of 127 cycles we have :—

Reactance $1/C\omega$ of 0.05μF condenser

$$= \frac{10^8}{5 \times 2\pi \times 127} = 25{,}000 \text{ ohms.}$$

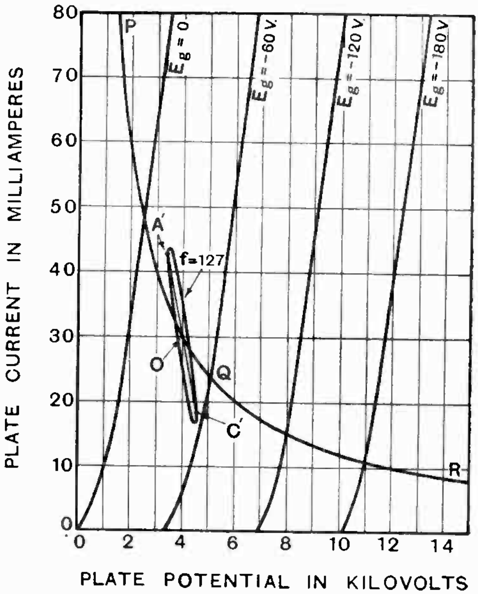

Fig. 5c.

Reactance of 0.2μF condenser

$$= \frac{10^7}{2 \times 2\pi \times 127} = 6{,}250 \text{ ohms.}$$

(At higher frequencies these reactances will be proportionately smaller.)

At this frequency (which may be taken as near the lower limit to be dealt with) the left hand branch is markedly capacitative, whilst the right hand branch is almost purely resistive since 150,000 ohms is much greater than 6,250 ohms. At higher frequencies the

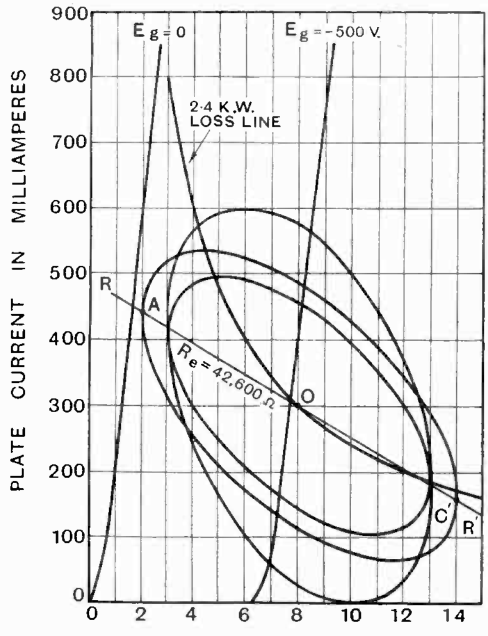

Fig. 6.

capacitative reactances are proportionately smaller, and the external load approximates to 50,000 ohms and 150,000 ohms in parallel which = 37,500 ohms.

The ellipse representing the capacitative load at 64 cycles and an amplitude of 500 volts across the 50,000 ohms is calculated in the appendix. In Fig. 5a are shown the I_p-E_p characteristics for one M.T.4B valve, which was originally used as the sub-modulator valve. The curve *PQR* represents the 120 watts loss line, the safe limit for the valve. The mean working point must not lie above this line. *ABC* is a line representing the external load of 37,500 ohms. The valve took 13mA at 9,000 volts with the grid bias used when the four M.T.7B's were the main modulating valves. These only required a maximum grid swing of about 180 volts, which could be provided at this setting with little distortion, since only a small range of the valve characteristics was used. For the four M.T.9A's, however, we saw that we required a maximum grid swing of 500 volts, and it was not possible to obtain this from a single valve. Capt. Round therefore put two M.T.4B valves in parallel as the sub-modulator system. The characteristics of these are shown in Fig. 5b, together with the working line *ABC*, for the external load of 37,500 ohms and the ellipse for the external load at 64 cycles. This ellipse is drawn the size required to give a maximum swing of 500 volts on the grids of the main modulating valves. This has been placed in the best position on the valve characteristics, from which we see that the grid bias should be —37 volts and the actual plate voltage 4,000 volts. The H.T. D.C. supply is at 8,000 volts, and the feed to the valves is 30mA; hence, the resistance in series with the anodes should be 133,000 ohms. The ellipse for a frequency of 127 and an amplitude of 500 volts across the 50,000 ohms is also shown in Fig. 5c.

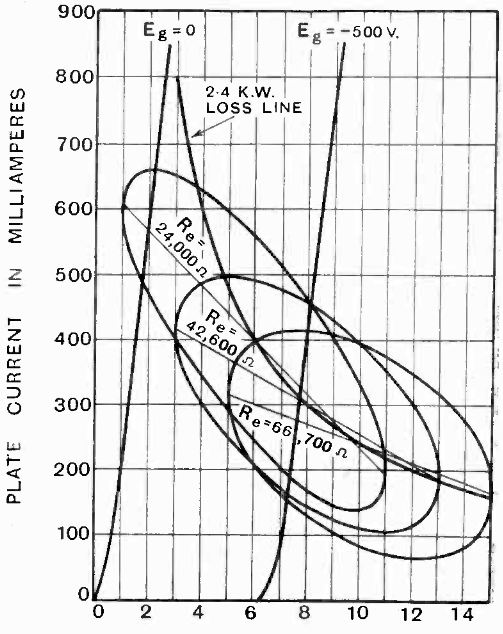

Fig. 7.

The conditions that arise in the last stages of audio frequency amplification for extra-loud-speakers might be studied on the same lines with advantage, to see whether capacity or inductance effects are limiting the power that can be obtained without distortion.

APPENDIX I.

Calculation of Ellipses for the Various Cases.

Throughout these calculations we shall take the positive direction of the I—E axes as shown in Fig. 8a, as these are the positive directions of current and voltage for the load R_e when we wish to place the ellipse on the I_p-E_p valve characteristics. The scales of I and E are the same as those used in plotting the valve characteristics of Figs. 4, 6 and 7, so that the ellipse can be transferred without alteration in shape or size.

Fig. 8 (not used).

Example I.

Resistance of 54,000 ohms in parallel with a capacity of $0.001\mu F$.

Amplitude of A.C. voltage = 5,000.

Frequency of A.C. voltage = 5,000.

First to determine the resistance line (see Fig. 8a: Mark off OA = 5,000 volts. For this amplitude of voltage the amplitude of current through R_e will be

$$\frac{5{,}000 \times 1{,}000}{54{,}000} \text{ mA} = 92\text{mA}.$$

Therefore draw AA' perpendicular to OA with AA' = 92mA. The straight line OR through O and A' is the resistance line required.

Secondly, we have to determine the ellipse for the capacity alone.

$$\text{Capacity reactance} = \frac{1}{C\omega} = \frac{10^6}{\cdot 001 \times 2\pi \times 5{,}000} = \underline{32{,}000 \text{ ohms.}}$$

$$\text{The maximum capacity current} = \frac{5{,}000 \times 1{,}000}{32{,}000} = \underline{156\text{mA.}}$$

Make OB and OD along the I axis each equal to 156mA, and $OC = OA$ = 5,000 volts.

Then A, B, C and D are points on the capacity ellipse.

Four more points on this ellipse can be found as follows: Since the capacity current leads the applied voltage by 90° we can write for the current and voltage at any particular instant,

$$i = I_{(max.)} \sin \omega t.$$

$$e = E_{(max.)} \cos \omega t.$$

When $\omega t = 45°$, $\sin \omega t = \cos \omega t = .707$.

So that $i = .707\, I_{(max.)}$ when $e = .707 E_{(max.)}$

This relation gives us four more points (F, G, H, and K) on the ellipse, and we can draw a curve freehand through the eight points found, which will be sufficiently accurate for our purposes.

$$LF = LG = NK = NH = .707\, I_{(max.)} = (.707 \times 156) = \underline{110 \text{ mA.}}$$

$$PF = MG = PK = MH = \cdot 707\, E_{(max.)} = (\cdot 707 \times 5{,}000) = \underline{3{,}535 \text{ volts.}}$$

The resultant ellipse for the resistance and capacity in parallel is obtained by adding the corresponding instantaneous currents in the resistance and the capacity. Draw a line $QSTU$ parallel to OI cutting the ellipse in Q and U, and the resistance line in T.

Make $TV = SU$ and $TW = SQ$.

Then for voltage OS the resultant current is $ST + SU = SV$ or $ST - SQ$ (which is negative) $= SW$.

V and W are therefore points on the resultant ellipse, and others can be found in a similar way.

From an examination of this ellipse we can, however, find a more direct way of plotting it. (Fig. 8b.)

The resistance line ROR' is drawn as before and $OA = OC = E_{(max.)}$ = 5,000 volts (in this case).

If AA' and CC' parallel to OI cut ROR' in A' and C', then A' and C' are points on the resultant ellipse.

Also, if $OB = OD$ = maximum value of capacity current = 156mA (in this case), B and D are also on the resultant ellipse.

Four more useful points to determine are :—

1. The two points at which the current has its maximum value;

2. The two points at which the current passes through its zero value.

The vector diagram for the circuit is shown in Fig. 8c where

$OE = E_{(max.)}$ and represents the applied volts.

$OI_R = E_{(max.)}/R$ in phase with OE, represents current through the resistance.

$OI_C = E_{(max.)}/X = E_{(max.)}\, C\omega$ (in this case)

and leads OE by 90°.

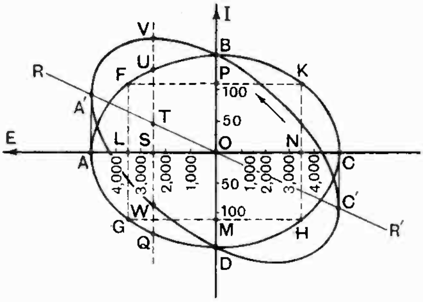

Fig. 8a.

The resultant current is therefore represented by $OI = \sqrt{OI_R^2 + OI_C^2}$ leading OE by an angle "θ" for which $\tan \theta = R/X$,

$$\cos \theta = \frac{X}{\sqrt{R^2 + X^2}} \quad \text{and} \quad \sin \theta = \frac{R}{\sqrt{R^2 + X^2}}$$

Now

$$OI = \sqrt{(E/R)^2 + (E/X)^2} = E\frac{\sqrt{R^2 + X^2}}{R \cdot X}$$

= maximum value of resultant current.

When this occurs the instantaneous value of the voltage is

$$E_{(max.)} \cos\theta = E_{(max.)} \frac{X}{\sqrt{R^2 + X^2}}$$

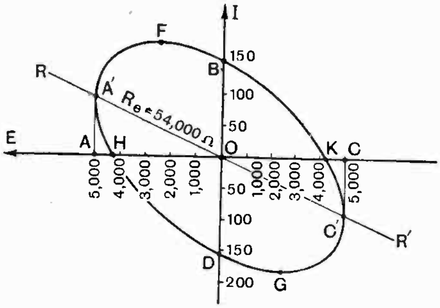

Fig. 8b.

Also, when the current is zero, the voltage

$$= E_{(max.)} \sin\theta = E_{(max.)} \frac{R}{\sqrt{R^2 + X^2}}$$

$$R = 54{,}000 \text{ ohms.}$$

$$X = 1/C\omega = 32{,}000 \text{ ohms.}$$

$$\sqrt{R^2 + X^2} = 62{,}800$$

Then for the points mentioned under (1) we have :

$$I_{(max.)} = \frac{5{,}000 \times 62{,}800 \times 1{,}000}{54{,}000 \times 32{,}000} = \underline{182\text{mA}}$$

$$\text{when the voltage} = \frac{5{,}000 \times 32{,}000}{62{,}800} = \underline{2{,}550 \text{ volts.}}$$

These results fix the positions of the two points F and G in Fig. 8b. For the points mentioned under (2) we have :—

Instantaneous current $= 0$

„ voltage $= E_{(max.)} \dfrac{R}{R^2 + X^2}$

This gives us the two points H and K in Fig. 8b. We can now draw the resultant ellipse through the points A', H, D, G, C', K, B, F, and A', remembering that the curve is tangential to AA' and CC', and parallel to ROR' at B and D.

The ellipse thus found is $A'BC'D$ of Fig. 4 in the main part of the article, and the ellipse for 10,000 cycles is also obtained in the same way.

Example II.

Fig. 9a shows the simplified diagram of the sub-modulator circuit. The external circuit consists of two branches in parallel. These are :—

1. 150,000 ohms (approximately, as the capacitative effect is negligible. See page 473 of main part of article).

2. 50,000 ohms in series with a capacity of 0·05μF.

At a frequency of 64 cycles ($\omega = 400$)

$$X = 1/C\omega = \frac{10^8}{5 \times 400} = 50{,}000 \text{ ohms capacitative}$$

reactance.

Probably the simplest method of finding the equivalent ellipse for this arrangement would be to find the resistance and capacity in parallel that would represent the left-hand branch. This is easily done by the graphical method given by F. M. Colebrook in his article "The Graphical Analysis of Composite Impedance," in *E.W. & W.E.*, Vol. II., No. 15, December, 1924. The construction as applied to this case is as follows :—

Draw OC (to scale) $= R = 50{,}000$ ohms (Fig. 9b).

Draw $CD = X = 50{,}000$ ohms at right angles to OC. Join OD.

Draw OP at right angles to OC and produce OC to a convenient length OQ. Draw AB at right angles to OD, cutting OP and OQ in A and B respectively. Then $OA = X' =$ the required capacitative reactance (to scale), and $OB = R' =$ the required resistance. We find that :—

Parallel resistance $R' = 100{,}000$ ohms.

Capacitative reactance $X' = 100{,}000$ ohms.

100,000 ohms and 150,000 ohms (right-hand branch) in parallel = 60,000 ohms. The complete circuit is therefore equivalent to 60,000 ohms resistance in parallel with 100,000 ohms capacitative reactance, and the equivalent ellipse can then be calculated as in Example I. :—

We require 500 volts across the 50,000 ohms, *i.e.*, 500 volts applied to the grids of the main modulating

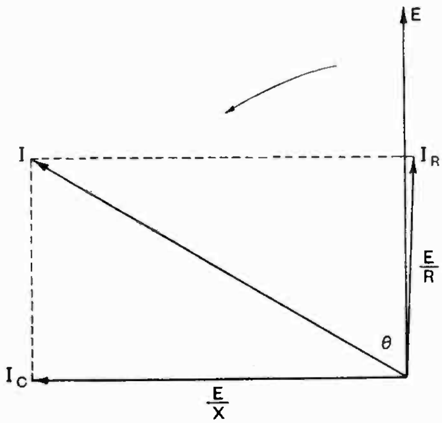

Fig. 8c.

valves. Now at 64 cycles we found that the reactance of the 0·05μF condenser was 50,000 ohms, and the resistance in the left-hand branch is also 50,000 ohms (Fig. 9a). The maximum voltage drops are therefore equal across the condenser and resistance, but in quadrature (Fig. 9c). Hence the resultant voltage required across AB (Fig. 9a) will be :—

$$(500 \times \sqrt{2}) = 707 \text{ volts.}$$

$R = 60,000$ ohms.

$X = 100,000$ ohms $\sqrt{R^2 + X^2} = 116,700$ ohms.

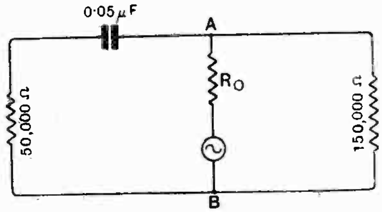

Fig. 9a.

In Fig. 9a (lettering as 8b) ROR' is the 60,000 ohms resistance line.

$$OA = OC = 707 \text{ volts.}$$

$$AA' \text{ and } CC' = \frac{707 \times 1,000}{60,000} = 11{\cdot}8\text{mA.}$$

Then $A'OC'$ is the resistance line and A' and C' are points on the required ellipse.

$OB = OD =$ max. value of capacity current

$$= \frac{707 \times 1,000}{100,000} = 7{\cdot}07\text{mA.}$$

B and D are points on the ellipse.

The resultant current is zero when voltage

$$= E_{(max.)} \frac{R}{\sqrt{R^2 + X^2}} = \frac{707 \times 60,000}{116,700} = 364 \text{ volts.}$$

This determines H and K.

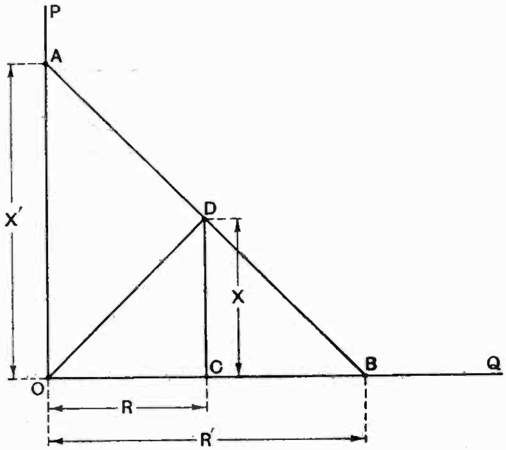

Fig. 9b.

Maximum resultant current

$$= E \cdot \frac{\sqrt{R^2 + X^2}}{RX} = \frac{707 \times 116{,}700 \times 1,000}{60,000 \times 100,000}$$
$$= 13{\cdot}7\text{mA.}$$

Voltage for maximum resultant current

$$= E_{(max.)} \frac{X}{\sqrt{R^2 + X^2}} = \frac{707 \times 100,000}{116,700} = 606 \text{ volts.}$$

This determines F and G and the ellipse may now be drawn.

As the frequency is increased this ellipse becomes narrower, and above 300 cycles the simple resistance line will show all that is required.

Example III.

Another method of obtaining the ellipse for the circuit shown in Fig. 9a is similar to that used in Example I., the various steps being as follows :—

Considering the left-hand branch of the circuit :

(1) Obtain the resistance line.

(2) Plot the ellipse for the capacity alone.

(3) Add (1) to (2) thus obtaining resultant ellipse for the left-hand branch. (NOTE.—Add instantaneous *voltages*, as current is the same through the resistance and capacity at any instant. (*Series* circuit) Ellipse shears *horizontally*.)

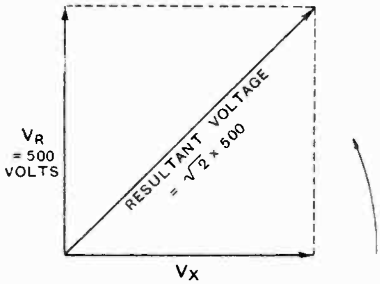

Fig. 9c.

(4) Obtain the resistance line for the right-hand branch.

(5) Add (3) to (4) thus obtaining the resultant ellipse for the whole circuit. (NOTE.—Add instantaneous *currents* as now the voltage is the same, at any instant, across the right-hand and left-hand branch. *Parallel circuit.* Ellipse shears *vertically*.)

The result (Fig. 10) should be the same as obtained in Example II. (Fig. 9d).

As before, we require 500 volts across the 50,000 ohms.

Frequency = 64 cycles.

Current in left-hand branch

$$= \frac{500 \times 1,000}{50,000} = 10\text{mA.}$$

(1) Mark off OA = 500 volts (Fig. 10). Draw AA' perpendicular to OA with AA' = 10mA. The straight line ROR' through O and A' is the resistance line required.

(2) Maximum current through the ·05μF condenser = 10mA. Make OB and OD along the I axis each equal to 10mA and $OC = OA$ = 500 volts. Then A, B, C, and D are points on the capacity ellipse.

As before, $i = 0{\cdot}707\ I_{(max.)}$ when $e = 0{\cdot}707\ E_{(max.)}$ This relation gives us the four points F, G, H, and K, as in Example I. The ellipse for the capacity alone may now be drawn through the eight points found.

(3) Adding (1) to (2) as previously explained we get the resultant ellipse *LMNP* for the left-hand branch of the circuit.

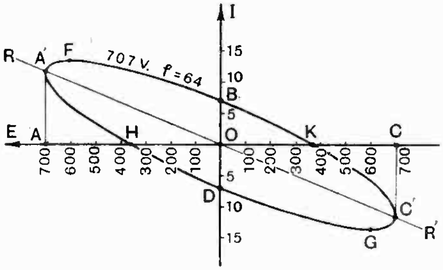

Fig. 9d.

(4) As before, in order to obtain 500 volts across the 50,000 ohms in the left-hand branch, we require 707 volts across *AB* (Fig. 9a), that is, we require 707 volts across the 150,000 ohms. Therefore the maximum current through this resistance is equal to

$$\frac{707 \times 1{,}000}{150{,}000} = 4{\cdot}7\text{mA.}$$

In Fig. 10, $OQ = OS = 707$ volts.
$QT = SU = 4{\cdot}7$mA.

TOU is therefore the resistance line for the right-hand branch of the circuit.

(5) Adding (3) to (4) we get the resultant ellipse *VMWP* for the whole circuit which is the same as obtained in Fig. 9 l.

APPENDIX II.

Power Relations in Oscillator and Modulator Circuits when using Choke Control.

In the article on I_p-E_p characteristics published in *E.W. & W.E.*, page 475. August. 1926 we saw that the maximum modulated power delivered from the modulators to the power oscillator was about 300 watts. This is in addition to the steady power that is supplied to the power oscillator when there is no modulation. But with choke control the H.T. D.C. power supplied from E (Fig. 11) is the same whether modulation is occurring or not. It follows that the power dissipated in the anodes of the modulators is decreased by the amount of modulated power supplied to the power oscillator. It is interesting to study in detail how this occurs. A simplified diagram of the circuit is shown in Fig. 11.

Let H.T. voltage of supply $= E$.

Steady current to power oscillator $= I_0$
Steady current to modulators $= I_M$

These are represented by the three horizontal lines in Fig. 12.

Then power to oscillator $= EI_0$
Power to modulators $= EI_M$
Total power $= E\ (I_0 + I_M)$

When a voltage varying as $sin\ \omega t$ is applied to the grids of the modulators their plate current will have a varying component which may be written as $kI_0\ sin\ \omega t$ where k is less than I.

The resultant instantaneous modulator current is now

$$I_M + kI_0\ sin\ \omega t$$

and since the current through the choke is practically constant (but note the later remarks*) the current to the power oscillator is

$$I_0 - kI_0\ sin\ \omega t = I_0\ (1 - k\ sin\ \omega t)$$

These two currents are shown in Fig. 12. Their arithmetic mean value is unchanged so that D.C. ammeters measuring I_0 and I_M should not alter in reading when modulation is occurring. Now we noted that the power oscillator behaves practically as a resistance to the comparatively low frequencies used in modulation. Therefore the voltage across it, at XY in Fig. 11, must be proportional to the current and must be

$$E\ (1 - k\ sin\ \omega t)$$

This is shown in Fig. 12.

The total power supplied to the modulators is calculated by taking the average value of the product instantaneous current and the instantaneous voltage.

In Fig. 12 it will be noticed that when the current through the modulators is high the voltage is low and *vice versa*. The power supplied will therefore be less then when no modulation is taking place.

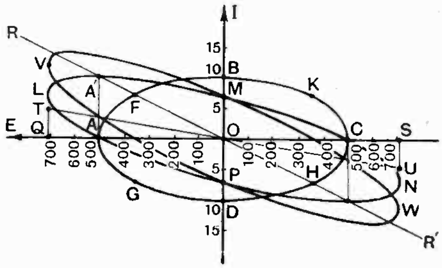

Fig. 10.

Expressing this in symbols we have :—

Power to modulators = average value of

$$E\ (1 - k\ sin\ \omega t)\ (I_M + kI_0\ sin\ \omega t)$$

= average value of

$$EI_M + EkI_0\ sin\ \omega t - Ek\ sin\ \omega t\ I_M - EI_0k\ sin\ \omega t$$
$$= EI_M - \tfrac{1}{2}\ k^2EI_0$$

since the average value of $sin\ \omega t = 0$
and the average value of $sin^2\ \omega t = \tfrac{1}{2}$

* Of this voltage, E is provided from the H.T. D.C. supply whilst $kE\ sin\ \omega t$ is the voltage across the speech choke, which must therefore carry an alternating current $kE\ sin\ \omega t/\omega L$.

This can be made negligibly small as compared with $kI_0\ sin\ \omega t$ by making ωL large enough.

The power to the modulators is thus diminished by the amount $\frac{1}{2} k^2 E I_0$.

In the case of the power oscillator, the instantaneous values of voltage and current have their maxima at the same time. We may conclude from this that the power is increased.

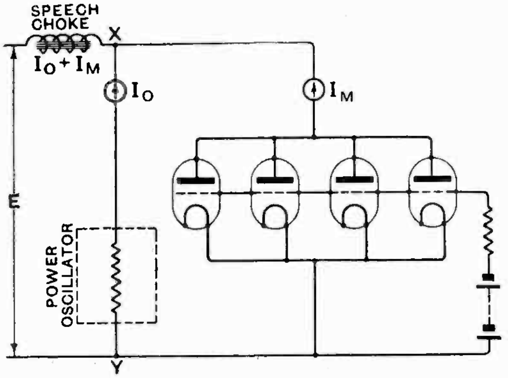

Fig. 11.

Power supplied to power oscillator

= average value of

$$E(1 - k \sin \omega t) I_0 (1 - k \sin \omega t)$$

= average value of

$$EI_0 (1 - 2k \sin \omega t - k^2 \sin^2 \omega t)$$

$$= EI_0 + \tfrac{1}{2} k^2 EI_0$$

The power to the oscillator is increased by $\frac{1}{2} k^2 E I_0$. The reading of the aerial ammeter should therefore increase when modulation is occurring, but under the usual conditions the change will be slight.

It is clear that k measures the depth of modulation. In the "*Q*" set using 4 M.T.7B valves, we saw that the maximum possible value of k was 0·64.

Therefore maximum increase in power

$$= \tfrac{1}{2} 0.64^2 EI_0$$

$$= 0{\cdot}204\ EI_0$$

$$= 0{\cdot}204 \times 1{,}500 = 306 \text{ watts.}$$

Maximum increase in aerial ammeter reading

$$= \sqrt{1.204} - 1 = 10 \text{ per cent.}$$

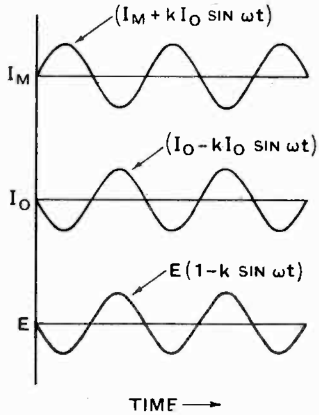

Fig. 12.

That is, with a depth of modulation of 64 per cent., the aerial current only increases 10 per cent.

For a depth of modulation of 100 per cent., the aerial current should increase

$$\sqrt{1.5} - 1 = 22.5 \text{ per cent.}$$

(The whole subject of modulation is treated very fully by Heising, in *Proc I.R.E.*, August, 1921.)

The "Law Correction" of Variable Air Condensers.

By W. H. F. Griffiths.

ONE of the most important factors to be taken into account in the design of plate shapes for variable air condensers to have definite laws connecting wavelength (or frequency) and angular movement is the minimum or "residual" capacity of the finished condenser as augmented by the capacity of the circuit of which it is to form part.

A condenser cannot therefore be designed without a knowledge of the conditions of its intended use; and from a study of the various laws it is at once seen that a slight under-estimation of the extent to which the minimum capacity will be augmented by the circuit will prevent the condenser from following closely its design law. The seriousness of a given error in the estimation of the augmented residual capacity of a condenser depends to a large extent upon the actual law to which it is to conform. It is more serious in condensers having uniform scales of frequency and not quite so serious in those having uniform wavelength scales.

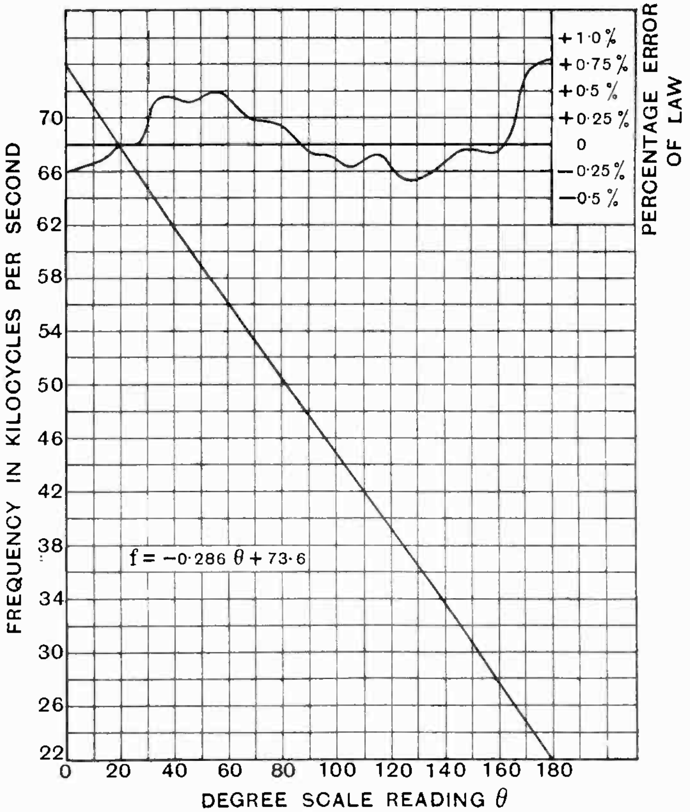

Fig. 1. *The almost perfect law of a modern commercial S.L.F. variable condenser, with curve of errors introduced by the use of the law.*

One can, of course, overestimate deliberately the value of augmented residual capacity in order to render possible a law satisfying adjustment by simply adding in parallel with the variable condenser a small fixed value unit to bring the resultant value up to that estimated. This can only be accomplished, however, at the expense of range of capacity variation; an additional $10\mu\mu$F on the residual value of a $500\mu\mu$F condenser may cause a 30 per cent. reduction in its capacity range.

It would be useful also when selecting a condenser for particular work to have stated the actual law of wavelength or frequency change when used with a coil of stated inductance, together with possible limits of deviation from that law.

A test recently made by the author on an S.L.F. variable condenser (commercially obtainable),* having, it is understood, a plate-shape designed by the makers, to the formulæ developed by the author,† showed how well an inexpensive "mass production" condenser can conform to its predetermined law if used in the correct manner. The

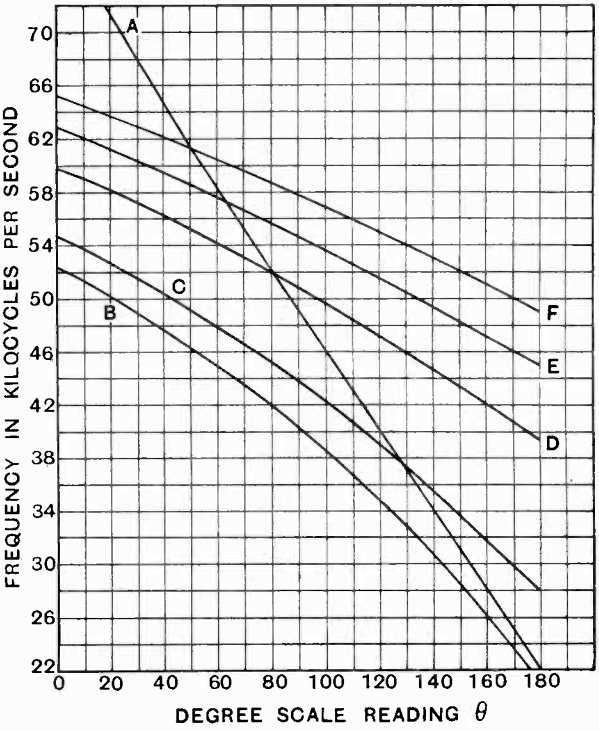

Fig. 2. *Curves illustrating the various stages of correction for the law distortion by excessive residual capacity in an S.L.F. condenser. Curve A is obtained under proper conditions. Curve B the law distortion introduced by $50\mu\mu$F excess residual capacity. Curve F the finally corrected curve obtained by the introduction of a series condenser of selected value.*
(All curves in this figure are plotted from actual measurements.)

A Commercial Example of "Law Correctness."

It is seen therefore how important it is that a value of "extra" or circuit capacity should be associated with a condenser declared to have, for instance, an S.L.F. law.

*The Ormond Engineering Company's S.L.F. Condenser.

† "The Laws of Variable Air Condensers," *E.W. & W.E.*, Jan., 1926.

condenser in question had a nominal maximum capacity of $500\mu\mu F$ and in Fig. 1 is given the curve connecting its degree scale reading with the natural frequency of a simple resonant circuit formed using an inductance of $10^5\mu H$. The total augmenting capacity of the circuit was in this case $26.3\mu\mu F$, and the actual capacity of the condenser $20\mu\mu F$ to $505\mu\mu F$, and the law was found to be

$$f = -0.286\theta + 73.6$$

[f in kilocycles; θ in degrees.]

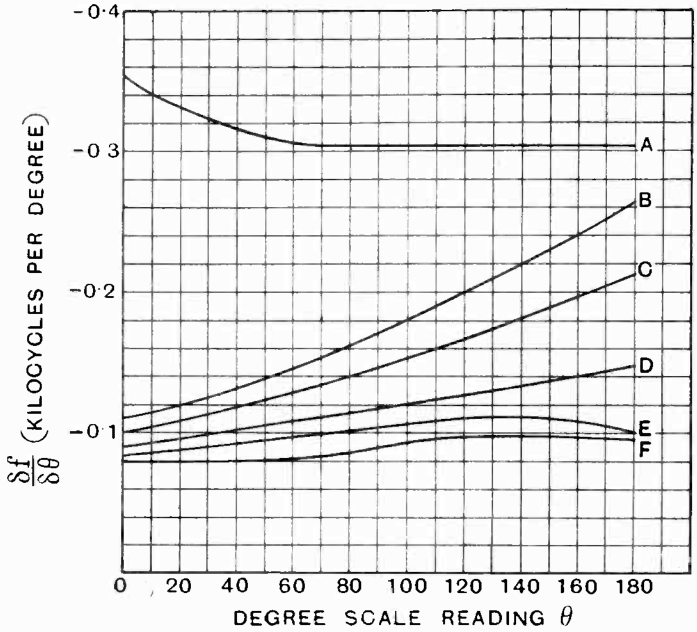

Fig. 3. *"Slope" curves to show more clearly the imperfections of the frequency curves of Fig. 2.*

S.L.F. Law.

$$f = -0.286\theta + 73.6$$

θ (degrees)	f (calculated from law)	f (exact)	Error introduced by the use of the law %	θ (degrees)	f (calculated from law)	f (exact)	Error introduced by the use of the law %
2.6	72.83	73	—0.23	96.4	45.96	46	—0.09
6.0	71.86	72	—0.20	103.6	43.92	44	—0.18
12.8	69.91	70	—0.13	110.7	41.94	42	—0.14
19.5	67.99	68	—0.01	117.5	39.96	40	—0.10
25.8	65.90	66	—0.01	124.8	37.88	38	—0.32
32.5	64.25	64	+0.40	131.7	35.88	36	—0.33
39.5	62.28	62	+0.45	138.7	33.93	34	—0.20
46.5	60.25	60	+0.41	145.5	31.98	32	—0.06
53.5	58.28	58	+0.48	152.3	29.98	30	—0.06
60.5	56.26	56	+0.46	159.0	27.98	28	—0.07
67.8	54.13	54	+0.24	165.8	26.08	26	+0.30
74.8	52.12	52	+0.23	172.4	24.18	24	+0.75
81.8	50.08	50	+0.16	179.5	22.18	22	+0.80
89.3	47.98	48	—0.04				

The imperfections in the curve of Fig. 1 are so small that they are only with difficulty seen in a small scale curve, but the actual deviations from the general law are also given in the curve of errors at the top of the same figure. It will be observed that the maximum deviation was 0.5 per cent. with the exception of a 0.8 per cent. departure from 170 degrees to 180 degrees. The mean deviation for 27 points, taken at intervals of exactly 2.0 kilocycles, being 0.25 per cent. as shown in the tabulation of calculated values below. The calibration points were obtained by using the even harmonics of a multivibrator system, vibrating at 1.0 kilocycle per second and controlled by a standard tuning fork standardised at this frequency.

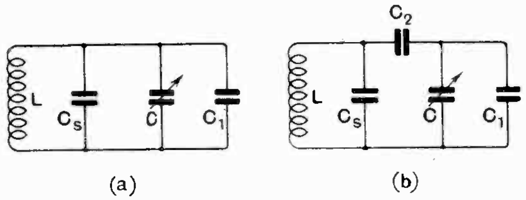

Fig. 4. *The connections of the "artificial excess residual capacity" C_1 and the series "law correcting" capacity C_2.*

Law Distortion and a Method of Correction.

The frequency curve *A* of Fig. 2 was also obtained with a coil of $10^5 \mu H$, but having a somewhat smaller distributed capacity (plus leads, etc.) of $21.3 \mu\mu F$. This curve, although very good, has a slight increase of "slope" at its lower scale reading characteristic of an insufficient residual capacity augmentation; the imperfection is better shown by the "slope" curve *A* of Fig. 3. In order to show the effect on the law of too high a

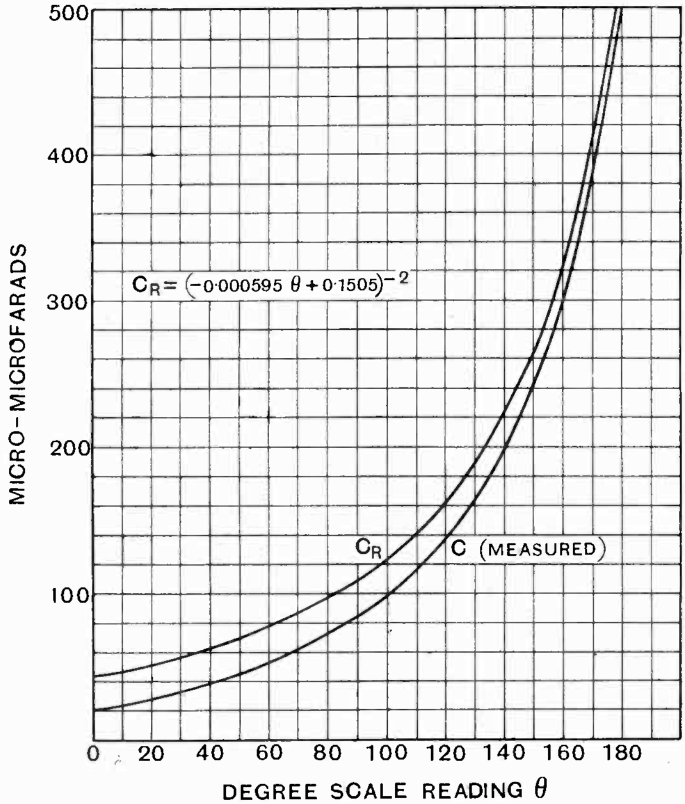

Fig. 5. *Capacity calibration curve C of a commercial S.L.F. condenser together with its corresponding "circuit value" curve C_R which follows the correct inverse square law.*

value of minimum capacity, a known fixed capacity C_1 of considerable value—50$\mu\mu$F—was paralleled with the variable unit as shown in Fig. 4a.

The frequency curve B, Fig. 2, obtained under these conditions bears no resemblance to the original law, its corresponding "slope" curve being given in Fig. 3—the scale of frequency obtained was very closed up at the end. From a study of the author's article* on the design of variable condensers to have definite laws of capacity change when connected in series with fixed value condensers, the idea will occur to connect a fixed condenser, C_2, in series with the variable condenser, as shown in Fig. 4b, in an attempt to straighten out again the frequency curves BB of Figs. 2 and 3.

It *is* possible to straighten these curves considerably, somewhat at the expense of total range, as is shown by the curves C, D, E and F of Figs. 2 and 3, obtained with values of C_2, 700, 190, 123, and 95$\mu\mu$F respectively.

It will be seen that curve F closely approaches the ideal uniform frequency change condition once again, although its average "slope" has been reduced from about 0.18 kilocycle per degree to about 0.09. It would have been possible to have straightened out the frequency curve with a much higher value of series capacity and therefore with a much smaller reduction of "slope" had the added "excess residual capacity" been given a less exaggerated value.

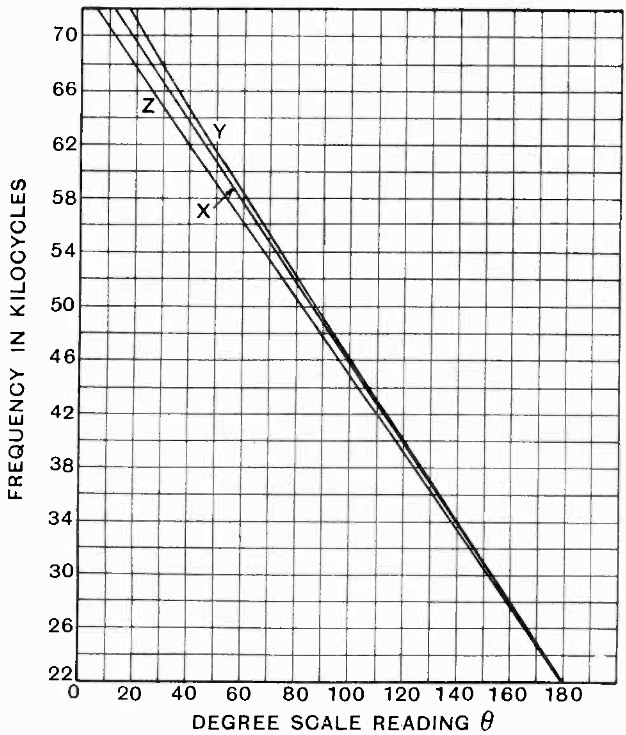

Fig. 6. *Frequency curves of an S.L.F. condenser plotted, from results of measurements and calculation, to show the effect of varying slightly the augmenting circuit capacity.*

$X = 24.0\mu\mu$F *augmenting capacity (calculated).*
$Y = 21.3\mu\mu$F ,, ,, *(measured).*
$Z = 26.3\mu\mu$F ,, ,, ,,

* "Further Notes on the Laws of Variable Air Condensers," *E.W. & W.E.*, December, 1926.

The curve C of Fig. 5 shows the actual measured capacity of the variable condenser, and if $24\mu\mu$F be added as an allowance for circuit capacity augmentation, the curve C_R is obtained. This latter curve was found to follow the law

$$C_R = (-a\theta + b)^{-2}$$

very closely when the constants a and b were given the values 0.000595 and 0.1505 respectively, and, since this was so, it follows that the frequency change produced by it in a circuit whose augmenting capacity is $24\mu\mu$F must closely follow a linear law.

In passing, it is perhaps worthy of note that on the particular condenser under examination the scale fitted gave a decrease of frequency for an increase of degree scale reading thus necessitating the minus sign in the law

$$C_R=(-0.000595\theta+0.1505)^{-2}$$

A scale reading in the reverse direction should more properly have been fitted so that an increase of frequency would have corresponded with an increase of degree scale reading—the corresponding law *for the same condenser* would then have taken the more usual form—

$$C_R=(0.000595\theta+0.0435)^{-2}$$

This scale reversal is, of course, not a serious fault, and would not be worth mentioning were it not for the fact that some explanation is required for the minus sign occurring in the law. The makers have, in fact, employed deliberately a reverse scale so as not to change the relative scalar positions at which well-known transmissions are received on ordinary S.L.C. and S.L.W. condensers.

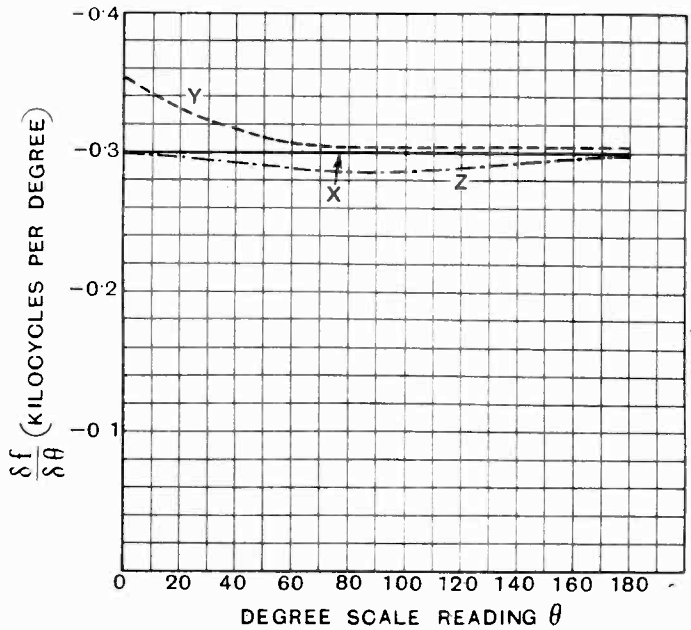

Fig. 7. *"Slope" curves to show more clearly the imperfections of the correspondingly lettered frequency curves of Fig. 6.*

Less "Law Distortion"—better Correction.

By employing a condenser having this law of capacity change in circuit with an inductance of $10^5\mu$H (and a circuit capacity of $24\mu\mu$F in order to reproduce exactly this capacity law) the law of uniform frequency change

$$f=-0.3\theta+75.8$$
(f in kilocycles)

is obtained. The frequency scale of this condenser calculated from the above law is plotted in Fig. 6 (curve X), its slope, of course, remaining constant as indicated by the horizontal line of Fig. 7. The actual measured frequencies obtained with this condenser in circuits having augmenting capacities slightly less than and greater than that for which the calculations were made are also given by curves Y and Z, the augmenting capacities (excluding the actual condenser minima) being $21.3\mu\mu$F and $26.3\mu\mu$F respectively.

The curves BB of Figs. 8 and 9 show the frequency law departures introduced by the addition of an *excess* of augmenting capacity of $20\mu\mu$F only, the ideal curves AA being given in the same figures. It should be a comparatively simple matter to straighten out these imperfect curves by the introduction of a series condenser C_2 (as already indicated in Fig. 4b) without such a great loss of range or "slope" as was experienced in the previous example. The curves CC and DD were plotted from computed values of frequency when $500\mu\mu$F and $200\mu\mu$F respectively were the values given to this series capacity.

Curves DD show how closely a series fixed condenser can be made to compensate for incorrect circuit conditions with very little loss of range, the reduction of mean "slope" in the case under consideration being only from 0.23 to 0.15 kilocycle per second per degree.

The curve of Fig. 10 has been plotted to show at a glance the rough values of series capacity required to straighten out frequency curves which have been distorted by various values of circuit augmenting capacity in excess of that for which this particular condenser was designed.

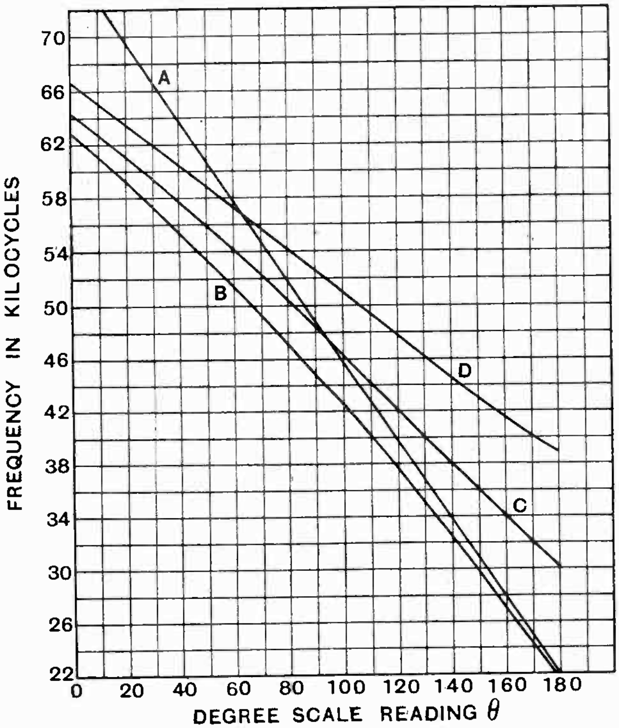

Fig. 8. *More perfect S.L.F. law correction. The excess augmentation of residual capacity is in this case much less than that for which the curves of Fig. 2 were plotted.*

The Correction of S.L.W. Condensers.

It has already been stated that an excessive residual augmenting capacity does not produce such marked departures from the general law in the case of condensers designed to have uniform *wavelength* scales. Moreover, it is not so difficult to compensate for any law departures that do occur.

As an example of this type of condenser one having augmented or "circuit values" of 36 to 500$\mu\mu$F and following the law

$$C=(0.0909\theta+6)^2$$

will be taken. The wavelength curve calculated from

$$\lambda=50\sqrt{C}$$

is shown in Fig. 11.

series condenser, but the correction is not such a drastic step as in the case of an S.L.F. condenser. Fixed series condensers of the same order of capacity as that of the variable condenser produce much over-correction as shown by the curves BB (Figs. 12 and 13) plotted for the case of a 500$\mu\mu$F series correction condenser.

A series capacity of 2,000$\mu\mu$F is still sufficiently small to over-correct very much, as shown by the curves CC of Figs. 12 and 13.

By giving the series capacity the value 5,000$\mu\mu$F the correction is almost perfect, as is shown by the curves DD, and it will be observed that this law correction has been obtained with very little attendant loss of "range," the reduction of mean slope being only about 6 per cent. It is very interesting to note that a series capacity of the order which has given such good law correction in this case was seen to be quite useless for this purpose in the S.L.F. condenser of approximately the same capacity value and having the same value of excess residual augmenting capacity. This is, of course, due to the much greater change of $dC/d\theta$ in the case of an S.L.F. condenser, and, in

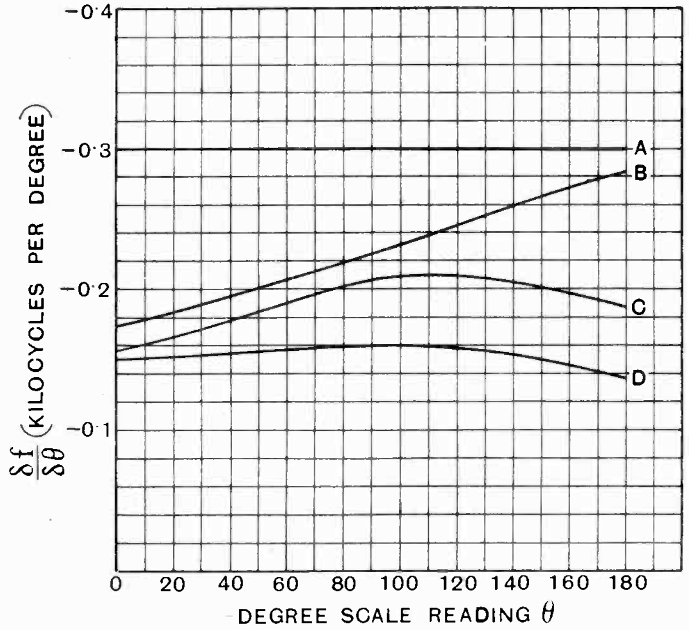

Fig. 9. *The "slope" curves to correspond with Fig. 8.*

The distortion of this wavelength curve by the addition of 20$\mu\mu$F extra capacity (in excess of that for which the condenser was designed) is shown in Fig. 12, curve A. The imperfections of this curve are more clearly seen from the similarly lettered "slope" curve of Fig. 13.

From these curves it will be seen that the amount of scale distortion introduced by a slight excess of circuit capacity is small in comparison with that obtained in the case of a uniform *frequency* scale condenser.

In this (present) case also it is possible to correct for the distortion by means of a

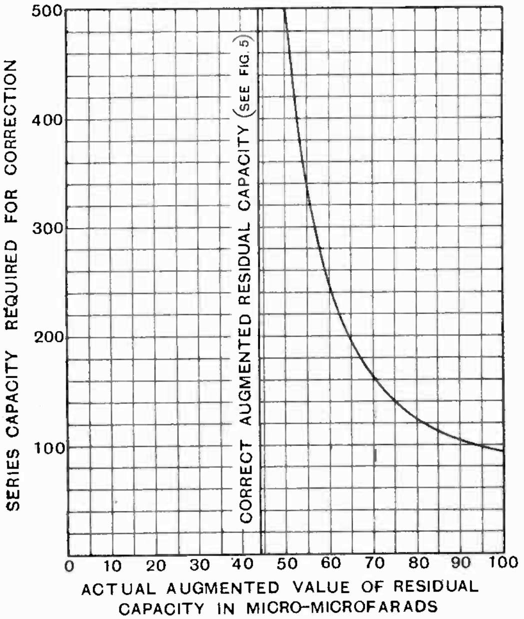

Fig. 10. *Curve showing the value of series capacity required for law correction for various values of excess augmentation of residual capacity of an S.L.F. condenser of 500μμF maximum capacity.*

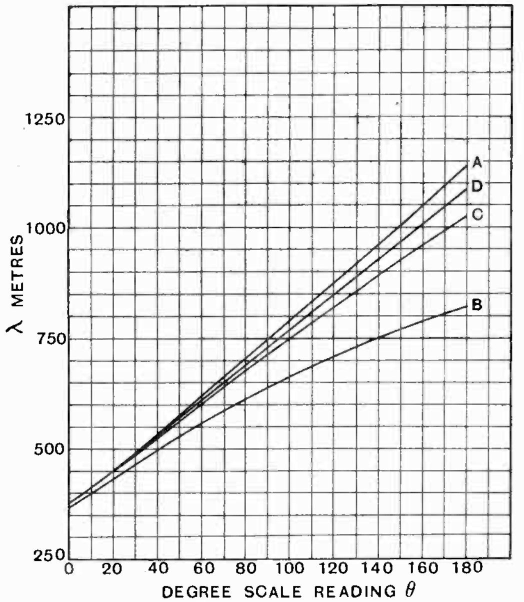

Fig. 12. *The correction (and over-correction) of the imperfect wavelength curve A.*

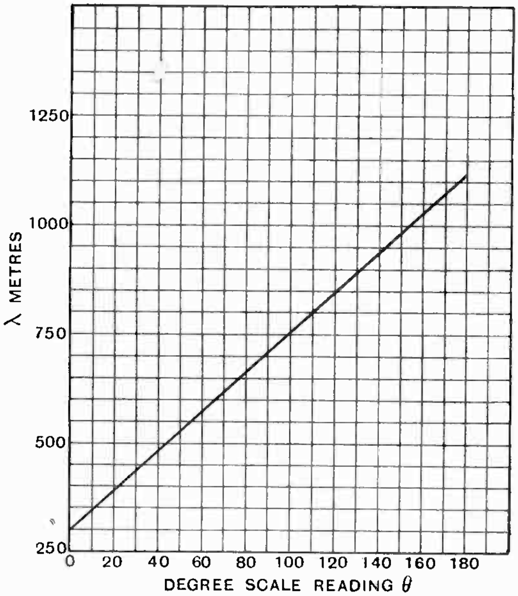

Fig. 11. *A perfect law for a "corrected square law" or S.L.W. condenser. (See Fig. 12 for imperfections introduced by excessive capacity augmentation and for law corrections by a series capacity.)*

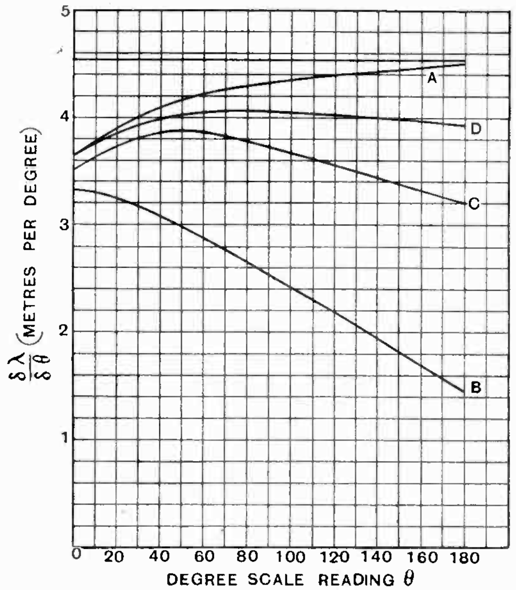

Fig. 13. *"Slope" curves lettered to correspond with the wavelength curves of Fig. 12.*

general, the greater the ratio of $dC/d\theta$ at 180 degrees and 0 degrees of the condenser scale (or the greater the ratio of moving plate radii at 180 degrees and 0 degrees) the greater will be the law alteration for a given excess of residual augmenting capacity and the more difficult will be the correction for law departures.

Conclusion.

In conclusion, it should be stated that although it is possible to design condensers which conform very closely to special laws of wavelength and frequency change, and, if necessary, to correct for varying circuit capacities, etc., it is better to employ variable condensers having uniform capacity scales where exact conformity to law is absolutely essential.

Tuning condensers in radio receivers need only conform approximately to law, but the variable condensers of wavemeters and measuring apparatus generally must conform *exactly* to law in order that the errors introduced by interpolation between points for which a calibration has been obtained may be reduced to a minimum.

The law of a semi-circular plate variable condenser remains purely linear whatever the circuit capacity happens to be and no adjustment is therefore necessary after the original law perfecting adjustments (mechanical in nature) have been effected.

It is often necessary to reduce the total capacity range of a variable condenser in measuring apparatus to quite a small percentage of the total capacity in use, by setting up its zero by varying amounts, by means of parallel condensers of fixed values. This can be done without fear of the introduction of interpolation errors since a full knowledge of the law is always possible if a uniform scale of capacity has once been obtained.

Mathematics for Wireless Amateurs.

By F. M. Colebrook, B.Sc., A.C.G.I., D.I.C.

(*Continued from page* 419 *of July issue.*)

PART III.

THE DIFFERENTIAL AND INTEGRAL CALCULUS.

1. The Object and Scope of the Differential Calculus.

THE Differential Calculus is concerned with the systematic study of variation, and its field of application is therefore co-extensive with the whole domain of natural phenomena. As Professor Whitehead has expressed it, ". . . the fundamental idea of change, which is at the basis of our whole perception of phenomena, immediately suggests the inquiry as to rate of change. . . . Thus the differential calculus is concerned with the very key of the position from which mathematics can be successfully applied to the course of nature."

2. Rate of Change.

The first requirement is make quite clear what is meant by "rate of change." Rate is the same word as ratio, so that "rate of change" can be paraphrased as "ratio of changes," in which form its meaning is already much clearer. It implies two quantities, one of which changes in consequence of a change in the other. In more technical language, it implies a function and an independent variable. The rate of change of the function is thus the ratio of the change in the function to the change in the variable which produces it.

The most suitable example to take will be that one the contemplation of which first evoked in the brain of Newton the ideas on which the present form of the calculus is based—a body moving in space, or, to make it a little less abstract, a train moving along rails. The distance (measured along the rails from some fixed point) which is travelled by the moving train is, in the full mathematical sense of the word, a function of time. In all such physical problems, "time" means, of course, an interval of time measured from some arbitrary "zero" of time. (Anyone who served in the war will know only too well what "zero hour" means.) To fix ideas in the above instance, we will take as the origin of distance some fixed point on the rails and as the origin or "zero" of time the actual clock time at which the engine passes this fixed point. The distance from the fixed point will be represented by the symbol s, which stands for a number (of miles, feet, inches, or whatever unit is most convenient) and the time will be represented by the symbol t (also a number of hours, minutes, seconds, or whatever time unit is most convenient). Then in general

$$s=f(t)$$

Suppose we are told that in a given case the form of the function is linear (see Section 5, Part I, October, 1926), *i.e.*,

$$s=a+bt$$

a and b being constant numbers. In the interval of time between t and $t+\delta t$ (δt being considered as a single symbol meaning "a change of t") s will increase by an amount which we will represent by δs. The relation between $s+\delta s$ and $t+\delta t$ is that given above, *i.e.*,

$$s+\delta s=a+b(t+\delta t)$$
$$=a+bt+b\delta t$$

and since

$$s=a+bt$$
$$\delta s=b\delta t$$

Therefore the ratio of the change of s to the change of t is

$$\delta s/\delta t=b$$

b representing a certain number of miles per hour or feet per second or whatever the selected units may be. It is in fact the speed or velocity of the train, and since it does not depend either on t or on δt the movement of the train is completely described by the single constant b.

But now suppose that the form of the function is given as

$$s=a+bt+ct^2$$

Then in precisely the same way as before it will be found that

$$\delta s=b\delta t+2ct\,\delta t+c\,\delta t^2=(b+2ct+c\delta t)\delta t$$

so that the rate of change of s is

$$\delta s/\delta t=b+2ct+c\delta t$$

This depends not only on t, the beginning of the interval δt, but also on δt, the length of the interval. If the interval δt could be reduced to zero we could say that at the instant t the train was travelling at a speed $(b+2ct)$ miles per hour or whatever the units might be. But that is just what we cannot do. One cannot measure the distance travelled in zero time. Putting it mathematically, since

$$\delta s=(b+2ct+c\delta t)\,\delta t$$

we get by dividing each side by the quantity δt the ratio

$$\delta s/\delta t=(b+2c\delta t+c\delta t)\ (\delta t/\delta t)$$

and if we reduce δt to zero the second term on the right-hand side becomes (0/0) which is not a number at all and may mean anything or nothing. (See para. E.4, August, 1926.)

This is the difficulty which confronted Newton. He probably solved it for himself so completely that he lost sight of the difficult character of the ideas involved. Be that as it may, he did not resolve the difficulty in language sufficiently clear to prevent confusion of thought on the part of some of his disciples. The more discerning mathematicians were greatly worried by this difficulty for a long while after Newton. It did not worry the less discerning ones, for they blotted it out under a cloud of bad philosophy—the sepia principle, invented by the octopus. It appeared that the quantity δt had to be both zero and not zero. "Fancy that!" they said, "What a wonderful quantity it must be!" and gave it a wonderful name, calling it an "infinitesimal." But, unfortunately, as Napoleon remarked on one occasion, "You can call a thing what you like but you cannot prevent it from being what it is." The infinitesimal in its original form was a disappointing child, and died comparatively young.

Actually, of course, there is no need for any mysticism in this matter. The difficulty is completely resolved by means of the conception of "limit" described briefly in Section 8 of Part I (February, 1927). The reader is strongly advised to read this section again, or, better still, to re-write it for himself in his own words. That is always the best way of learning a new set of ideas.

As long as δt remains finite, however small it may be, then $\delta t/\delta t$ is 1, and

$$\delta s/\delta t=(b+2ct)+c\delta t$$

Now by taking δt sufficiently small $\delta s/\delta t$ can be made to differ from $(b+2ct)$ by less than any assigned amount, *i.e.*, it can be made to approximate to $(b+2ct)$ within every standard. This is expressed symbolically

$$\underset{\delta t\to 0}{lt.}\ (\delta s/\delta t)=b+2ct.$$

The expression on the left is inconveniently long to write down and it is commonly abbreviated to ds/dt. Thus, if

$$s=a+bt+ct^2$$
$$ds/dt=b+2ct$$

The symbol ds/dt is called "the differential coefficient of s with respect to t." Notice "the symbol ds/dt"—not the fraction ds/dt, because it is *not* a fraction. The parts ds and dt considered separately are quite undefined. The ds is *not* the limit of ds when ds tends to zero, because then ds would be zero. Similarly for dt. The symbol ds/dt is always to be considered as single and undecomposable like any other simple algebraic symbol—x for instance. It is no more than a convenient abbreviation for

$$\underset{\delta t\to 0}{lt.}\ \delta s/\delta t.$$

There are various other ways of writing the differential coefficient which will perhaps be met with later, but this one is universally accepted and will be used exclusively for the present.

In the present instance the number ds/dt is the instantaneous velocity of the train at the instant t. It is called instantaneous because there is no finite interval of time for which it remains constant. At a particular instant t_1 its magnitude would be $(b+2ct_1)$. The magnitude of ds/dt at the instant t_1 can conveniently be written ds/dt_1, or alternatively $(ds/dt)_{t=t_1}$. The first is preferable for compactness, but the second is more explicit.

The differentiation of s with respect to t leads to the equation

$$ds/dt = b + 2ct.$$

This is known as a differential equation, this name being applied to any equation in which differential coefficients appear. By the solving of a differential equation is meant the reversing of the process that has just been described, *i.e.*, deriving from the differential equation the ordinary algebraic equation to which it corresponds. Notice that in the present case for given values of b and c the differential coefficient would be the same whatever the magnitude of a in the original equation. There are therefore an infinite number of solutions of the above differential equation, and additional information (generally referred to as a " boundary condition ") is required to make the solution complete and unique for the given case considered. Suppose for instance we are told that

$$dy/dx = px + q$$

p and q being known numbers, and that y is known to have the value y_0 when x is zero. By analogy with the equation that has just been considered the solution of the above differential equation is

$$y = (p/2)x^2 + qx + K$$

where K is any independent constant number. But we are told that the relation between y and x is such that when x is zero y is y_0. Putting these related values in the above equation

$$y_0 = (p/2)0 + q0 + K = K$$

so that the complete solution for y is

$$y = (p/2)x^2 + xq + y_0$$

being the only expression for y which satisfies both the differential equation and the given " boundary condition."

This, however, is by way of a digression. It is put in simply to show what is meant by a differential equation and by the solution of a differential equation, and is included at this place because it follows so naturally from the above introduction to the differential coefficient. It is with the latter that we are more concerned at the moment and the next thing to do will be to generalise this important idea.

3. General Definition of "Differential Coefficient."

Given that y is a function of x, the differential coefficient of y with respect to x at any value of x in the neighbourhood of which the function is finite and continuous is defined by

$$\frac{dy}{dx} \text{ or } \frac{d}{dx}f(x) = \underset{h \to 0}{lt.} \frac{f(x+h) - f(x)}{h}$$

The reader should have no difficulty in seeing that this is only the general statement of the process which was illustrated for a particular function in the preceding section.

4. Geometrical Interpretation of the Differential Coefficient.

The curve shown in Fig. 29 is assumed to represent the variation of $f(x)$ with x, *i.e.*, if $OS = x$, $SP = f(x)$. An increase of x from

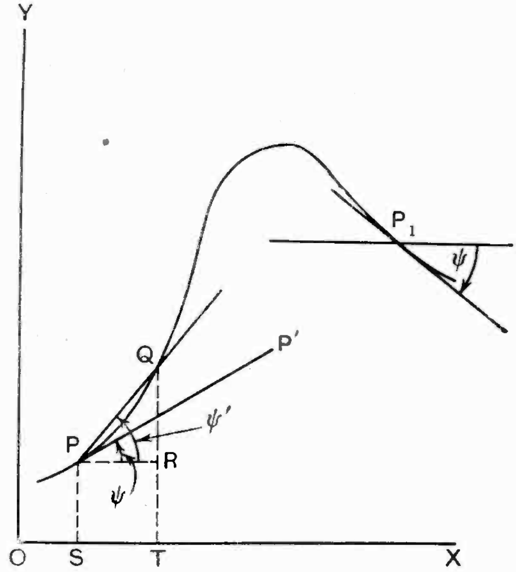

Fig. 29.

OS to OT produces in $f(x)$ an increase represented by RQ. Therefore putting h for the magnitude of PR,

$$\frac{f(x+h) - f(x)}{h} = \frac{RQ}{PR} = \tan \psi'$$

As h tends to zero, Q moves down the curve towards P. In the limiting position when Q tends to coincidence with P the chord PQ becomes what is known as the tangent at P.

Therefore if PP' in Fig. 29 represents the tangent at P to the curve which represents the function, then

$$\frac{d\,f(x)}{dx} = \underset{h\to 0}{lt.}\ \frac{f(x+h)-f(x)}{h} = \tan\psi$$

where ψ is the inclination of the tangent at P with respect to the x axis. For this reason the differential coefficient is sometimes referred to as the slope of the function.

5. The Sign of the Differential Coefficient.

If at the point $x, f(x)$ is increasing with x (as at the point P in Fig. 29) then

$$f(x+h)-f(x)$$

will be a positive number and the differential coefficient will be positive. Conversely if the function is decreasing with x, as at the point P_1 in Fig. 29, then the differential coefficient will be negative in sign, corresponding to the fact that the tangent makes a negative angle with the x axis.

6. The Differentiation of Positive Integral Powers of x.

The differentiation of $y=x^n$ where n is a positive integer is a good illustration of the application of the above general definition of the differential coefficient. By the Binomial Theorem,

$$(x+h)^n = x^n + nx^{n-1}h + \frac{n(n-1)}{2}x^{n-2}h^2 + \frac{n(n-1)\,(n-2)}{2.3}x^{n-3}h^3 \text{ etc.}$$

there being $n+1$ terms in the expansion. Therefore as long as h is finite

$$\frac{(x+h)^n - x^n}{h} = nx^{n-1} + \frac{n(n-1)}{2}x^{n-2}h$$

+ terms containing h^2 and higher powers of h.

By taking h sufficiently small, the right-hand side can be made to differ from nx^{n-1} by less than any finite quantity, however small. Therefore

$$dy/dx = dx^n/dx = \underset{h\to 0}{lt.}\ \frac{(x+h)^n - x^n}{h} = nx^{n-1}$$

For instance $dx^2/dx = 2x$; $dx/dx = 1$. Notice that the above determination of dx^n/dx depends on the fact that the limit of the sum of a *finite* number of terms is the sum of the limits of the terms. The reader is cautioned against assuming that the limit of the sum of an *infinite* number of terms is equal to the sum of the limits of the terms. It may or may not be so, and frequently isn't.

If the above brief introduction to the differential calculus is thoroughly understood, the reader will have no difficulty in understanding the subsequent sections of this part of the series, which will consist mainly of applications and developments of these few comparatively simple ideas.

Examples.

1. Show that the area of a parallelogram having the vectors **a** and **b** as sides is $\sqrt{(ab)^2-(\mathbf{a}\cdot\mathbf{b})^2}$.

2. Two sides of a triangle are 10 cms. and 25 cms. in length, and the angle between them is 50°. Find the length of the third side.

3. Given that $\sin 60°$ is .866, calculate $\tan 60°$ and $\sec 60°$.

4. Show that :—
   (i.) $\tan(A+B) = (\tan A + \tan B)/(1 - \tan A \tan B)$.
   (ii.) $\tan 2\theta = 2\tan\theta/(1-\tan^2\theta)$.
   (iii.) $\sin 3\theta = 3\sin\theta - 4\sin^3\theta$.
   (iv.) $\cos 3\theta = 4\cos^3\theta - 3\cos\theta$.

5. Given that :— $z_1 = 3+j4$, $z_2 = 4+j5$, $z_3 = 5+j6$
   (i.) Find $|z_1|$, $|z_2|$, $|z_3|$.
   Express in the form $r\epsilon^{j\theta}$
   (ii.) $(z_1+z_2+z_3)$.
   (iii.) $(z_1+z_2-z_3)$.
   (iv.) $(z_1+z_2)/z_3$.
   (v.) $(1/z_1)+(1/z_2)+(1/z_3)$

6. Show that the vectors
   $\{(a-b)+j(d-e)\}v$
   $\{(b-c)+j(e-f)\}v$
   $\{(c-a)+j(f-d)\}v$
   form a triangle.

7. Express in the form $(a+jb)$ the cube roots of $(1+j2)$.

8. The instantaneous rate of motion of a particle moving in a straight line is given as $50+100t$ cms. per second. How far will it travel in an hour from its position at the instant $t=0$?

9. The distance from a fixed point travelled by a particle moving in a straight line is given as $10+500t-5t^2$ cms., t being the time in seconds. At what distance from the starting point will it come to rest, and in how long ? How long will it take to return to its starting point ?

(To be continued.)

The Hot-Wire Microphone and Audio-Resonant Selection.

Paper read by G. G. BLAKE, M.I.E.E., F.Inst.P., to the Radio Society of Great Britain at the Institution of Electrical Engineers, 25th May, 1927.

IN a lecture before the Royal Society in 1880, Sir William Preece described a thermo-telephone receiver, which consisted of a tightly stretched length of fine platinum wire, fixed at one end and attached at its other extremity to the centre of a diaphragm, as shown in Fig. 1(*a*).*

The wire is heated by a current from battery *B*, and the expansion and contraction of the wire in response to words spoken towards the microphone *M*, cause the diaphragm to vibrate.

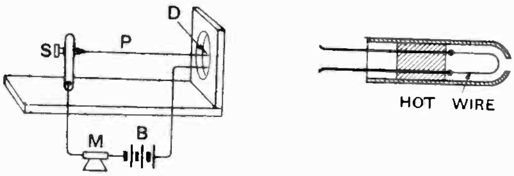

Fig. 1.

In 1887 Prof. Geo. Forbes, in a paper before the Royal Society, described the employment of a red hot wire as a telephone transmitter. A fine platinum wire was included in circuit with a battery and the primary of a transformer, the secondary of which was connected to a telephone receiver. When the wire was incandescent, words spoken towards it could be heard in a receiver owing to its change of resistance, due to the cooling action of the air movements (sound waves). This form of transmitter was insensitive to mechanical vibration.

In 1906 Dr. Eccles† invented a telephone receiver which he called a "Thermophone." This is shown in Fig. 1(*b*). The instrument was actually inserted in the ear of the listener, and the expansion and contraction of the air within the tube and the aural passages, due to the rapid changes of temperature of a fine platinum wire, affected the human diaphragm, and could be heard without any other mechanism.

Hot wires have of course been employed for many purposes in connection with radio, for example Fessenden's barretter (patented in 1902),* Duddell's thermo-galvanometer, hot wire milliameters of various types, Langley's bolometer, Tissot's bolometer bridge,† The Snow Harris thermo-galvanometer,‡ etc. §

In 1923, in a lecture before the Royal Society of Arts, Major W. S. Tucker ‖ demonstrated the extraordinary sensitiveness of a hot wire to sounds, when it was included in one arm of a Wheatstone bridge, and placed at the orifice of a suitably constructed acoustic resonator. By tuning the latter the hot wire was only affected by the note to which it was tuned. He described how this instrument was successfully employed during the Great War in locating the enemy's big guns, and how it detected them without experiencing interference from nearby rifle fire and other noises, which so far as ordinary oral reception was concerned, entirely obliterated the sounds of the distant big guns.

The din of battle could be rejected with

* Fig. 1 is a reproduction from G. G. Blake's *History of Radio-Telegraphy and Telephony*. Reproduced by the courtesy of the Radio Press (the Publishers).

† See *Handbook of Formulæ, Data and Information*. By W. H. Eccles. Published by the Electrician Printing and Publishing Co.

* See G. G. Blake's *History of Radio-Telegraphy and Telephony*.

† See *Journal of I.E.E.*, 1906.

‡ See *Handbook of Wireless Telegraphy*. By J. Erskine-Murray.

§ Our Chairman (of the R.S.G.B.), General Capel Holden, has himself made a number of inventions which embody the employment of a hot-wire. See "Holden–d'Arsonval Universal Reflecting Galvanometer." *Electrician*, vol. 29, p. 589, 7th July, 1893. Both the Holden hot-wire recording voltmeter and ammeter are manufactured by Messrs. James Pitkin.

‖ See also *Phil. Trans.*, 1921, 221, A.389.

ease, as it consisted of sounds having far shorter wavelength than those coming from the distant guns, to which the resonator was tuned. This demonstration which I witnessed impressed me with the idea that the hot wire microphone and resonator might be employed for audio-resonant radio reception. In a paper to the Radio Society of Great Britain in 1924* the writer

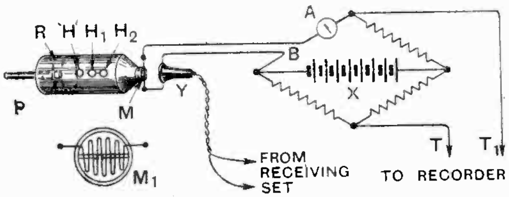

Fig. 2.

suggested that when two or more stations are jamming one another to such an extent that it becomes a difficult problem to cut out the interfering stations, use might well be made of the hot wire microphone and acoustic resonator.

Fig. 2† illustrates the scheme in which the signals should be given a distinct note at the transmitting station, either by a spark interrupter operating at an audio-frequency, or in the case of C.W. transmission by tonic train interruption; or alternatively that the required musical note could be produced by heterodyning at the receiving station.

In the American journal *Radio News* for December, 1926, a description was given by O. C. Roos of the "Acoustat." In this instrument resonating tubes are employed in quite another manner, for the elimination of statics. This apparatus has been employed at Rockland, Maine. Its action is briefly as follows: Signals are first received in the usual manner by aid of a heterodyned receiver, and given a pure note of known acoustic frequency. The telephone receiver is then placed in front of a "Percussion" chamber, which turns the noise of the static cracks into one pure musical tone, carefully arranged so as not to resonate with the note previously given to the incoming signals; by the employment of a suitable series of resonating chambers it is possible to pass both these sounds, and by placing a receiver in the right position to pick up the signals and to reject the unwanted note produced in the "Percussion" chamber by the atmospherics. The signals are brought to focus by a concave sound reflector at the diaphragm of a telephone receiver, the movements of the diaphragm of which generate currents which are amplified as may be found necessary for recording or aural reception. The system is based, I believe, upon a scheme of audio-resonant selection for spark signals developed in 1910 or 1911 by Braun in Germany.

In 1927 Dr. H. E. Watson of the Indian Institute of Science, Bangalore, published a paper describing how he had put the writer's suggestion to the test.*

Fig. 3(*a*) shows the circuit he employed :—

R is a 3-valve receiver.

A is C Mark II. audio - frequency amplifier.

T is a resonator with a hot wire microphone at its centre instead of at its end. This consisted of a Wollaston wire 0.00024 in. run at a dull red heat.

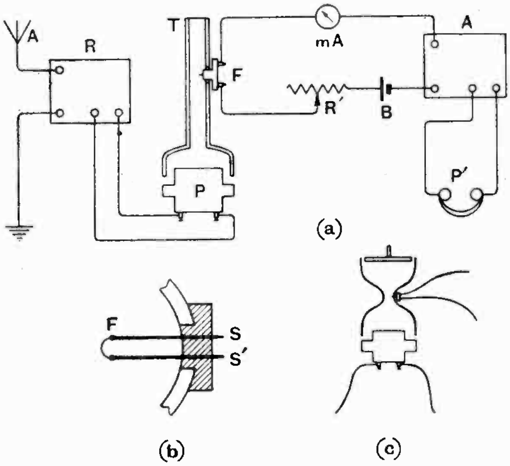

Fig. 3.

Fig. 3(*b*) shows his method of mounting the Wollaston wire by soldering it across two 40-gauge Constantan wires.

* "Some Suggested Lines for Experimental Research," *Wireless World*, Vol. XIV., 25th June, 1924.

† Reproduced by permission of the Publishers from G. G. Blake's *History of Radio-Telegraphy and Telephony*.

* Paper "The Tucker Microphone for Reception." Prof. H. E. Watson, D.Sc., *E.W. & W.E.*, Vol. IV., March, 1927, pp. 148-150.

Fig. 3(*c*) is another form of resonator which he employed.

The following is a quotation from his paper :—

"Finally a few words may be said as to the selectivity of the microphone as experimentally determined. The apparatus was not suitable for quantitative measurements by the Wheatstone bridge method and so the experiments were merely qualitative. It may be mentioned, however, that they are of the order which would be expected if the resonance curve at a frequency of 1,000 were similar to the one given by Tucker & Paris for 250 periods.

"In one experiment, Madras (VWO), working on 4,000 metres, was tuned in"— on a particularly unselective receiver— "autodyne reception being used. A local oscillator was arranged to transmit Vs on a near wavelength so that the signals received were much weaker than those from VWO. Tuning was carried out by means of a vernier condenser. When VWO was tuned in the Vs were almost inaudible ; when the local oscillator was tuned in, the signals from VWO were audible but not loud enough to interfere with accurate reading. The change of the capacity of the condenser between the two settings was $6\mu\mu F$, say 1 in 250, corresponding to a change in frequency of 1 in 500, *i.e.*, 150 cycles for the frequency of 75 kilocycles employed.

"The corresponding wavelength difference of the two transmissions is only 8 metres. As it is the difference in frequency which determines the change of pitch of the beat note, it is this quality which we will assume to be about 150 cycles, for signals not differing very widely in intensity, which determines the possibility of separating two signals whatever the operating frequency.

"Expressed in wavelengths, a separation could be effected of two stations working not less than 200 metres apart at 20,000 metres, or 0.02 metre apart at 200 metres. By using a beat note of lower frequency, still sharper separation could be obtained, but as already pointed out, other factors render this inadvisable. Data regarding the performance of tuned audio-frequency transformers appear to be scanty, reference may however be made to a paper on the subject by A. Pagès.* From the one resonance curve given, the selectivity of the transformers described appears to be considerably inferior to that of the hot wire microphone.

"The effect of the microphone upon the confused noises usually heard when receiving upon the longer wavelengths with an unselective receiver is striking. With perhaps a few exceptions each station may be tuned in separately and clearly. For example, no trace of the strong signals from SIAGON (HZA 15,750 metres) or Malabar (PKX, 15,600 metres) could be heard when listening to Lyon (YN, 15,300 metres)."

Having followed the applications of the hot wire up to this point the writer decided to conduct some experiments on his own account.

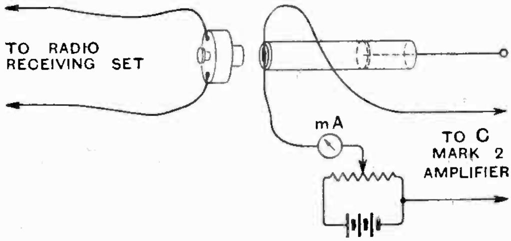

Fig. 4.

Fig. 4 illustrates the first experiment.

Signals from numerous C.W. and spark stations were received on an ordinary autodyne receiving set, consisting of one valve detector followed by one stage of note magnification, and in the case of weaker stations by two stages. Signals were received on various wavelengths.

Three resonators were tested, the smallest consisted of a tube ½ in. in diameter and 9 in. long, resonating to a wavelength of 3 ft., and having a frequency of approximately 373 when its plunger was fully extended.

The next resonator was 1 in. in diameter and 21 in. long, this when the plunger was fully extended had a wavelength of 7 ft. and an approximate frequency of 160.

Another resonator was 6 in. in diameter and 15 in. long ; roughly not allowing any extra for its excessive diameter, this had an approximate wavelength of 5 ft. and a frequency of 224.

All these resonators worked well. In practice it was found that the best scheme was to set the resonator to respond to some predetermined frequency, say to a

* *L'Onde Electrique*, June, 1926, pp. 276-283.

frequency of about 376 (9 in. long) and to heterodyne the incoming signals to give a beat note of that same frequency. For these early experiments a 0.00024 Wollaston wire was employed. A heating current of 4.5mA was supplied from a 6-volt accumulator, which maintained the filament at a dull red heat, both potentiometer and series resistance control were alternately employed, with equally good results. The circuit was completed through the primary of the input transformer of a "C Mark II." amplifier,

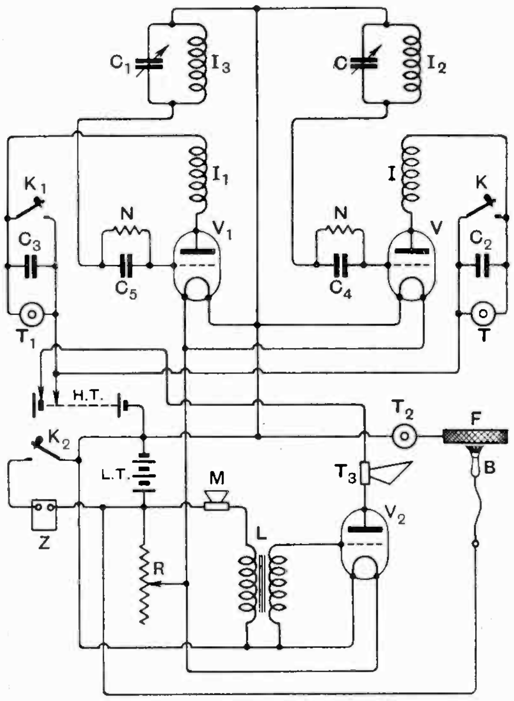

Fig. 5.

and the signals were finally received by headphone. It should be mentioned also that an adjustable slit diaphragm was employed with the resonators.

The results were most encouraging, even when several stations were working with considerable interference and when atmospherics were bad only the selected station could be heard. In order to put the selectivity of the hot wire microphone to a more stringent test, the writer next fitted up the arrangement shown in Fig. 5. The arrangement of my "Interference tester," as will be seen, comprises four separately controlled circuits all of which obtain their H.T. and L.T. supply from a common source.

Morse keys K and K_1 control two separately tuned oscillating valve circuits. Normally the keys short circuit the telephone earpieces T and T_1, and notes are sounded in the phones when the keys are depressed. The frequency of the notes can be controlled in several ways: By an adjustable grid-leak and fixed grid condenser, or by the employment of a fixed grid-leak and an adjustable grid condenser.

Another method is to employ a fixed condenser and grid-leak, and to alter the frequency by the insertion to a greater or less extent of an adjustable iron core within the fields of the grid and plate coils.

Or again, the frequency can be controlled in the manner we are employing this evening, by means of a variable condenser across the grid coil.

There are doubtless various other methods which might be employed, for instance the adjustment of the filament current, or the plate voltage, or the coupling between the grid and plate coils, or again variometer tuning might be employed.

Key K_2 controls a simple buzzer circuit.

The fourth circuit shown on this slide was employed to produce unpleasant noises to approximate the sounds of atmospherics, these noises were produced in phone T_2, when a steel file F was brushed with a metal brush B.

For the purpose of our demonstration this evening, I have removed this arrangement and substituted a simple telephone earpiece, which is connected to a valve receiving set connected to the outside aerial. In order to save me the trouble of having to bring an excessive amount of apparatus, my friend Mr. Maurice Child has kindly brought along his receiving set, and I will now ask him to pick up some C.W. signals.

These we will mingle with our artificially produced interference, and I will then endeavour to demonstrate to you that it is possible to rescue them again from the apparently hopeless jumble of interfering sounds.

Before we put on the next slide please again note the three telephones T, T_1 and T_2 and the buzzer Z. The three phones and buzzer, as will be seen from Fig. 6, are all mounted on a baseboard, forming the back of a concave cavity, where all the sounds are collected and directed against a paper diaphragm D to the centre of which is attached a microphone.

The microphone currents are amplified by a valve V_2 (which was also shown in Fig. 5).

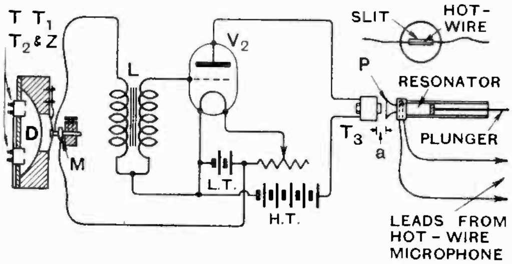

Fig. 6.

Demonstration.

You can now hear four sets of signals all interfering. Referring again to Fig. 6, you will see that the loudspeaker (denuded of its horn) is now placed in front of a resonator fitted with a hot wire microphone.

Numerous experiments were made with different wavelengths. Wollaston wire of various gauges were tested, and the best results were obtained by the employment of a single wire $\frac{3}{16}$ in. long and 0.0001 in. in diameter. In order to obtain the maximum cooling effect from the pulses of air (sound waves) as they pulsed through the mouth of the resonator, a slit diaphragm was employed (see inset Fig. 6). The width of this slit was critical and was arrived at experimentally. In order to obtain really sharp tuning, and to make the arrangement extremely selective, in addition to tuning the resonator accurately by means of its plunger, to the same frequency as the beat note of the received signals, it is necessary (in order to prevent forced resonance) to adjust the distance between the loudspeaker phone T_3 and the resonator, according to the strength of the received signals, as shown at (*a*).

During the initial experiments the hot wire microphone was heated by means of a 4-volt accumulator, the heating being controlled either by a potentiometer or a series resistance as already described. The variations in current as determined by a milliammeter in the hot wire circuit were (even for powerful signals) in the order of less than 1mA, *i.e.*, with a steady filament heating current of 16.5mA the current rose during the reception of a signal to a value of 17.4mA.

Although it would not be difficult to devise means of recording directly with these small current changes (one very simple way which occurs to me would be to make use of a device described by J. H. Powell* in 1924. In place of a recording pen he places a small speck of radium under the needle of a galvanometer movement. The rays from this fall upon photographic paper on a revolving drum—the latter need not be in the dark, as the radium rays easily penetrate through a layer of black paper which protects it from the light until it is developed. With this arrangement the needle need not touch the paper, and there is therefore no friction).

I decided to make things more certain by the addition of one stage of amplification, and for this purpose I employed the "Zero shunt" circuit.

Before proceeding further I may perhaps make a biographical note on this subject, the zero shunt as originally devised by J. J. Dowling† is shown in Fig. 7. As can

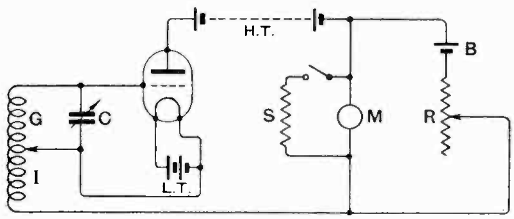

Fig. 7.

be seen the steady plate current is balanced out by an opposed E.M.F. applied from a battery B in series with a high resistance,

* J. H. Powell "Radium Recording Devices." *Journal of Scientific Instruments*, Vol. I., April, 1924, pp. 205-209.

† See G. G. Blake's *History of Radio-Telegraphy and Telephony*. Radio Press.

J. J. Dowling, *Proc. Royal Dublin Society*, Vol. XVI., 1921, pp. 175-184 and pp. 185-188; also *Phil. Mag.*, Series Six, Vol. XLVI., July, 1923, pp. 81-100.

which together form a shunt circuit across a galvanometer *M*.

In 1926 the writer* published the circuit shown in Fig. 8. in which it will be seen that the opposing E.M.F. is obtained from the filament heating battery by means of a potentiometer. As this circuit enabled a Siemen's relay to be operated quite satisfactorily in the plate circuit of a B.T.H.

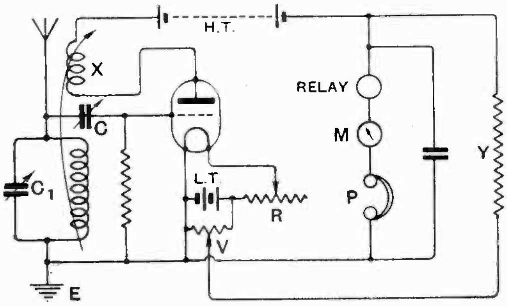

Fig. 8.

B4 valve it seemed admirably adapted for use in conjunction with a hot wire microphone.

The next circuit (Fig. 9) shows the arrangement we are using this evening. It requires very little explanation. One 12-volt battery supplies current for all circuits with the exception of the plate circuit. The full 12 volts is applied through the primary *T* of a transformer (wound to a resistance of 222 ohms), a milliammeter and the Wollaston wire filament of the hot wire microphone. A potentiometer across half the accumulator supplies the opposing E.M.F. for the zero shunt. A 4-volt tapping from the same accumulator provides the current for the secondary circuit of the relay. The secondary of the transformer *T′* is wound to a resistance of 9,600 ohms. The plate circuit of the valve includes a 75-volt H.T. battery, a delicate galvanometer, and the primary windings of the relay. The resistance *R* included in the zero shunt circuit is adjustable between the values of 100 and 666 ohms.

The selectivity of this method of audio-resonant selection was then put to the test, signals were received by Mr. Child on the outside aerial, and then badly jammed by three volunteer transmitters operating the morse keys of the "interference tester," and it was shown that either these or any of the other signals could be picked out from the medley of noises, and recorded by means of a "siphon recorder."

To make the recorded signals visible to the audience the recorder movement was magnified and thrown on the lantern sheet.

Before bringing this paper to a conclusion, there is one other hot wire application which should be mentioned. In 1907 A. Kœpsel* patented a relay which bears a strong resemblance to Tucker's hot wire microphone. He also employs a hot wire in one arm of a Wheatstone bridge, this is stretched between two supports, in front of but not in contact with one surface of a mica disc, a slot is cut in the disc so that when the latter is in one position, a surface of mica is presented to the whole length of the hot wire. A slight rotation of the disc replaces the mica by an air space, the effect is to regulate the heat radiated from the hot wire, and so to vary its resistance. This small rotation is applied electromagnetically by the currents which it is desired to relay.

The sensitivity is greatly increased by allowing the movements of the disc to cover one arm of a bridge while uncovering the other

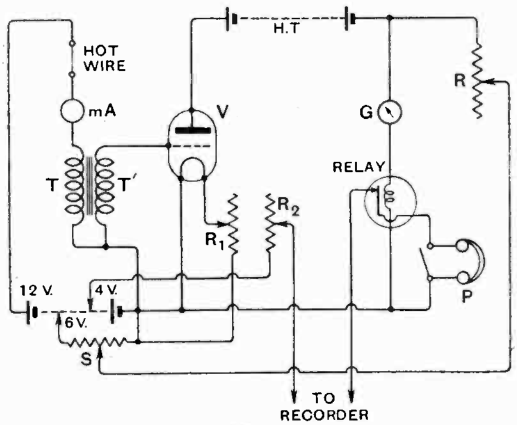

Fig. 9.

arm. Consideration of this device suggests the possibility of the employment of two hot wire microphones placed at suitable distances apart in a resonator, and forming

* "A Sensitive Valve Relay," *Wireless World*, Vol. XIX., 11th August, 1926.

* Kœpsel, British Patent No. 18,238 of 3rd September, 1907.

two arms of a Wheatstone bridge circuit. Or again the pulses of air into and out of a resonator might be employed to operate the mica vane of a Kœpsel relay.

When receiving C.W. signals by heterodyne a very small change of frequency produced by a movement of only one or two divisions on the scale of a .0005 condenser is sufficient (if the loudspeaker is correctly distanced from the resonator) to tune a station completely in or out. As far as I can judge from the comparatively few tests which I have made, reception would appear to be quite free from atmospherics of average strength, and to my mind this is all that we can expect from the system. So long as the atmospheric disturbances are only of the same order of magnitude as the signals, the great majority of them at least are quite perfectly eliminated; but it must be obvious that neither this method nor the "Acoustat" are likely to be of any use in dealing with powerful static discharges which momentarily bias the grid of the detector valve, often sufficiently to paralyse it so that it ceases to function. The cure, if there is one, for these static disturbances, must obviously be applied on the aerial side of the detector.

By aid of audio-resonant selection I think it may be possible to open up the already overcrowded ether to a great many more stations. If the audio-frequency notes of the stations are fixed at the transmitting end either by the employment of tonic train, or musically modulated carrier wave, I see no reason why many more stations should not be squeezed into the wavebands not at present employed for Broadcasting (before they are all appropriated for that purpose) and allowed to overlap their signals.

At the receiving station any one of these signals could be received by a hot wire microphone and resonator or a number of resonators could be employed, each tuned to a different station, and all the signals recorded simultaneously.

The system would also appear to be applicable to wired wireless, and to multiplex line telegraphy.

In conclusion I wish to thank my assistant, Mr. Harwood, for his skilled help in preparing the experiments; Mr. Child for so kindly bringing his receiving set and getting signals for us this evening; Messrs. Lissen for the loan of the H.T. batteries; also the lanternist who has been showing the slides for us all the evening.

DISCUSSION.

Mr. F. H. Haynes: Although certain of the fundamentals dealt with by Mr. Blake are old, he has covered ground which to many of us is entirely new. It is the picking up of the threads of former experiment and weaving them together to give new results that constitutes progress. As the paper covers new ground I can offer no useful comment and I rather search for applications to which the effects demonstrated to us this evening can be applied. It is possible that the note selecting properties of the hot wire microphone combined with the adjustable resonator might be used to analyse loud speaker response to various frequencies though the temperature fluctuations would not of course be uniform for any given amplitude with changes in frequency. The connection between mechanical and electrical resonance which has been so successfully developed has no doubt many useful applications. This is not the first time that Mr. Blake has shown to us results dependent for their success upon sheer manipulative skill and our thanks are due to him for presenting to us a new line of development.

Mr. Maurice Child: This is the first opportunity I have had of seeing Mr. Blake's experiments and I feel that he has done a great deal of valuable work. I think it is useful work because we are inclined to-day to spend most of our time on this miserable broadcasting business—if I may put it that way—and we are forgetting the other side of wireless work to a very great extent, I mean the very important side of telegraphy. After all, telegraph work at high speeds has got to proceed, but I find that very little attention is paid to it to-day in the Press. Most publications are concerned with broadcasting, but Mr. Blake has brought us back to the very important question of the selection of notes for telegraphic work and fairly high speed work. The station we heard to-night was Ongar and the speed of transmission was about 30 to 35 words per minute (I should not think it was much more than that because it would not have been recorded with this particular relay) but it is obvious that with a little trouble improvements can easily be made and a relay obtained which would be absolutely reliable when working at higher speeds. I think we have got to a stage now with this note selection when we can really say that atmospheric disturbances for telegraphic purposes can be practically eliminated. Mention has not been made of the fact that by combining this apparatus with a suitable limiting arrangement of high frequency valves, we have a pretty complete system for the elimination of atmospherics. If atmospherics come in very strongly indeed, far above the signal strength on the aerial, they can be "limited" by dimming the filament of the valves and in other ways so as to reduce their strength before we come to the actual amplification of the final note by its selection with the hot wire selector which Mr. Blake has designed. There is one other thing which I should like to mention. I notice that Mr. Blake rather prefers to select notes of the order of 300 or 350 cycles. At the moment it occurs to me that that is rather unfortunate because the type of telephone required for energising the hot wire usually responds best at frequencies round about 900 cycles and therefore there must be some loss in efficiency because of this. I imagine there will be some little difficulty, perhaps mechanical, in getting an instrument to respond at, say, 1,000 cycles, but it is all a matter of delicacy of adjustment of the resonating column of air. That, however, may be easily got over because it is a mechanical detail. If we can get a series of fixed resonators set up it would be very useful from a telegraphic point of view. Thus, with a series of such resonators we can quickly switch over and try one after the other and see which is free. If we can do this we should have a pretty useful system for selection without much delay in the actual telegraphic work. Mr. Blake has taken an enormous amount of trouble to come here to-night and bring down all this apparatus, and personally I have enjoyed listening very much to his lecture.

Mr. E. Kilburn Scott: What one might call the psychological factor of Mr. Blake's work, interests me more than the scientific, because his record shows once again the falsity of the assumption held by so many that academic training is a necessary preliminary to scientific research. He is also an example of one who was helped by a father at an early age to make scientific apparatus and experiments, and thus gained adaptiveness in improvising scientific apparatus which is so useful.

The late Mr. Duddell, President of the Institution of Electrical Engineers, was such another in that he developed the oscillograph at an early age and it was partly due to a father who helped and encouraged his experimental work.

The most creative time of life is in the 'twenties and 'thirties, and as each generation produces only a few who are capable of creative scientific work, it is necessary that those who have that special ability should be discovered and encouraged at the right time. Far too many young men are being herded through routine courses of study and examinations in which bookiness and memorising are emphasised at the expense of craftsmanship and the development of original creative talent.

To put it bluntly, I believe that more useful creative work is likely to come from types such as Duddell and Blake than from those who have many academic distinctions.

I take it that Mr. Blake is aiming at eliminating the trouble with atmospherics when receiving wireless messages from overseas. During a recent transmission from Schenectady, I noticed that the announcer's voice was quite clear, whereas the music was not, especially in the high notes. Is it right to assume that atmospherics have less effect on lower tones, for example would a song by a contralto be received better than one by a soprano? Tests on these lines might be useful.

Mr. E. H. Robinson: I should like to ask Mr. Blake about one point with regard to the very interesting subject he has dealt with this evening. The thing that naturally puzzles me is what advantage acoustic selectivity has over electrical selectivity? You can get audio-frequency tuning with audio-frequency tuned electrical circuits in an exactly analogous manner to the acoustic resonator, and I am wondering whether Mr. Blake can point out any advantage in using acoustic resonators over electrical resonators. I have had no experience of these acoustic resonators myself and what I have learned to-night has been extremely interesting. On the other hand, I have had a fair amount of experience in electrical audio-frequency tuning, and I am able to pick out one station from a whole lot, and it is for this reason that I should like to know whether the acoustic method has any definite advantages. It seems to me that we are introducing slightly cumbersome methods in departing from electrical tuning but I may be wrong and I should like Mr. Blake's observations on this point.

Mr. G. G. Blake, replying to the discussion, said: I would like to reply first to the last speaker. With regard to the difference between audio-resonant selection and electrical methods of tuning. Let me say at once that they do not come into conflict at all. My idea is as follows: First of all to get the maximum amount of selectivity possible by the ordinary electrical methods. If you can get all that is necessary in that way, well and good; and there is no need to trouble about audio-resonant selection. On the other hand, if having got the maximum amount of selectivity possible by electrical methods of tuning, you still find stations are jamming one another to such an extent that you cannot separate them out with any ordinary form of receiver, then is the time to make use of some such method as this. I do not suggest that this method is in any way a rival to electrical tuning, but it is an auxiliary method. Mr. Haynes mentioned that this might form a way of testing loud-speakers, and I think there may be a possible application for the hot wire microphone and resonator in making such tests. We might be able to find the predominant notes prevailing in certain loud-speakers by this method. Mr. Child mentioned high speed telegraphy. I quite agree with him as to the possibilities of the hot wire method in this direction. My experiments have, as you can see, been carried out with home-made apparatus, and so far as I can judge, the hot wire appears to follow almost any speed of signals. It does not seem to miss anything as far as I can tell. Mr. Child made a most valuable suggestion when he pointed out that "limiting devices" could be used in conjunction with this apparatus in order to reduce the effect of atmospherics. Mr. Child evidently appreciated the point that this apparatus is not in any way intended as a rival to electrical tuning but that one should first tune electrically and then obtain still further selectivity by this method. Mr. Child discussed the problem of frequency and raised the question, to which note should the resonator be attuned? The resonators you see on the table are quite crude in construction. The plungers are made of cardboard packed with cotton wool and very sharp tuning can hardly be expected. With more perfectly made resonators, however, I see no reason why one should not be able to work over a wide range of frequencies. I have merely used the frequency which I found best for this particular piece of apparatus. Mr. Kilburn Scott made some very kind remarks and I agree that many of us owe a great deal to our parents for the help they have given us in our early days. I personally owe a great debt of gratitude to my parents which I gladly acknowledge. Mr. Bevan Swift mentioned the Southern Railway, I do not know exactly what he wants me to do. Does he suggest that we should turn our tube railways into a system of electrical resonators with huge hot wire microphones at the openings of the tubes ? I do not see how we are to apply audio resonant selection to the railways, but of course his remarks were only jocular and not intended to be taken seriously.

The President (General Sir Capel Holden, F.R.S., M.I.E.E.,) in proposing a vote of thanks, said : I am sure you will all agree with me that we have had a most interesting lecture from Mr. Blake. He has opened up a new field for thought and also for experiment, and I can only hope that he will bring his experiments to a very successful issue. When I say successful issue, I am not thinking of Mr. Child and his telegraphy, because there are only a very few people, comparatively speaking, interested in telegraphy. I think the public generally are interested in broadcasting and I refer to it because I want to suggest to Mr. Blake that if he could have tried some of his apparatus on the relay which the B.B.C. gave us last night, which consisted of atmospherics and a little music from America in the background, and if he could have given us the music without the atmospherics, then the B.B.C ought to take him and put him into one of its highest salaried posts.

Mr. Blake acknowledged the vote of thanks, and added : Before I sit down I ought to mention that perhaps Mr. Child may be willing to tell you a few things about his set, to which I have already referred and which is rather unique in construction. There are some points about it which I think will be of interest.

Mr. Child : This particular set which I asked Messrs. Henderson, of Fulham Road, to make for me is an endeavour to try and get something which will interest probably a good many of us here. It is nothing very special as regards circuit arrangements, but it is interesting as an example of a complete two-valve receiver employing the comparatively new KL1 valves worked from 50 cycle 200 volt supply. There are no batteries associated with the receiver at all beyond the little grid battery inside. To make sure that the signal strength would suit Mr. Blake's apparatus to-night I had to bring down a small experimental low frequency amplifier so as to have a margin of strength for him to play with, because I did not know exactly what he would require. The only addition that has been made is a little rejector circuit which I have put direct into the aerial for the purpose of cutting out 2LO.

Abstracts and References.

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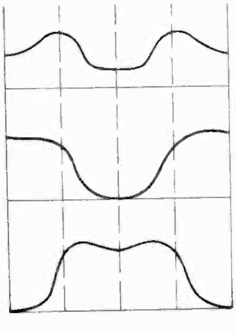
PROPAGATION OF WAVES.

La Notion Experimentale d'une Surface de Référence dans la Propagation des Ondes Courtes (Empirical idea of a surface of reference in the propagation of short waves).—R. Bureau. (*L'Onde Electrique*, 6, 64, April, 1927, pp. 168-169.)

Communication made to the French U.R.S.I. meeting, June, 1926. From a series of observations carried out on board the *Jacques Cartier* (*C.R.* 180, 2,025, 1925) and the *Jeanne d'Arc* (*O.E.* 5, 53, 1926) the author concludes that the greater part of the diverse phenomena found in the propagation of short waves can be referred to a regular variation of a general simple character, compared to which the divergences that are found on certain days may be regarded as accidental disturbances.

Whatever the wavelength (at least between 25 and 115 metres, the range covered in this investigation), the diurnal variation of signal intensity at a given distance from the transmitter presents two minima, which can reach complete extinction. One generally occurs somewhere about mid-day and may be called the day minimum, the other the night minimum. The former becomes more pronounced as the distance increases, as the wavelength increases, and as summer approaches; the latter becomes marked as the distance and wavelength diminish and as winter approaches. One of these minima may flatten out and the two maxima on either side join together, giving the diurnal variation the appearance of a wave with a single undulation and hiding its double undulatory character.

Plotting the three variables: distance, time of day, and signal strength, yields surfaces whose

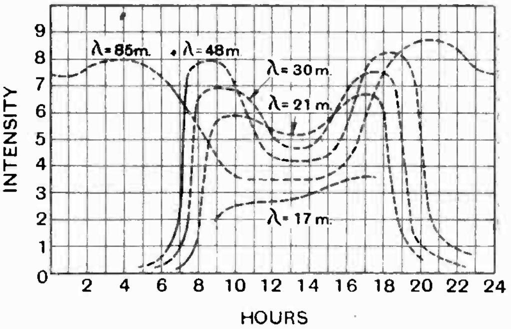


sections all present these same general characteristics. The figure shows three extreme types of surface section; a section of given shape being obtainable by varying indifferently the distance, the time of day, or the wavelength.

Disturbances of this surface can be introduced by the latitude, the orography, and the atmosphere, and before they can be studied, must be isolated from the variations coming simply from the general phenomenon represented by the surface of reference.

Remarque sur la Propagation des Ondes Courtes à Distance Fixe (Note on the propagation of short waves over a given distance). — A. Jouffray. (*L'Onde Electrique*, 6, 64, pp. 170-172, April, 1927.)

M. Bureau has set out the laws of the diurnal variation of the signal strength of short waves as a function of the distance and time of day and shown the existence of two maxima (morning and evening) and of two minima (day and night).



The isolated experimenter, however, relying only on his own observations and forced to regard the distance as a constant, is able to study these same laws by taking for variables the time of day and the wavelength (listening to several emissions quasi simultaneously emanating from the same region). He will find that after the night minimum the emissions appear in general in the order of decreasing wavelength, while in the evening after the second maximum they disappear in the order of increasing wavelength, showing that the maxima are not simultaneous for the different wavelengths but are produced successively. Thus plotting the time of day as abscissæ and signal strength as ordinates, the following graph is given for a distance of about 400 kilometres.

The curves are drawn in only approximately and the author is of the opinion that it would be of great interest to verify the non-simultaneity of the maxima with different wavelengths and find their position accurately by prolonged tests bearing on the two branches of the curves including the same maximum. These same tests would enable the relative values of the maxima to be determined (the evening one generally appearing the higher) as well as the values of the day minima. Thus one would arrive at a definition of the normal law of short wave propagation and then be in a position to broach the study of the perturbations, which is likely to be more fruitful in both theoretical and practical results.

ANOMALIES DE LONGUE DURÉE DANS LA PROPAGATION DES ONDES COURTES (Anomalies of long duration in the propagation of short waves). — R. Bureau. (*Comptes Rendus*, 184, 18, pp. 1078-1080, 2nd May, 1927.)

Experimental study of the propagation of waves between 20 and 115 metres led the author in June, 1926 (*O.E.*, April, 1927, see abstract above) to point out that this propagation is subject to a regular law. According to the law the signal strength of a wavelength λ at a distance d presents two minima: one towards mid-day which is more pronounced as λ and d increase, and the other towards midnight which becomes more marked as λ and d diminish (if d is sufficiently great for the direct ray to be absent), also either of these minima can be attenuated and practically disappear for suitable combinations of the values of d and λ, so that for each distance there are waves that are propagated by day and not by night.

Similar results were arrived at in America at the same period (Heising, Schelleng and Southworth, *Proc. Inst. Radio Eng.*, October, 1926) and were explained as follows: the day minimum is due to absorption caused by ionisation, the effect of which increases with the wavelength, while the night minimum is due to an insufficient curvature of the rays, the curvature decreasing as the wavelength diminishes, and thus the increase in ionisation due to solar radiation in the layers of the atmosphere where the waves travel suffices to explain the law given above.

The results of observations in France over distances of from 10 to 1,500 kilometres have persuaded the author that this law, which he denotes by A, is not only disturbed by accidental and irregular phenomena, but that there is superimposed upon it sometimes an effect of long duration which goes on increasing from week to week. This action, called B, only makes itself felt on pretty short wavelengths (less than 50 metres) without appearing seriously to affect longer ones. Its effect is to reverse in some way that of A, so that, for instance, waves of 30 metres appear earlier before sunrise than waves of 48 metres, and waves of 20 metres present an extinction at mid-day while those of 30 metres continue to be propagated freely. It is as though, beyond a certain limit, the shortening of the wavelength improved night propagation and was less favourable to day propagation.

The author states that these anomalies (as well as others) are best explained by supposing the existence of two ionised layers at altitudes h and H (where $H>h$). The law of propagation A would be due to the first layer, which would be very sensitive to solar action. The propagation of type B would be controlled by the layer H for waves whose curvature is sufficiently small for them to traverse h. The rays of a wave λ_1, reaching H, could be brought back to the ground before the rays of a wave λ_2 longer but entirely refracted by h. This could happen if the layer H is less sensitive to the diurnal variation than the layer h. Further, the rays refracted by H will be equally refracted on the return journey by the layer h and deviated upwards: this phenomenon will be the more perceptible the more ionised h is and the greater the distance. Thus can be explained why it is that at mid-day the wave of 30 metres is received while that of 21 metres no longer comes through when the distance *exceeds* some hundreds of kilometres.

The study of the variations of terrestrial magnetism has led to supposing the existence of two ionised layers, one at an altitude of 50 kilometres presenting marked diurnal variation and the other at an altitude of 90 kilometres localised in two large caps around each pole. The author states that the existence of these two layers would accord entirely with the mechanism suggested here to explain these long period anomalies in the propagation of short waves that experiment reveals.

NOTE SUR CERTAINES ANOMALIES DANS LA PROPAGATION DES ONDES COURTES (Note on certain anomalies in the propagation of short waves.)—R. Bureau. (*L'Onde Electrique*, 6, 61, January, 1927, pp. 52-55.)

The meteorological reports wirelessed from the two ships, the *Jacques-Cartier* and the *Jeanne-d'Arc*, making successive journeys between France and America, have been received regularly in Paris since 1925. The ships transmit simultaneously on two short waves, one in the neighbourhood of 60 metres and the other about 30 metres. Up to last autumn it had always been found that the longer wave was received much better during the night and the shorter wave by day, but since October this has no longer been the case. Waves of the order of 20 to 30 metres cease to arrive in the Paris district except from relatively small distances (of the order of 1,000km.), so that waves of 60 to 75 metres appear by far the more favourable even at midday. This is the case not only with the ships, but also the daily meteorological report from Washington on 24 metres at 21 h. 30 G.M.T., received regularly in September, is completely inaudible since October.

In order to find out whether the phenomenon is only local and confined to Paris or whether it extends also to other parts, inquiries as to the reception of these short waves were made at Bergen, in Norway, and Rabat, in Morocco, with the result that reception there was found to be fairly similar to that obtained previously in Paris. It might thus be concluded that the anomaly observed in Paris since October, 1926, is of a purely local character. However, from one month to the next, it is found to gain in extent and gradually affect the observations in Morocco. For instance, the Washington signal at 21 h. 30 which was received normally at Paris in September, but not at all since, was heard regularly at Rabat with the same intensity up to 10th October, and then disappeared until 20th December, since when it has been irregular and too faint to read. The anomaly is still less marked than at Paris, but it looks as if it were beginning to reach Morocco making itself first felt in waves of the order of 24 metres.

The investigation is being continued.

THE ABSORPTION OF RADIO WAVES IN THE UPPER ATMOSPHERE.—E. O. Hulburt. (*Physical Review*, 29, 5, May, 1927, pp. 706-716.)

The following abstract is given: Recent measurements have shown that radio waves below 150 metres fall off in intensity faster than required by an inverse square law for distances up to 1,000 miles. This points to absorption of the wave by the medium, in this case the upper atmosphere. The absorption of the waves variously polarised is calculated on the assumption that it results from collisions between the electrons and molecules of the atmosphere. With reasonable average values of the electronic and molecular densities, the amplitude A of the wave λ cms. at a distance x cms. is $A = ax^{-1}$ exp. $(-11.8 \times 10^{-16}\ \lambda^2\ x)$, theoretically valid for waves from 16 to 160 metres to distances of 1,000 miles. This agrees well enough with the scant range and intensity data, and it is pointed out that an extension of these data may lead to more exact knowledge of the overhead electronic and molecular pressures. From the absorption curves interesting possibilities appear of polarisation of waves in the broadcast band 200-600 metres.

EXPERIMENTAL CONFIRMATION OF THE INFLUENCE OF A LOW-RESISTIVITY LAYER SUBSOIL ON THE FORWARD INCLINATION OF RADIO WAVES.—J. Cairns. (*Journ. Washington Acad. Sc.*, 17, 10, pp. 264-269, May, 1927.)

The author summarises his paper as follows :—

Over soil, the mean resistivity of which had been measured *in situ* down to depths of 60 to 100 metres, and which consisted of a layer of sand of an exceptionally high resistivity over a layer at no considerable depth of very low resistivity, radio waves of wavelength 1,250 metres were found to experience no forward inclination. This is regarded as being more definite proof than has hitherto been given of the effect of ground-water or a low-resistivity layer a short distance below the surface, owing to the greater precision of the resistivity measurements of the undisturbed soil.

The apparatus employed is described and the observations are tabulated.

HIGH ANGLE RADIATION OF SHORT ELECTRIC WAVES.—S. Uda. (*Proc. Inst. Radio Engineers*, 15, 5, May, 1927, pp. 377-385.)

An account of experiments in the field distribution due to a straight vertical unloaded antenna operating at one of its harmonics. Short waves of 2.66 metres were employed and observations were made with the antenna both grounded and ungrounded.

The results are also given of tests on a new wave projector designed by the author with special reference to high angle radiation of short waves.

RADIO PHENOMENA RECORDED BY THE UNIVERSITY OF MICHIGAN GREENLAND EXPEDITION, 1926.—P. Oscaryan, Jr. (*Proc. Inst. Radio Engineers*, 15, 5, May, 1927, pp. 425-430.)

Experimental proof was obtained of the fact that when a receiving station, working on 50 metres or under, is placed at the foot of a hill or mountain of greater height than 17° from the station level, then signals are screened off from the receiver. This fact is thought to bear on wave propagation theory. It would also appear that atmospherics in the Arctic are the overflow from more harassed lower latitudes, since they were not observed until the station had been removed from its screened position. Another point noted is that the distance within which " brute force " signals may be heard is greatly increased at sea.

There is to be another expedition, planning to remain up there all during the winter of 1927-28. The writer, who will be in charge of radio, would be glad to co-operate with anyone who wishes to collect comparative data or would like to suggest some particular field of radio to explore.

RADIO TELEGRAPHY AND THE ECLIPSE OF THE SUN.—O. F. B. (*Eclipse Supp. to Nature*, 18th June, 1927, pp. 85-88.)

ÜBER DIE IONISATION DER ATMOSPHÄRE UND IHREN EINFLUSS AUF DIE AUSBREITUNG DER KURZEN WELLEN DER DRAHTLOSEN TELEGRAPHIE (On the ionisation of the atmosphere and its influence on the propagation of short wireless waves).—H. Lassen. (*Telefunken Zeitung*, 58, 44, pp. 26-35.)

A more popular version of the author's theoretical paper of this title that appeared in *Zeitschr. f. Hochfrequenz.*, 28, 4 and 5 (these Abstracts, *E.W. & W.E.*, February, 1927, p. 115), giving the results there obtained, but omitting the mathematics.

PROPAGATION OF SHORT WAVES AROUND THE EARTH.—(*Proc. Inst. Radio Engineers*, 15, 4, April, 1927, pp. 341-345.)

Translation of Herr Quäck's article in the December number of the *Zeitschrift für Hochfrequenztechnik*.

WIRELESS TRANSMISSION AND THE UPPER ATMOSPHERE.—(*Nature*, 7th May, 1927, pp. 679-680.)

Report of Prof. Appleton's discourse at the Royal Institution, 29th April, 1927.

MAGNETIC STORMS AND WIRELESS TRANSMISSION.—(*Electrician*, 6th May, 1927, p. 496.)

A letter from Mr. Sreenivasan, of the Indian Institute of Science, referring to Prof. Appleton's article in the *Electrician* of 11th March, where the effect is discussed of an increase in the charged ions in the upper atmosphere on radio wave transmission.

According to Sir Joseph Larmor's suggestion that a magnetic storm is due to an incursion of free electrons into the upper atmosphere and all the regular ray paths are twisted out, the signals of the England-Canada beam service, reported to have been almost completely blocked during the magnetic storm of October, 1926, should have been heard at some other part of the earth, for which, unfortunately, no evidence is forthcoming.

With reference to long wave transmission, the increase in the number of electrons should mean an increased reflection co-efficient, but the writer again observes that there does not seem to be any support for this from available published data, and raises the question as to whether long waves go into the disturbed higher regions at all, but are bent at lower regions that are comparatively unaffected by the changes in ionisation higher up.

ACTIVITÉ SOLAIRE ET PROPAGATION DES ONDES (Solar activity and wave propagation).—G. Pickard. (*L'Onde Electrique*, 6, 62, February, 1927, pp. 91-96.)

The reception of short waves is found to be perceptibly influenced by solar activity, like that of lower frequencies, but while low frequencies (15 to 25 kilocycles) are always attenuated by an increase of solar disturbance, it is found that, at least in the band of 8 to 9 megacycles, reception becomes stronger as the sunspots increase in size. This is thus another of the many phenomena that becomed reversed as one passes from the reception of lower to higher frequencies (*cf.* effects on reception of 1925 eclipse, *Proc. Inst. Radio Engineers*, October, 1925, p. 539).

Graphs are reproduced showing the relation between the reception of three widely-spaced bands of frequency and the variation of sunspots, also between the reception of a distant station working on 1,330 kilocycles and the variations of terrestrial magnetism.

One would expect these relations obtained at Washington between solar activity, magnetic disturbance and reception, which are best defined between about 500 and 1,500 kilocycles, to exist simultaneously over the whole earth, and the author would be glad to compare his results with similar ones made in Europe.

DISCUSSION ON THE CORRELATION OF RADIO RECEPTION WITH SOLAR ACTIVITY AND TERRESTRIAL MAGNETISM. — J. Dellinger. (*Proc. Inst. Radio Engineers*, 15, 4, April, 1927, pp. 326-329.

Discussion of Mr. Pickard's paper that appeared in these Proceedings of last February, pp. 83-97.

ATMOSPHERICS AND ATMOSPHERIC ELECTRICITY.

STUDIES ON RADIO-ATMOSPHERIC DISTURBANCES—(1) DIRECTIONAL OBSERVATIONS AT TOKYO. —J. Obata. (*Journ. Inst. Elect. Eng., Japan*, No. 465, pp. 372-379.)

A preliminary account of the observations of the direction of atmospherics that are being carried out at Tokyo, begun in July, 1926. The apparatus employed is a simple radiogonimeter. The frame antenna is 5 ft. square and has 60 turns of thin stranded wire wound with ¼ in. spacing and is tuned to a wavelength of 10,000 metres. With suitable amplification, records of atmospherics are obtained by means of a high frequency oscillograph: directing the frame to various azimuths, the number of atmospherics per eight seconds is found in each direction.

Although it would be very premature to draw any definite conclusion from observations only extending over a short period of time as to the nature of such a geophysical phenomenon as radio-atmospheric disturbance, which appears to suffer the influence of various causes, yet the results so far obtained seem to indicate that the majority of the atmospherics observed at Tokyo come from a definite region, which varies according to the season.

The apparent direction of arrival of most atmospherics at Tokyo during summer and autumn, when they are most prevalent, are given in the following table:—

July, Aug.	N.W.—W.N.W.	Oct. S.S.W.
Aug., Sept.	W.N.W.—W.	Nov. S.S.W.

These results, compared with those obtained by Nakagami and other at Osaka, indicate that the origin of atmospherics in summer and the beginning of autumn lies in the mountain region of Honshu (Main Island) of Japan.

A STATISTICAL STUDY OF THE EFFECTS OF THE ATMOSPHERIC - ELECTRIC ELEMENTS ON BROADCAST RECEPTION.—J. Cairns. (*Terres. Mag. and Atmos. Elect.*, 32, 1, March, 1927, pp. 11-16.)

An attempt is made to correlate the variations in broadcast reception with the variations of the atmospheric-electric elements, positive and negative conductivity, and potential gradient. Two analyses are given, the one dealing with the results obtained for all days, regardless of the local disturbing effects of smoke, rain, etc., on the atmospheric-electric elements, and the other dealing with the results from "selected" days, that is, days that are considered to be free from any such local effects.

The result of the first analysis shows that when the conductivity, both positive and negative, is subnormal there is a greater probability of better signal reception; the potential gradient, apparently, has little effect.

From the analysis for "selected" days, which is considered the more valuable, it appears that the positive conductivity has little effect on the received signals, whereas when the negative conductivity is low the signals are stronger; also, better signals are received when the potential gradient is high.

MESURES DE LA CONDUCTIBILITÉ ÉLECTRIQUE DE L'ATMOSPHÈRE DANS LA RÉGION DU PÔLE NORD (Measurements of the electric conductivity of the atmosphere in the region of the North Pole).—MM. Malmgrön and Běhounck. (*Comptes Rendus*, 184, pp. 1185-1187, 16th May, 1927.)

The results of observations made during the Amundsen expedition are given, showing the electric conductivity of the atmosphere at the Pole to be of the same order of magnitude as that found in Central Europe, at the same latitudes, and with the same predominating unipolarity. These results are contrary to the hypothesis which looks for an afflux of negative electricity in the North Pole region, as a consequence of Bauer's magnetic measurements, unless the afflux in question consists of electrons that are too rapid, which, according to Swain, are no longer able to ionise.

ON THE ELECTROSTATICS OF THE THUNDERSTORM. —A. Simon (*Physical Review*, 29, 5, May, 1927, p. 754.)

Abstract of a paper presented at the Los Angeles meeting of the American Physical Society, March, 1927.

The action of the storm cloud is shown to be analogous to the generation of charges and potentials by rubbing together two dissimilar substances, *i.e.*, the fundamental experiment of frictional electricity. The generation of potentials and electric stresses by precipitation of charged rain and by the inductions of charges at the earth's surface is discussed. It is shown that the "impulsive rush" lightning discharge of Lodge is electrostatically impossible. A relation between the change of gradient in an area, the polarity of the overhead cloud is developed. Approximate numerical relations between gradients, charges, and potentials are deduced.

PROGRESSIVE LIGHTNING.—C. Perrine. (*Nature*, 4th June, 1927, p. 816.)

A letter referring to Prof. Boys's comments on the phenomena of "Progressive Lightning" in *Nature*, of 19th February last (these Abstracts, *E.W. & W.E.*, April, 1927, p. 245), followed by a further note from Prof. Boys.

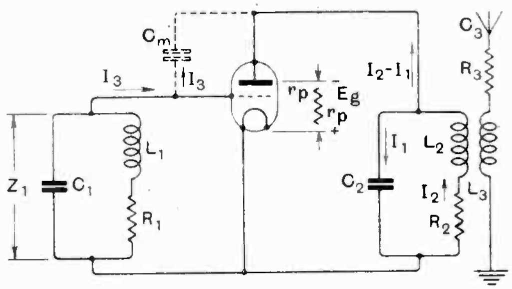
MESURES SUR LES GROS IONS À PARIS (Measurement of large ions at Paris).—J. MacLaughlin. (*Comptes Rendus*, 184, pp. 1183-1185, 16th May, 1927.)

The number of large ions, which is found to be closely related to the distribution of factory chimneys, undergoes daily variation characterised by two maxima and two minima, similar to that found in the case of dust particles at London. It is thought probable that the diurnal variation of large ions, the electric field, and particles of dust, is due to the same causes. Also an *annual* variation of large ions is found of the same amplitude as that ordinarily obtained for the terrestrial electric field.

PROPERTIES OF CIRCUITS.

THE TUNED-GRID TUNED-PLATE CIRCUIT USING PLATE-GRID CAPACITY FOR FEED-BACK.—J. Dow. (*Proc. Inst. Radio Engineers*, 15, 5, May, 1927, pp. 397-400.)

Equations are developed showing the conditions for oscillation in the following circuit which has been recently in favour for short-wave transmission.



SELECTIVITY OF TUNED RADIO RECEIVING SETS. —K. Jarvis. (*Proc. Inst. Radio Engineers*; 15, 5, May, 1927, pp. 401-423.)

In designing modern broadcasting receivers, the radio engineer has three technical objectives: the obtaining of selectivity, fidelity of reproduction, and adequate sound volume. In the ideal receiver these factors will be absolutely independent, a perfecting of any of them contributing to the intrinsic value of the receiver. Unfortunately this state of affairs is not even approached in present practice, a change in design affecting any one of these factors will affect also the other two. A paper on "selectivity" has therefore to consider the entire combination of effects, and show how amplification and quality vary when selectivity is the independent variable. In this paper the term "selectivity" is used to represent the ratio between the wanted signal and an interfering signal, and this ratio is determined and discussed together with its bearing on amplification and quality of reproduction.

ÜBER RELAXATIONSSCHWINGUNGEN II. (On relaxation-oscillations II.).—B. van der Pol, jun. (*Zeitschr. f. Hochfrequenz.*, 29, 4, April, 1927, pp. 114-118.)

An article on this subject appeared in this *Zeitschrift* for last December, pp. 178-184, of which there was an English version in the *Philosophical Magazine*, of November, pp. 978-992 (these Abstracts *E.W. & W.E.*, January, 1927, p. 51.)

Owing to further investigation by the author, both theoretical and experimental, and publications by others on the subject, the first article is here extended and supplemented, the summary of the whole being given as follows:

The behaviour is studied of the solution of

$$L\ddot{v} - R(1-v^2)\dot{v} + \frac{1}{C}v = 0$$

for the two cases

$$(a)\quad R\sqrt{\frac{C}{L}} << 1 \text{ (periodic case)}$$

and

$$(b)\quad R\sqrt{\frac{C}{L}} >> 1 \text{ (quasi-aperiodic case).}$$

The condition (*a*) is characteristic of maintained sinusoidal oscillations, while case (*b*) allows also of a periodic solution that deviates considerably from the sine form. The times of oscillation T_{sin} and T_{rel} in cases (*a*) and (*b*) are given respectively by

$$(a)\quad T_{sin} = 2\pi\sqrt{CL}$$

$$(b)\quad T_{rel} = \frac{\pi}{2}RC$$

The period of the quasi-aperiodic case (*b*) is thus determined by a "time of relaxation," wherefore this type of oscillation is called "relaxation-oscillation." The form of the oscillations in both cases is studied by means of the "method of isoclynes."

Various applications of relaxation-oscillations are described: the multi-vibrator of Abraham and Bloch, a double-grid multi-vibrator, etc. It is further shown that the periodic pole change of an externally excited motor, supplied by a series dynamo rotating with constant velocity, belongs to the type relaxation-oscillations, whereby some difficulties in practice not hitherto understood are explained by means of oscillograms. It is pointed out that, contrary to sinusoidal systems (*a*), the frequency of systems, which left to themselves execute relaxation oscillations (*b*), can be influenced by outside forces within wide limits (a property utilised by Dr. Dye in his multi-vibrator).

THE THEORY OF THE LINEAR ELECTRIC OSCILLATOR AND ITS BEARING ON THE ELECTRON THEORY.—G. Schott. (*Phil. Mag.*, 3, 16, Suppl. April, 1927, pp. 739-752.)

TRANSMISSION.

ÉTUDE EXPERIMENTALE DU FONCTIONNEMENT D'UN TRIODE EMETTEUR (Experimental investigation of the operation of a triode transmitter).—R. Jouaust. (*L'Onde Electrique*, 6, 65, May, 1927, pp. 200-210.)

The characteristic curves of a triode transmitter of one kilowatt, obtained with reduced filament heating, have enabled the laws regulating the emission of secondary electrons by the grid to be studied. From the results obtained an approximate method is deduced of determining the conditions beforehand under which a triode should function.

APPROXIMATE THEORY OF THE FLAT PROJECTOR (FRANKLIN) AERIAL USED IN THE MARCONI BEAM SYSTEM OF WIRELESS TELEGRAPHY.—J. A. Fleming. (*E.W. & W.E.*, July, 1927. pp. 387-392.)

ELECTRICAL FILTERS.—A. Morrice. (*Phil. Mag.*, 3, 16, Suppl. April, 1927, pp. 801-843.)

Extract from paper given before the Institution of Post Office Electrical Engineers, which includes the use of electrical filters in radio-telephony.

VACUUM TUBES AS OSCILLATION GENERATORS.—D. Prince and F. Vogdes. (*General Electric Review*, 30, 6, pp. 320-321, June, 1927.)

This first part of a serial deals simply with the nature of high frequency circuits.

DISCUSSION ON FIELD DISTRIBUTION AND RADIATION RESISTANCE OF A STRAIGHT, VERTICAL, UNLOADED ANTENNA RADIATING AT ONE OF ITS HARMONICS. (S. Levin and C. Young.)—O. Roos. (*Proc. Inst. Radio Engineers*, 15, 5, May, 1927, pp. 439-443.)

Contribution to the history of the early aspects of the subject, referring particularly to the early work on antenna radiation at shorter than fundamental wavelengths, by John Stone Stone, of Boston, and the German, F. Hack, neither of whom was mentioned in the paper of Messrs. Levin and Young (*Proc. Inst. R.E.*, 14, 5, October, 1926).

SECRET RADIO-TELEPHONY SYSTEMS.—O. F. Brown. (*Wireless World*, 8th and 15th June, 1927, pp. 713-716 and 763-765 respectively.)

A review of the problems involved and solutions suggested.

RECEPTION.

L'ALIMENTATION DES LAMPES BIGRILLES PAR LE COURANT ALTERNATIF (Supplying four-electrode valves with alternating current).—R. Barthélemy. (*Radio-Revue*, June, 1927, pp. 382-386.)

The four-electrode valve is more sensitive to disturbance in the current source than the triode and the methods employed for the latter do not suffice to secure correct operation for the tetrode.

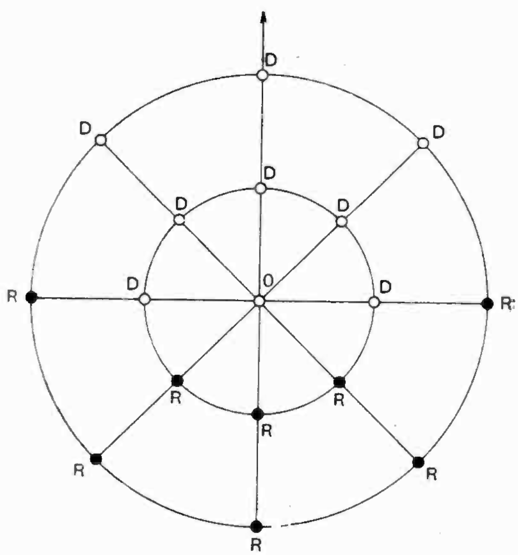
The filament supply is the most difficult, and details are given here with circuit-diagrams of a self-regulating converter, ensuring successful filament heating.

DESIGN AND CONSTRUCTION OF A SUPERHETERODYNE RECEIVER.—P. K. Turner. (*E.W. & W.E.*, May, June and July, 1927, pp. 286, 339 and 402 respectively.)

DIRECTIONAL WIRELESS.

ON THE WIRELESS BEAM OF SHORT ELECTRIC WAVES.—VI. (Direction control of the beam). S. Uda. (*Journ. Inst. Elect. Eng. Japan.* No. 465, pp. 396-403.)

This paper describes a new method of direction control of the short-wave beam, and gives the experimental results. The arrangement of the system for the case of eightfold directionality is shown in the following figure:—



where O is the transmitting aerial, R are reflectors and D directors.

The sixteen conductors, of which half are reflectors and half directors, are arranged around a vertical sending antenna on two concentric circles whose radii are $\frac{1}{4}\lambda$ and $\frac{1}{2}\lambda$ respectively. Maximum energy is radiated in the direction of the arrow. When the length of the Ds is varied, the radiation in the direction of the arrow changes; so long as the length is larger than $\frac{1}{2}\lambda$, the wave is almost screened and comparatively little energy is transmitted, but when the length is made smaller than $\frac{1}{2}\lambda$, there is a region in which the received energy becomes much increased due to the existence of the rods. If means are provided to control the natural wavelength of the rods, so that the wave may be radiated in any other desired direction, then a beam of variable directionality can be produced. Thus the wave may be sent into several different directions in any desired order and particularly in rotation. The control of the rods may be effected electrically or mechanically, by push-button device or automatic means, and the beam can thus be rotated without either changing the position of the conductors or revolving a large structure.

The case for 16 different directions has also been investigated, and the polar curve is given. More wave directors may conveniently be arranged along the radial lines to improve the sharpness of the beam in these directions. The interval between these directors must, of course, be larger than $\frac{1}{4}\lambda$ and smaller than $\frac{1}{2}\lambda$.

This type of short-wave radio beacon is quite simple, and is believed to find application in directing ships approaching the shore or guiding aviators flying in the dark.

ÉMISSIONS DIRIGÉES PAR RIDEAUX D'ANTENNES, ANTENNES EN GREQUE (Directional emission by curtain antennæ; antennæ in the form of the Greek key-pattern).—R. Mesny. (*L'Onde Electrique*, 6, 65, May, 1927, pp. 181-199.)

Lecture given to the S.A.T.S.F., 8th February, 1927.

Two methods of using directional emission are distinguished :—

1. Concentrating the energy in a narrow beam, thereby securing a certain degree of secrecy and reducing interference in communication.

2. Causing a beam to rotate for enabling ships at sea and aircraft to determine their position.

In the first case the energy must be practically nil in the whole of the unused sector, also since the apparatus is fixed it can be of any desired dimensions; while in the second case, there must be a distinctly recognisable energy maximum in a certain direction, but in other directions the radiation need not necessarily be nil or even weak, also since these beacons have to rotate, perhaps in the open air to avoid irregular absorption by buildings, they have to be made as small as possible.

This paper examines the properties of curtain antennæ, for producing such beams. The difficulties of current supply are said to be eliminated by employing curtains made of a single wire, bent in the shape of the Greek key-pattern, supplied with current at its middle point. By modifying these curtains, various kinds of beam are produced, the diagrams of which, obtained by measurement, are shown and compared with those produced by other methods.

A SENSITIVE LONG RANGE RADIO DIRECTION FINDER.—R. L. Smith-Rose. (*Journ. Scientific Instruments*, 4, 8, May, 1927, pp. 252-262.)

The author summarises his article as follows :—

A description is given of a single-frame coil type of direction-finder which was constructed for the purpose of taking wireless bearings on long-wave transmitting stations at distances of several thousand miles. The precautions taken to overcome sources of error in these direction-finders are described in some detail, and a brief account is given of some typical results obtainable with the instrument.

VALVES AND THERMIONICS.

DAS INNERE WIDERSTAND DER ELEKTRONENRÖHRE (The internal resistance of the valve).—W. Bermbach. (*Zeitschr. f. Hochfrequenz.*, 29, 4, April, 1927, pp. 119-120.)

Assuming the anode current equal to the emission current ($v_g \leqq 0$), the following formula for the internal resistance of a valve is derived :—

$$R_i = \tfrac{2}{3} K^{-\frac{2}{3}} \cdot D^{-1} \cdot x^{-\frac{1}{3}}$$

Where K is the valve constant, D the "Durchgriff," and x the anode current in amps. The equation shows that the internal resistance of a given valve is inversely proportional to the cube root of the anode current.

The influence exerted by the "Durchgriff" on the amplification factor is discussed under the conditions of resistance amplification (high ohmic resistance in exterior part of anode circuit). For a given case it is shown how the internal resistance changes with the grid tension. An explanation is attempted of how it is that $i_a(R_{ext.}+R_i)$ is smaller than the battery tension.

THE INTERNAL ACTION AND PRINCIPLES OF DESIGN OF THERMIONIC VALVES. — A. Bartlett. (*E.W. & W.E.*, July, 1927, pp. 430-439.)

Lecture before the R.S.G.B. at the Institution of Electrical Engineers, April, 1927.

PUNCTURE DAMAGE THROUGH THE GLASS WALL OF A TRANSMITTING VACUUM TUBE.—Y. Kusunose. (*Proc. Inst. Radio Engineers*, 15, 5, May, 1927, pp. 431-437.)

The causes of the frequent occurrence of valve puncture in short-wave transmission have been investigated by the writer, and are attributed to the dielectric loss in glass. Precautions to be taken to prevent the damage are enumerated.

THE WORLD'S LARGEST VALVE.—(*Wireless World*, 15th June, 1927, pp. 743-744.)

Description of the new 100kW valve used by WGY, the General Electric Company's large broadcast transmitter at Schenectady, N.Y.

LES COURBES POTENTIOMÉTRIQUES (Potentiometer curves).—S. Lwoff. (*Radio-Revue*, June, 1927, pp. 388-389.)

Description of a new method of determining the amplification factor of a triode.

THE CHARACTERISTICS OF TUNGSTEN FILAMENTS AS FUNCTIONS OF TEMPERATURE.—I.—H. Jones and I. Langmuir. (*Gen. Elect. Review*, 30, 6, pp. 310-319, June, 1927.)

The purpose of this article is to present the most accurate data to hand on the characteristics of tungsten filaments in vacuo, at various temperatures, in as convenient and complete a form as possible.

FACTORS INFLUENCING THERMIONIC EMISSION.—A. K. Brewer. (*Physical Review*, May, 1927, p. 752.)

Abstract of a paper presented at the Los Angeles meeting of the American Physical Society, March, 1927.

The thermionic emission from gold is determined in the presence of various gases at atmospheric pressure. Both the positive and negative currents follow the Richardson equation, although there is no semblance of saturation. A distinct proportionality exists between the difference in the values of b_1 (Δb), for the positive and for the negative emission, and for the corresponding differences in the values of T_1 (ΔT). Again, when an emitter, such as iron, is slowly oxidised over, there is a gradual increase in the values of b and T for the positive emission, which is concomitant with a corresponding decrease for the negative emission. When the value of b is the same for ions of each sign, T is likewise the same. The relationship between Δb and ΔT is accounted for by the presence of an intrinsic force at the surface, possessing the properties of a resultant field. The change in T and b accompanying the oxidation of a surface is doubtless due to the presence of the negative oxygen ions neutralising the positive intrinsic field, and upon high oxidation, actually giving rise to a resultant negative field.

DAS ELEKSTROSTATISCHE FELD EINER RAUMLADUNG.—I. (The electrostatic field of a space charge. I.).—O. Emersleben. (*Annalen der Physik*, 82, 6, April, 1927, pp. 713-774.)

Classical valve theory, as it originated about ten years ago, assumes quasi-stationary conditions. Proceeding from given (static) valve characteristics, showing the electronic current as a function of the potential difference between the electrodes, it is sufficient to know the potential difference to know the behaviour of the valve. Further, to study the emission current proceeding from the individual electrons, one starts from purely electrostatic considerations (assumption of constant potential on the electrodes) without needing to take any account of the electrons moved within the valve.

These theories are entirely "macroscopic," but even in papers where the current emitted by the incandescent filament is investigated or space charges are reckoned with (*e.g.*, in the case of double-grid valves) the authors are far from considering the *individual* electrons "microscopically." Even when the production of oscillations of the Barkhausen and Kurz type is explained through oscillations of the space-charges, only their frequencies are calculated, and no one, when considering the field produced by space charges, yet seems to have made the movement of the electrons the object of *quantitative* study. In this "microscopic" investigation, the treatment of electronic *movement* is reserved for a later paper, the present paper calculating the electric field produced by the electrons in a state of rest. The purpose of the long mathematical discussion is to provide an answer to the following question: The n electrodes $E_1, E_2 \ldots E_n$ have each the constant potential $V_1, V_2, \ldots V_n$. At the N points $P_1, P_2, \ldots P_N$ there are respectively the stationary charges $-e_1, -e_2, \ldots -e_N$. What is the potential $\Phi(Q)$ at any point Q of the space R between the electrodes?

GENERAL PHYSICAL ARTICLES.

DISPERSION OF AN ELECTRON BEAM.—E. Watson. (*Phil. Mag.*, 3, 16, Suppl., April, 1927, pp. 849-853.)

An analysis showing how a cathode ray beam, used as an indicator, should be adjusted to work at maximum efficiency.

YEARLY VARIATION OF THE QUANTITY OF OZONE IN THE UPPER ATMOSPHERE.—F. Goetz. (*Beitr. z. Physik d. f. Atmosphäre*, 13, No. 1.)

The quantity of ozone present in the upper air is estimated from the observed absorption suffered by the wavelength $320\mu\mu$ from the sun. The relative amounts of ozone in the four seasons are found to be, in arbitrary units, 1922, winter, 97; spring, 112; summer, 95.5; autumn, 92; and 1923, winter, 103.5; spring, 115.

At Arosa, where the author's laboratory is situated, changes in atmospheric pressure and in ozone content take place in opposite directions.

SUR LA PERMÉABILITÉ DU FER AUX FRÉQUENCES ELEVÉES (On the permeability of iron at high frequencies).—C. Gutton and I. Mihal. (*Comptes Rendus*, 184, pp. 1234-1237, 23rd May, 1927.)

M. Arkadiew found in his experiments that the permeability varies within wide limits and very irregularly as the frequency is changed. M. Laville, on the other hand, found that the value remains nearly constant. The experiments described here, like those of M. Laville, do not permit the conclusion to be drawn that variations in the permeability of iron exist analogous to the variations of the dielectric constant in the neighbourhood of absorption bands.

L'INFLUENCE DES ACTIONS MÉCANIQUES ET DES COURANTS ALTERNATIFS SUR LES DISCONTINUITÉS D'AIMANTATION DU FER (The effect of mechanical action and alternating current on the discontinuities in the magnetisation of iron).—S. Procopin. (*Comptes Rendus*, 184, pp. 1163-1164, 16th May, 1927.)

BRUISSEMENT DANS L'AIMANTATION DU FER (Acoustical phenomena accompanying the magnetisation of iron). — W. Arkadiew. (*Comptes Rendus*, 184, pp. 1233-1234, 23rd May, 1927.)

In 1919, Barkhausen discovered discontinuity in the magnetisation of some specimens of iron, revealed by noises in the telephone connected to the coil surrounding the specimen. The writer here describes a simple method of observing directly the sounds, which are due to discontinuous deformation of the substance undergoing magnetisation.

THE APPLICATION OF THE METHOD OF THE MAGNETIC SPECTRUM TO THE STUDY OF SECONDARY ELECTRONIC EMISSION.—C. Sharman. (*Proc. Cam. Phil. Soc.* V., pp. 523-530.)

ELECTRIC DOUBLE-REFRACTION IN RELATION TO THE POLARITY AND OPTICAL ANISOTROPHY OF MOLECULES. — PART I. — GASES AND VAPOURS.—C. Raman and K. Krishnan. (*Phil Mag.*, 3, 16, Suppl., April, 1927, pp. 713-723.)

NOTE SUR L'HYSTÉRÉSIS DIÉLECTRIQUE DES SUBSTANCES PHOSPHORESCENTES. (Note on the dielectric hysteresis of phosphorescent substances.)—F. Dacos. (*L'Onde Electrique*, 6, 65, pp. 211-214.)

Brief description of a qualitative investigation leading to the conclusion that hysteresis loss is greatest for the substance that is the most phosphorescent.

ON THE RELATION BETWEEN THE SECONDARY ELECTRON EMISSION FROM NICKEL AND TUNGSTEN AND THE TEMPERATURE. — H. Nukiyama and H. Horikawa. (*Journ. Inst. Elect. Eng. Japan*, No. 465, pp. 424-433.)

THE THERMIONIC EMISSION FROM IRON-ALKALI MIXTURES USED AS CATALYSTS IN THE SYNTHESIS OF AMMONIA.—C. Kunsman. (*Journ. Franklin Institute*, May, 1927, pp. 635-645.)

ELECTRON EMISSION UNDER THE INFLUENCE OF CHEMICAL ACTION AT HIGHER GAS PRESSURES, AND SOME PHOTO-ELECTRIC EXPERIMENTS WITH LIQUID ALLOYS.—O. W. Richardson and M. Brotherton. (*Proc. Roy. Soc.*, A, 115, pp. 20-41, June, 1927.)

A NOTE ON THE THEORY OF ELECTRICAL PHENOMENA IN AN IMPERFECT DIELECTRIC MEDIUM. — H. Nukiyama. (*Journ. Inst. Elect. Eng. Japan*, No. 464, pp. 306-324.)

A CONTRIBUTION TO MODERN IDEAS ON THE QUANTUM THEORY.—H. Flint and J. Fisher. —(*Proc. Roy. Soc.*, A. 115, pp. 208-214, June, 1927.)

A mathematical discussion indicating that by the introduction of a new element into Physics, it appears possible to include in one uniform scheme gravitational, electrical and quantum phenomena.

WAVE MECHANICS AND CLASSICAL MECHANICS AND ELECTRODYNAMICS.—G. Schott. (*Nature*, 4th June, 1927, pp. 820-822.)

LIGHT-TRANSMITTED SOUND BY MODULATION OF MERCURY-ARC RADIATION.—D. Stickbarger. (*General Electric Review*, 30, 5, pp. 261-263, May, 1927.)

ON THE SPARKING POTENTIALS OF GLOW DISCHARGE-TUBES.—J. Taylor. (*Phil. Mag.*, 3, 16, Suppl. April, 1927, pp. 753-770.)

POTENTIAL OF SYSTEMS OF ELECTRIC CHARGES.—C. Wall. (*Phil. Mag.*, 2, 16, Suppl., April, 1927, pp. 660-688.)

IONISATION BY COLLISIONS OF THE SECOND KIND IN THE RARE GASES.—G. Harnwell, (*Physical Review*, May, 1927, pp. 683-692.)

STATIONS: OPERATION AND DESIGN.

UNITED STATES—NEW RADIOGRAM RELAY STATION. —(*Electrical Review*, 17th June, 1927, p. 978.)

Transoceanic traffic is now handled at the Belfast, Maine, receiving station of the Radio Corporation of America, since extensive tests have proved that the reception of European signals is much better there than at Riverhead, on Long Island, where the main receiving station is located. A survey of thunderstorms during the past decade indicates that there are twice as many thunderstorms at Riverhead as at Belfast, and so reception at the former point is more affected; also, while Belfast is nearly north of Riverhead, it lies almost directly on the great circle route from Riverhead to Europe, and is 300 miles nearer the distant transmitters than Riverhead; for this reason the European radio signals are at least 30 per cent. stronger at Belfast. The new station at present houses 12 complete long-wave receiving sets, operating on wavelengths from 8,000 to 23,000 metres in addition to battery and motor-generator equipment. The station picks up European signals on a Beverage unidirectional triple antenna, nine miles long, but only 20 feet above the ground. By means of wave traps and filters the desired signals are taken from the antenna, amplified, detected and again amplified, and then relayed automatically over telegraph lines to the central office in New York City.

UNITED STATES—SHORT WAVE ARMY COMMUNICATION.—(*Electrical Review*, 3rd June, 1927, p. 887.)

Short-wave transmitters are being used by the Army Signal Corps to circumvent static in the transmission of official messages over the Army radio net which connects the War Department with the Corps area headquarters and Army posts throughout the country. The sets are crystal controlled and designed to operate in two frequency bands, one of approximately 4,000 to 4,500, and the other of 8,000 to 9,100 kilocycles.

BULGARIAN WIRELESS CONTRACT.—(*Electrician*, 98, p. 662, 10th June, 1927.)

A contract for the supply of wireless transmitting and receiving stations to the Bulgarian Government for the purpose of placing Bulgaria in direct communication with England, Austria and other European countries, has been secured by the Marconi Company in competition with French and German wireless engineering firms. Among the apparatus to be installed at Sofia is a high-speed transmitter with a power of 10 kilowatts to the anodes and a wavelength range between 36 and 72 metres. This transmitter will be used for communication with Marconi stations in England, through which Sofia will be in touch with the principal cities of the world. The Sofia stations will also contain a high-speed long-wave combined telegraph and telephone transmitter for communication with Vienna, with a wave range of from 2,000 to 4,000 metres, all the necessary electric supply equipment and reserve generating plant being installed under the contract.

TURKEY—NEW STATION.—(*Electrical Review*, 17th June, 1927, p. 978.)

At present Turkey has only one station—" Radio Stamboul," erected at Osmanie, 16 miles out of Constantinople. A new station, however, is being opened this month at Angora, which will be the most powerful in the Near East. It has cost over £100,000. The control of wireless telegraphy in Turkey is in the hands of a limited company in which the Post Office, the official Anatolian News Agency, and the Banque d'Affaires are interested. A licence costs the equivalent of 30s., and a heavy fine is imposed on persons who listen without one.

DITTON PARK RESEARCH STATION.—J. Herd. (*Wireless World*, 15th June, 1927, pp. 740-742.)

Account of apparatus used during the eclipse for studying the propagation of waves and atmospherics.

LE NOUVEAU POSTE D'EMISSION " RADIO-VITUS." —THE NEW TRANSMITTING STATION, " RADIO-VITUS."—(*Radio Revue*, June, 1927, pp. 386-388.)

This station, constructed by M. Vitus, has been set up to broadcast a group of artists and literary men, and transmit to France and beyond " the radiation of French thought and art." A brief technical description is given here of the station, which works on a wavelength of about 310 metres.

MEASUREMENTS AND STANDARDS.

ZUSAMMENFASSENDEN BERICHT. NORMAL FREQUENZEN UND ABSOLUTE FREQUENZMESSUNG (Survey of the subject of standard frequencies and absolute measurement of frequency.)—A. Scheibe. (*Zeitschr. f. Hochfrequenz.*, 29, 4 and 5, pp. 120-129 and 158-162, resp., April and May, 1927.)

The following methods are used for the determination of frequency :—

1. Comparing the frequency of the oscillations with a standard frequency.
2. Measuring the frequency with a standard frequency meter.
3. Calculating the frequency from the wavelength of the oscillations obtained by means of Lecher wires.

Of these three methods, only the first refers the frequency to be measured to an exactly known standard frequency by direct comparison. The other two need the first method to prove their applicability. In the present paper, the methods for obtaining standard frequencies, and comparing and measuring frequency, are only discussed in so far as they meet the present requirements of determining frequency correct at least to some ten thousandths, and therefore wavemeters such as those used commercially are not considered.

A multiple of the frequency unit of 1 Hertz forms the fundamental frequency of a graduation of standard frequencies. As the source of this fundamental frequency of some hundred to thousand Hertz, alternating current from a rotating machine can be employed, or interrupted direct current or a standard tuning fork. Interrupted direct current has the advantage over the other two frequency sources that it yields a frequency sum rich in powerful higher harmonics.

The first part of the paper deals with the production of standard frequencies and is divided into sections as follows :—

(*a*) The standard tuning fork
 (α) The valve tuning fork
 (β) The valve tuning fork as frequency standard.
 (γ) Control by means of the valve tuning fork ; relays.
(*b*) Tuning fork—neon lamp oscillator.
(*c*) The multivibrator.
(*d*) Transmitter with discrete standard frequencies.
(*e*) Synchronisation of standard transmitters.
(*f*) Quartz crystal controlled transmitters.
(*g*) Transmitters with continuous standard frequency graduation.

The second part of the paper is concerned with frequency measurement under the following headings :—

(*a*) Audible frequencies.
(*b*) Medium and high frequency.
(*c*) Standard frequency meters.

A bibliography of the literature consulted is appended.

THE EXACT AND PRECISE MEASUREMENT OF WAVE-LENGTH IN RADIO TRANSMITTING STATIONS. —R. Braillard and E. Divoire. (*E.W.& W.E.*, July, 1927, pp. 394-401.)

Conclusion of an article begun in previous issue, continuing the description of the wavemeter, and then passing on to the method of standardisation and the precision of the measurements.

ÜBER EINE EINFACHE METHODE ZUR INDIREKTEN MESSUNG VON GITTERSTRÖMEN (On a simple method of measuring grid currents indirectly.) —M. v. Ardenne. (*Zeitschr. f. Hochfrequenz.*, 29, 3, pp. 88-90.)

A simple method is given which, for example, in the case of ordinary valves with indicating instruments of sensitivity 10^{-3} to 10^{-4} ampere, permits the measurement of grid currents of 10^{-7} to 10^{-8} ampere. The method depends upon the fact that, as soon as grid current flows, the tension on the grid changes, through the tension drop across an ohmic resistance in the grid circuit, causing the anode current to vary in the well-known way. The presence and direction of the grid currents are found from the variation of the anode current that occurs on bridging over the ohmic resistance in the grid circuit.

ELECTRICAL MEASUREMENTS AT RADIO FREQUENCIES.—S. Brown and M. Colby. (*Physical Review*, 29, 5, May, 1927, pp. 717-726.)

Resistance, inductance, capacity and impedance are measured at radio frequencies with the aid of a valve voltmeter. The experiments described and the data presented illustrate methods of measurement at radio frequencies that are comparable to the corresponding measurements at low frequencies with regard to both simplicity and accuracy.

The methods of making many radio frequency measurements have been improved: (*a*) By using such a low resistance circuit that the coupling to the source of power could be made very loose. The coefficient of coupling was frequently as low as 1×10^{-6}. (*b*) By using a negligible amount of power from the oscillator, with the result that the E.M.F. induced in the tuned circuit remained constant. The power drawn seldom exceeded 2×10^{-5} watts. (*c*) By employing a sensitive and accurate voltmeter that is independent of frequency with which voltage changes of 0.2 millivolt could be detected.

Etalonnage direct d'un Ondemètre en Fonction des Harmoniques d'un Diapason (Direct calibration of a wavemeter in terms of the harmonics of a tuning-fork.)—F. Bedeau and J. de Mare. (*Comptes Rendus*, 184, pp. 1161-1162, 16th May, 1927.)

Notes on Radio Receiver Measurements.—T. Smith and G. Rodwin. (*Proc. Inst. Radio Engineers*, 15, 5, May, 1927, pp. 387-395.)

Description of attempts to obtain a basis of comparison for radio receivers of different types, and to co-ordinate the testing of receivers, so that the results obtained may be correlated with broadcasting station performance.

Loud-Speaker Testing Methods.—I. Wolff and A. Ringel. (*Proc. Inst. Radio Engineers*, 15, 5, May, 1927, pp. 363-376.)

An account is given of a satisfactory system which makes a written record in two or three minutes of the loud-speaker output measured in pressure of the sound wave. The apparatus used and procedure followed are described under the three headings: "Oscillator," "Sound Pickup and Recording Apparatus," and "Position of Sound Pickup."

An Improvement on the "Double Click" method of measuring the Resonant Wavelength of a Circuit.—(*E.W. & W.E.*, July, 1927, pp. 392-393.)

A Wireless Works Laboratory.—P. K. Turner. *E.W. & W.E.*, July, 1927, pp. 422-429.)

Paper read before the Wireless Section, I.E.E., May, 1927, describing the equipment of the Laboratory of the Research Department of Messrs. Burndept Wireless, Ltd.

SUBSIDIARY APPARATUS.

A Simple Theory of Kenotron Rectifier Circuit.—S. Kanazawa. (*Journ. Inst. Elect. Eng. Japan*, No. 464, pp. 300-305.)

In this paper the action of a single phase kenotron rectifier, supplying an output voltage with a considerably smaller pulsation, is explained, also, assuming that the supplied voltage is of sinusoidal wave-form, the relation between the ratio of working resistance of the kenotron to load resistance and that of supplied to output voltage, is simply obtained.

A Radio-Telephone Loud-Speaker. E. Braendle. (*Electrical Review*, 3rd June, 1927, pp. 876-878.)

Description of a new form of large diaphragm hornless loud-speaker, for which both rigidity and mobility are claimed.

In the review of 17th June, p. 997, Mr. Tyers comments on this article asking for justification of various statements made.

MISCELLANEOUS.

Television.—E. Taylor Jones. (*Nature*, 18th June, 1927, p. 896.)

Brief description of the demonstration of television by Mr. Baird between London and Glasgow last month, with additional information as to the method.

Prof. Jones' impression after witnessing the demonstration is that the chief difficulties connected with television have been overcome by Mr. Baird, and that the improvements still to be effected are mainly matters of detail.

Regular Broadcast Transmissions. (*Wireless World*, 15th June, 1927, pp. 760-762.)

A list, as complete as possible, of stations likely to be heard in England, giving also the call sign, nominal power, and wavelength.

D. E. H.

Esperanto Section.

Abstracts of the Technical Articles in our last Issue.

Esperanto-Sekcio.

Resumoj de la Teknikaj Artikoloj en nia lasta Numero.

PROPAGADO DE ONDOJ.

PROKSIMUMA TEORIO DE LA PLATA ANTAŬENĴETA ANTENO UZITA ĈE LA MARCONI'A UNUDIREKTA SISTEMO DE SENFADENA TELEGRAFIO.—D-ro. J. A. Fleming, F.R.S.

La teorio estas donita pri la unudirekta tipo de radiado, kiel uzita ĉe la Marconi'a-Franklin'a Unudirekta Sistemo. La unudirekta radio estas akirita per aranĝo de vertikalaj antenaj fadenoj je egalaj distancoj, kaj en unu plato, kun serio de reflektaj fadenoj malantaŭ ili en paralela plato je distanco de unu-kvarona ondolongo.

La teorio de radiado per tia antena aranĝo estas diskutita, kaj esprimoj donitaj por la valoroj de radiado je diversaj anguloj. Laŭ tabeloj, kiuj resumas ĉi tiujn esprimojn, oni montras, ke estas kompleta antaŭena ĵetado de la radiado, kaj kompleta malhelpo de iu ajn radiado malantaŭen. Oni ankaŭ montras, ke estas meniom da radiado ortangule, t.e., en direkto al la plato de la vertikalaj antenoj.

Kurvo de intenseco kontraŭ angula diverĝo montras serion de interferaj grupoj, analogiaj je tiuj de optikaj eksperimentoj.

RICEVADO.

DESEGNO KAJ KONSTRUO DE SUPERHETERODINA RICEVILO.—P. K. Turner.

Ĉi tiu artikolo estas daŭrigita el du antaŭaj numeroj. En la nuna parto la aŭtoro unue traktas pri l'aranĝoj por refleksi la kombinitan Interfrekvencan kaj Malaltfrekvencan amplifadon, aparte la reakciajn aranĝojn, por lasi la I.F. agordon simila al la aliaj cirkvitoj por " grupa kontrolo."

Oni poste montras la kompletajn cirkvitojn de la ricevilo, kun notoj pri la tipo kaj valoro de la konstrueroj uzitaj.

La sternado kaj konstruado estas poste pritraktitaj, ilustritaj per desegnaĵoj de la ĝenerala sternado, kaj detaloj de diversaj partoj. Fine oni donas notojn pri la ricevilo dum funkciado, kaj pri modifaĵoj kaj sugestoj por plibonigo.

TRAMVOJA INTERFERO KONTRAŬ BRODKASTA RICEVADO.

Redakcia noto priskribanta eksperimentojn lastatempe faritajn pri ĉi tiu temo en Berlin.

VALVOJ KAJ TERMIONIKO.

LA INTERNA FUNKCIO KAJ DESEGNAJ PRINCIPOJ DE TERMIONAJ VALVOJ. Raporto de Parolado ĉe la Radio-Societo de Granda Britujo, de S-ro.—A. C. Bartlett.

La parolinto traktis ĉefe pri la interna funkcio de valvoj kaj pri kelkaj el la punktoj, kiuj prezentas sin je la desegnado de pligrandaj tipoj de valvoj.

Unue traktante pri la malgranda du-elektroda valvo, li diskutis la faktorojn, kiuj regas la anodan kurenton, uzante proksimuman matematikan traktadon ŝuldatan al Langmuir. Poste li diskutis la desegnadon de valvoj cilindroformaj, inkluzive je rektifikatoroj de la binokla tipo, kaj la efekton rezultintan kiam la filamento estas varmigita per alterna kurento. Li poste pritraktis la efekton de la proporcio $\frac{\text{Anoda Radio}}{\text{Katoda Radio}}$ montrante la avantaĝojn havigotajn per valvoj de la tipo kun sendepende varmigita katodo.

Fine li diskutis metodojn de regado de anoda kurento, ekzemple, magneta regado, kaj la ordinara metodo de krada regado.

Raporto pri la diskutado, kiu sekvis la paroladon, estas donita.

MEZUROJ KAJ NORMOJ.

PLIBONIGAĴO DE LA " DUOBLA-KLAKETA " METODO MEZURI RESONANCAN ONDOLONGON.

Post diskutado pri la malavantaĝoj de la " duobla-klaketa " metodo, la aŭtoro sugestis la utiligon de kradrezistanca interuptora efekto, kiel montrita de F. M. Colebrook en *Wireless World*, 6a de Oktobro, 1926a. Se la krada kondensatoro de la ondometra interuptora cirkvito estas alĝustigita, tiel ke interupto estas *apenaŭ* kreita, la agordado pro resonanco de la provata cirkvito estingas la interupton super spaco kunrespondanta al la spaco inter la ordinaraj klaketoj. Per nerigidigo de la kuplado, la larĝeco de ĉi tiu " silenta spaco " povas esti multe malpliigita, ĝis ĝi fariĝas nur ŝanĝo de kvalito kaj tono de la zumado.

LA ĜUSTA KAJ PRECIZA MEZURADO DE ONDOLONGO EN RADIO-SENDAJ STACIOJ.—R. Braillard & E. Divoire.

Daŭrigita el la antaŭa numero, de la Prezidanto kaj Sekretario de la Teknika Komisiono de la *Union Internationale de Radiophonie*.

La nuna parto daŭrigas la priskribon de la normiga ondometro por brodkastaj sendaj stacioj, traktante pri la indikatora cirkvito. La elektraj dimensioj de ĉi tiu cirkvito estas diskutitaj, aparte rilate al komuna indukteco kaj la permesebla resisteco.

La aŭtoroj poste priskribas la metodon de normigado. Multavibratoro estas uzita, funkciigita de valvsubtenita forko, harmonikoj estante elektitaj laŭordinare. Aldona heterodina oscilatoro povas esti uzita por eĉ plialtaj frekvencoj. La normigaj cirkvitoj estas ilustritaj, kaj la antaŭzorgoj necesaj je la funkciado estas pritraktitaj. Fine la aŭtoroj diskutas la diversajn faktorojn, kiuj tuŝas ondometran normigadon kaj korektecon.

HELPA APARATO KAJ MATERIALOJ.

NOVA TIPO DE LAŬTPAROLILO.

Redakcia noto pri nova tipo de kondensatora laŭtparolilo, ŝuldata al D-ro. G. Green, de Glasgow.

DIVERSAĴOJ.

RESUMOJ KAJ ALUDOJ.

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

LABOREJO DE SENFADENA FABRIKEJO. Resumo de prelego legita de S-ro. P. K. Turner, A.M.I.E.E., ĉe la Senfadena Sekcio de la Institucio de Elektraj Inĝenieroj, Londono, je 18a Majo 1927a.

La prelego priskribas la ekipaĵaron de la Laborejo de la Esplora Fako de Burndept Wireless Ltd., Londono.

La afero estas dividita laŭ la rubrikoj, Funkcioj Lokigo kaj ĝeneralaj Aranĝoj, Kontinukurenta Laborado (inkluzive je bateria provizado, mezuraj instrumentoj kaj normiloj, rezistiloj, kondensatoraj provoj, k.t.p.), Proviza Frekvenca Laborado, Aŭdfrekvenca Laborado (inkluzive je Malaltfrekvenca fonto laŭ la heterodina principo, valva voltmetro, kombinita Alternkurenta kaj Kontinukurenta Ponto, k.t.p.), Radio-Frekvenca Laborado (inkluzive je mezurado de frekvenco, kapacito kaj indukteco, altfrekvenca rezisteco, k.t.p.).

La resumo estas ilustrita per diagranoj kaj fotografaĵoj, plispeciale de la valvprova aparato, aŭdfrekvenca fonto, kombinita A.K. kaj K.K. Ponto, k.t.p.

Raporto pri la diskutado, kiu sekvis la legadon de la prelego estas ankaŭ donita.

MATEMATIKO POR SENFADENAJ AMATOROJ.—F. M. Colebrook.

Daŭrigita el antaŭaj numeroj. La nuna parto traktas pri la operatoro "j," la operatoro $(a+jb)$, adicio de operatoroj, egaleco de operatoroj, multipliko de operatoroj, alternativa formo por $(a+jb)$, adicia formularo de trigonometro, la eksponenta formo por (kosinuso $\theta + j$ sinuso θ) seria formo por sinuso kaj kosinuso, radiokoj de operatoroj, k.t.p.

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.

Slope Inductance.

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

SIR,—The subject raised by Mr. C. R. Cosens in your issue for June is one which has interested me for some time, as the behaviour of iron-core inductances in valve circuits is, as he points out, vastly different from that in, say, power transformers. Its investigation is, however, beset with many pitfalls, and I submit that some of these have not been avoided by the treatment in question.

The method which I have found most satisfactory for measuring inductances in the presence of polarising current is similar to that described by Mr. Cosens, but with this important difference, that in addition to the voltmeter readings across the impedance to be measured and across the non-reactive rheostat, a third reading is taken across both in series. It is then possible to deduce the effective A.C. resistance of the impedance, which is information quite as valuable as that concerning the inductance. Results obtained by this method showed that the usual assumptions regarding A.C. resistance were quite erroneous, as pointed out in my letter on the subject in your issue of September, 1926. A number of most interesting facts have thus been brought to light, such as the variation of A.C. resistance with amplitude of A.C. and D.C., the effects of various numbers of shorted turns and of resonance, the motional loads of loud-speakers, etc., into which it is impossible to enter in a brief space: but it may be stated shortly that even the assumption that the A.C. resistance is double the D.C. resistance is justifiable in only a very few cases of practical importance. Even at low commercial frequencies the A.C. resistance of, say, an amplifying transformer winding may exceed 15 times the D.C. resistance.

In the analysis given, Z is referred to as the impedance of the choke: it would appear, however, from Mr. Cosens' equation (1) that Z is the impedance of both choke and rheostat in series, though there is no indication that this quantity is actually measured, mention being made only of measurements across the two components separately.

It is rather difficult to see why, in Fig. 2, a complicated arrangement of chokes and condensers is shown in order to separate the D.C. and A.C. supplies. Personally, I have found it much simpler to run them both in series. I should like, also, to ask why the battery and milliammeter should be damaged by superimposing an A.C. ripple of amplitude less than the D.C.; it is a common enough condition in radio work. The reading of the D.C. meter is not affected by the ripple, as a simple integration will show, provided that a moving coil instrument is used.

The suggestion that in the case of a transformer test the D.C. should be applied to the other winding is one that would naturally be made; but on consideration it will be seen that in order to maintain a D.C. supply it is necessary to have a closed circuit and neither the inductance nor the resistance of the transformer measured in this condition will be even approximately the same as if measured otherwise.

It has been found that a slide-back voltmeter is superior to the Moullin type, as the range of the former is unlimited, whereas there are difficulties with the latter when the potentials to be measured are greater than 10 volts: the grid Moullin in particular is inadvisable owing to its load, which is sufficient to cause considerable error in practical cases. A slide-back voltmeter with grid condenser appears to be less liable to error than any other type when correctly applied, and no difficulty has been experienced in getting cheap paper condensers of $0.25\mu F$ with an insulation resistance of over 10,000 megohms. The frequency and leakage errors can be calculated, and are utterly negligible.

In describing the connections of the Moullin voltmeter, Mr. Cosens advises that the filament should be permanently connected to the junction of the choke and rheostat. This means that opposite halves of the A.C. are connected to the grid in turn in taking the two readings: error has been traced to this practice, since it is not possible to assume that the wave form of the supply mains is symmetrical about the zero line, and valve voltmeters are sensible to variations in peak value. It is therefore safer always to rectify the same half cycle.

I agree in principle with Mr. Cosens' recommendation to measure one thing at a time, but is it not desirable to make sure that the right thing is selected? It is, in my opinion, less interesting to know the true inductance of a coil, neglecting such effects as the self-capacity of the windings, than to know the apparent inductance, which includes all effects present when the coil is actually in use. A statement of apparent inductance and resistance at all working frequencies is, it is true, a confession of ignorance as to the exact composition of these fictitious quantities, but it nevertheless gives the information which can be applied in practical design: a neglect of any of the factors involved lowers the value of the statement greatly.

MARCUS G. SCROGGIE.

The Audio-Transformer Problem.

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

SIR,—I was pleased to find, on opening my June number of *E.W. & W.E.*, a contributory letter on this subject from Mr. P. K. Turner. On perusal of this, however, I cannot clearly gather what factors of the problem he considers I have neglected, and regret the absence of a clear statement to that effect.

On various points in the letter may I make a few minor criticisms?

Why introduce (as the "simplest form"!) the relatively complicated mathematical procedure leading up to the simple equation (7) which could have been written down at once from first principles? It appears to me liable to confuse those of us who could otherwise follow the remainder quite well.

Are not equations (2) only approximations *after* s^2X_1 has been neglected in comparison with Z_3? Surely the correct equations on the initially made assumptions, viz.:—

1. No leakage,
2. No secondary resistance,
3. No core losses,

are

$$R' = R_1 + \frac{s^2X_1^2}{R_3^2 + (s^2X_1 + X_3)^2} \cdot R_3$$

$$X' = X_1 - \frac{s^2X_1^2}{R_3^2 + (s^2X_1 + X_3)^2}(s^2X_1 + X_3)$$

though admittedly this correction does not affect Mr. Turner's procedure.

Now, passing over a considerable portion of the letter, Mr. Turner says, ". . . . L_1 will be as large as we can make it" and "L_1 will probably be limited simply by the wire that can be got on." With these statements I do not in general agree, though, of course, it all depends upon what is meant by "as large as we can make it" and upon the dimensions of the transformer core and the amount of space allotted to the primary winding. My reasons for non-agreement have been given in my letter which you have published in your July issue. As pointed out earlier in Mr. Turner's letter, we do make the secondary inductance (in a given winding space) as high as we can. It would, however, defeat the purpose of a transformer to make the primary of equally high inductance.

I maintain that a first-class stage transformer will be such that its primary winding is *not* of the highest inductance possible in the space occupied by it, even when intended for use with a valve of usual impedance, and certainly when intended for use with a valve of low impedance.

In my last letter I gave reasons for the use of *high* primary inductance. May I now be permitted to cite one or two reasons against making this primary inductance unduly high? They are:—

1. Loss of general amplification as a result of a lowering of the turns ratio.
2. The maintenance of uniformity of amplification of the high frequencies with those of medium register is impaired by the increase of the effective primary capacity equivalent of that of the secondary.
3. Increasing initial magnetising effect of steady plate current of valve.
4. The increased possibility of self-oscillation of the andio-frequency amplifying train.

E. FOWLER CLARK.

New Developments in Resistance Amplification.

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

SIR,—The interesting article by Mr. Colebrook on Resistance Amplification in the April issue of *E.W. & W.E.* appears to be misleading in one place. In discussing multi-stage amplifiers Mr. Colebrook states that the grid-leak resistance must be large compared with the internal slope resistance of the preceding valve and need not be large compared with its anode resistance. Surely this must be incorrect, because the grid-leak and anode resistance are in parallel and the two together in series with the internal slope resistance of the previous valve: if the grid-leak were zero the anode resistance would be short-circuited and the amplification would become zero. The formula for the amplification has been reduced to a form which leads readily to misinterpretation and evidently this has been the cause of the misconception. We will assume the impedance of the coupling condenser is sensibly zero and then the network shown in Fig. 9 of Mr. Colebrook's article reduces to the grid-leak R_1 in parallel with the anode resistance R of the previous valve, these two together being in series with the internal slope resistance R_a. It then follows readily that the amplification factor m is given by the expression

$$m = \frac{R\ R_1}{R\ R_a + R_a\ R_1 + R\ R_1}\mu$$

This expression may be re-arranged in the form

$$m = \left(\frac{R_1}{R_1 + \dfrac{R\ R_a}{R + R_a}}\right)\left(\frac{R}{R + R_a}\right)\mu$$

$$= \left(\frac{R_1}{R_1 + R_0}\right)\left(\frac{R}{R + R_a}\right)\mu$$

and this is the expression given by Mr. Colebrook.

Now since $R \gg R_a \quad R_0 \doteqdot R_a$

$$\therefore \qquad m \doteqdot \left(\frac{R_1}{R_1 + R_a}\right)\left(\frac{R}{R + R_a}\right)\mu$$

This expression for m is the product of the amplification factors which would obtain if R and R_1 respectively were infinite. It is true that if $R_1 >> R_a$ and if $R >> R_a$ then the value of m tends to unity, but unless $R_1 >> R$ the first factor is the dominant term. Let us take the values used by Mr. Colebrook in his numerical example: viz., $R = 2\,\text{M}\Omega$, $R_1 = 5\,\text{M}\Omega$, $R_a = 0.4\,\text{M}\Omega$. If R_1 is infinite then $m = 0.83\mu$, but if $R_1 = 5\,\text{M}\Omega$ then $m = 0.78\mu$. Thus the 5 MΩ grid-leak has reduced the value of m by 6 per cent. If we make $R = 4\,\text{M}\Omega$ vice 2 MΩ, then $m = 0.85\mu$, whereas if R_1 had been infinite then $m = 0.91$. Again if $R_1 = 20\,\text{M}\Omega$, $R = 2\,\text{M}\Omega$ and $R_a = 0.4\,\text{M}\Omega$ then $m = 0.82\mu$. Hence I maintain that the grid-leak resistance must be many times the previous anode resistance if we are to obtain sensibly the full advantage of very high anode resistances. It is interesting to compare the values just found for m with the values we might readily obtain with moderate anode resistances and using the straight portion of the characteristic. For example, if $R_a = 20 \times 10^3\,\Omega$, $R = 100 \times 10^3\,\Omega$ and $R_1 = 0.5\,\text{M}\Omega$, then $m = 0.81\mu$: a value which is 4 per cent. higher than that contemplated in Mr. Colebrook's example with an anode resistance of 2 MΩ. Therefore it seems that practical limitations of the grid-leak resistance will obliterate the gain which otherwise could result from the use of a very high anode resistance. Thus it seems that the system of using very high anode resistances has the advantage only of permitting a smaller filament current and a possible slight reduction of high tension voltage. We must be prepared to pay for this small advantage by some small additional distortion and very great additional care in the insulation of component parts.

E. B. Moullin.

Cambridge.
21st June, 1927.

Some Recent Patents.

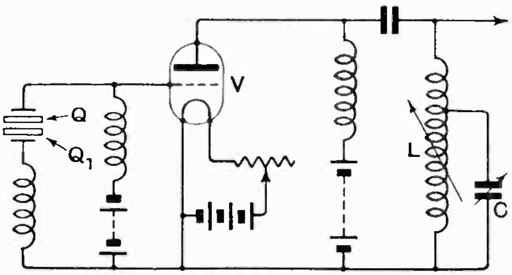
The following abstracts are prepared, with the permission of the Controller of H.M. Stationery Office, from Specifications obtainable at the Patent Office, 25, Southampton Buildings, London, W.C.2, price 1/- each

PIEZO CRYSTAL CONTROL.

(*Convention date* (*U.S.A.*), *2nd October*, 1925. *No.* 259,174.)

In this patent, Wired Radio Inc., an American Corporation, cover the simultaneous application of a number of piezo crystals, of different fundamental frequencies, to a circuit which allows any one of the crystals to be selected at will to determine the output frequency. As shown in the figure a stack of crystals Q, Q_1, ground to different frequencies, are mounted between a pair of metallic electrodes, shunted across the grid and filament of the valve V.

The method of selection depends solely upon the tuning of the plate circuit L, C. It is found that each of the crystals Q, Q_1 will function independently of the others, so that a stabilised output can be maintained, at the fundamental frequency of any selected crystal, merely by tuning the plate circuit to that frequency. It is not desirable to use a stack of crystals separated too far apart in



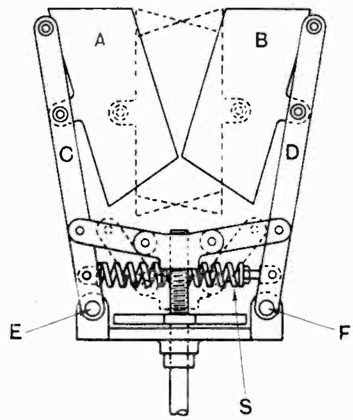
fundamental frequency, but satisfactory results have been secured in shifting the stabilised output from 3,300 to 4,000 kilocycles, that is, over a belt of 700 kilocycles. The arrangement can be used for heterodyne reception or for controlling the output of a transmitting station at any one of a number of different frequencies.

LATERAL-MOTION CONDENSERS.

(*Application date*, 10*th February*, 1926. *No.* 270,020.)

It is a characteristic of the straight-line frequency type of condenser that as the capacity in circuit increases so should the rate of overlap of the condenser plates increase for equal angular movements of the control knob. This result is secured in Mr. T. S. Riley's patent by mounting the pairs of co-acting plates A, B on two converging arms C, D, pivoted to the frame at E and F. Relative movement of the plates is secured by means of a slider carrying a pair of links connected to the arms C, D.

As the slider is moved downwards along a screw-threaded spindle, the plates move inwards towards full engagement against the pressure of a spring S. Owing to the toggle-joint arrangement of the arms and links, the rate of overlap is gradually accelerated for successive equal movements of the slider or,

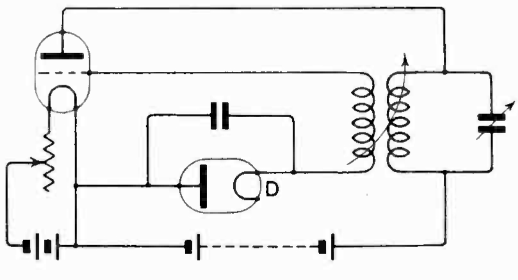


in other words, for equal angular displacements of the condenser control knob. Pinion gearing is provided for fine tuning.

POWER OSCILLATORS.

(*Application date*, 6*th May*, 1926. *No.* 270,488.)

The danger of a sudden reversal of grid current, owing to secondary emission from the grid momentarily exceeding the primary emission, is prevented according to this patent of the N. V. Philips Gloeilamp Co. by inserting an auxiliary diode tube in the grid circuit as shown. The one-way conductivity of the diode ensures the correct polarity

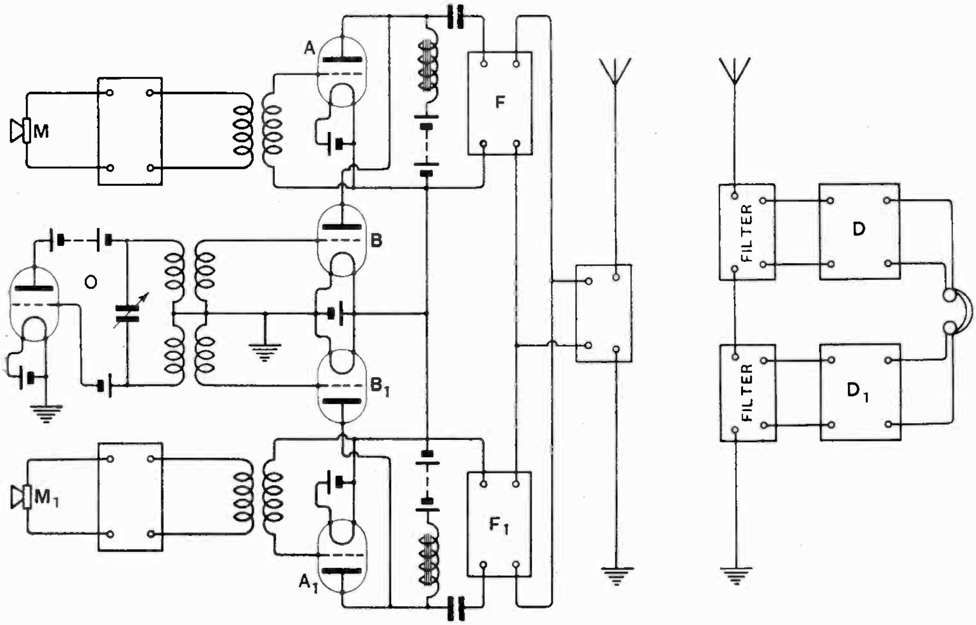


of the grid current, and thus acts as a safeguard against possible damage. In the same way any excessive potential difference between the grid and plate, which might lead to puncturing, is relieved by shunting a safety diode valve directly across the terminals in question.

STEREOPHONIC BROADCAST.

(*Application date, 2nd February*, 1926. *No.* 270,001.)

So-called " plastic " or stereophonic effects in broadcast reception have been secured by radiating simultaneously two carrier-waves of different wavelengths, these carrying the modulation from two separate microphones so as to maintain the phase-difference necessary to ensure a true binaural effect. The Standard Telephones & Cables, Ltd., propose to simplify this procedure by making use of only one carrier, and diverting the upper and lower sideband frequencies into separate channels.



As shown in the figure a valve generator O supplies the carrier frequency to modulators B, B_1. The low-frequency signals are supplied through amplifiers A, A_1 from two microphones spaced sufficiently apart to impart the required phase-displacement. The output from the modulator will contain sum and difference frequencies, which are kept separated by two filters F and F_1, the former passing the higher sideband and the latter the lower sideband. In addition there is sufficient overlap between the cut-off characteristics of the filters to pass a proportion of the original carrier frequency.

The radiated energy will therefore contain two versions of the original sound, although the wave as a whole will occupy only the same width as a single broadcasting channel, a point of outstanding importance in the present state of ether congestion. Moreover, as only one aerial and one amplification system and power supply are required, the cost of initial equipment and upkeep is materially reduced.

At the receiving end, Fig. 2, the signals are passed first through two filters similar to F and F_1 of Fig. 1, and then through two separate detectors D, D_1, the final output being led to the individual earpieces of a pair of telephones or to two separate loud-speakers.

LIGHT-SENSITIVE CELLS.

(*Application date, 21st October*, 1925. *No.* 270,222.)

In order to minimise the time-lag effect of light-sensitive devices used in television systems, Mr. J. L. Baird proposes to use the " first differential " of the initial cell response, either alone or in combination with the normal primary response.

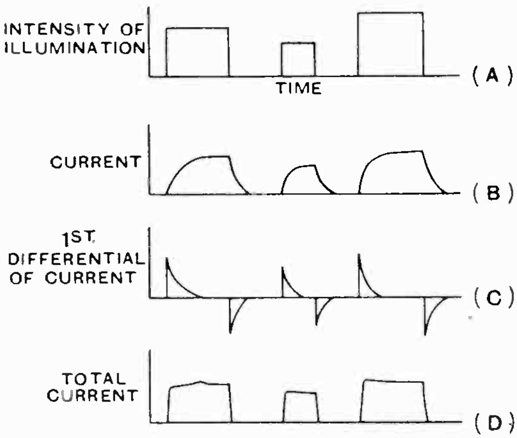


Fig. A shows, on a time basis, the intensity of illumination applied in the first instance to the sensitive cell. B is the corresponding "response" current from the cell. If this current is passed through the primary winding of a transformer, the induced current (or "first differential") in the secondary winding will have the form shown in graph C. For impulses of very short duration, the form of C will approximate more closely to the original stimulus A than the form shown in B. By combining B and C together upon the modulator, or other device to be operated, the effective result is as shown in the graph D. The latter is nearer A in form, for light impulses of comparatively long duration, than either B or C.

SUPPLY FROM THE MAINS.

(*Convention date* (*U.S.A.*), *27th April*, 1925. *No.* 251,240.)

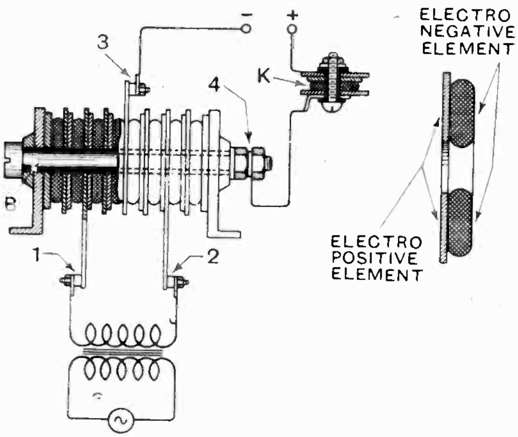
Both the plate and filament supply are taken directly from the house-supply mains through a battery of electrolytic cells A, B, C, D arranged to give full-wave rectification in the case of an A.C. supply. In the case of direct-current mains the supply leads can similarly be connected across the same terminals without danger of short-circuit. Each rectifying cell comprises an aluminium electrode and one of iron or lead immersed in an electrolyte of borax, sodium, or ammonium phosphate.

The filaments are fed in series through a resistance R, from which successive tappings are taken to the plates as shown. Parallel resistances r . . . . r_5 are shunted across each of the filaments, and are made of decreasing value to compensate for the fact that the anode current of each valve is added to the filament current of succeeding valves. Tappings are taken from the resistances r, r_1, etc., to furnish the operating grid potentials. A master rheostat is provided at r_6, whilst an additional resistance r_7 ensures a high negative resistance on the grid of the last amplifier.

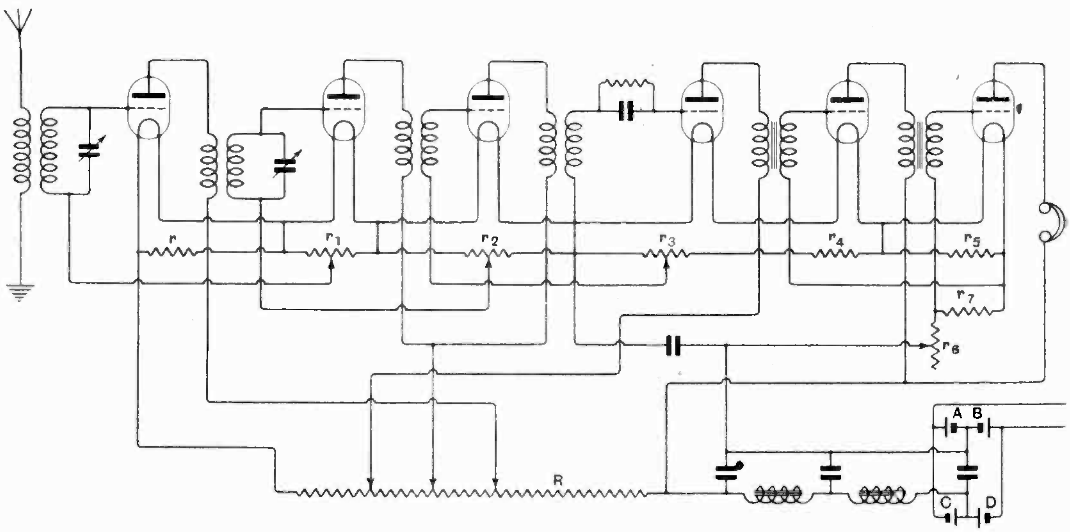
DRY SURFACE CONTACT RECTIFIERS.

(*Application date*, *2nd December*, 1925. *No.* 270,362.)

A rectifying couple having inherent film-forming characteristics is described by Mr. Rubens, in which the electro-negative unit is made or compounded of metals of the sixth group in the Periodic table, whilst the positive element comprises one or more of the lighter metals of the second and third Periodic groups. More particularly the negative unit may be made of a mixture of 85 per cent. copper with 15 per cent. zinc, whilst the positive unit is preferably formed of copper combined or alloyed with silver, zinc, tin or antimony.



The elements are made in annular form, and are assembled in successive pairs on an insulated bolt B, the completed stack being maintained under lateral pressure. As employed for full-wave rectification, the input from the A.C. source is connected across the electrodes 1, 2, the rectified output appearing across the terminals 3, 4.



NEUTRALISING VALVE CAPACITIES.

(*Application date, 14th August*, 1926. *No.* 270,531.)

In this arrangement Mr. C. P. Allinson pushes the utility of the Wheatstone bridge as a radio-frequency stabiliser another step forward by including the internal plate-grid capacity as well as the grid-filament capacity in the balancing arms.

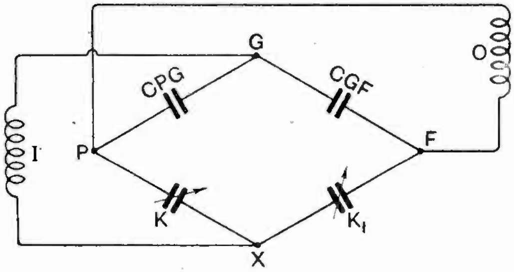


Fig. 1.

The schematic diagram of Fig. 1 shows the internal plate-grid capacity at *CPG*, whilst complementary grid-filament capacity is represented by *CGF*. Condensers K, K_1 of manageable size are included in the remaining arms and are adjusted to secure a correct balance.

The input coil 1 is connected from the grid G to a point X, which is separated from the filament F or earth potential by the condenser K_1. The plate or output coil occupies its usual position across plate and filament. Alternatively the input coil may connect grid and filament direct, in which case the output is branched from the plate to a point separated from the filament by the condenser K_1.

One circuit embodiment is shown in Fig. 2, the relation of which to Fig. 1 will be obvious from a study of the various reference letters. A high resistance R for stabilising the grid potential may be inserted across the condenser K_1, or in either of the positions shown in dotted lines. The balancing condensers K, K_1 may be replaced by equivalent inductances. Fig. 3 shows such an

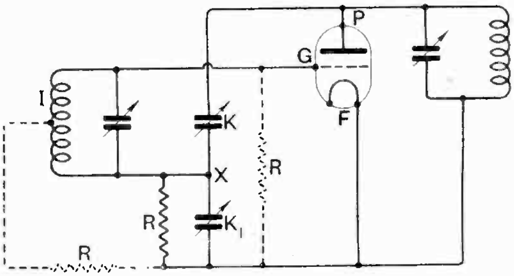


Fig. 2.

arrangement in which the two parts L, L' of the output coil on either side of the tapping point X

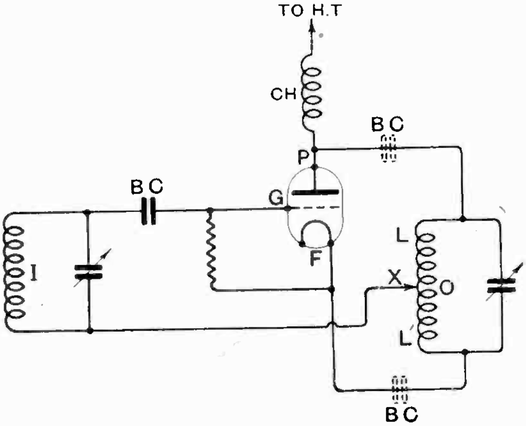


Fig. 3.

are made to serve this purpose. A blocking condenser *BC* may be inserted in any one of the positions shown.

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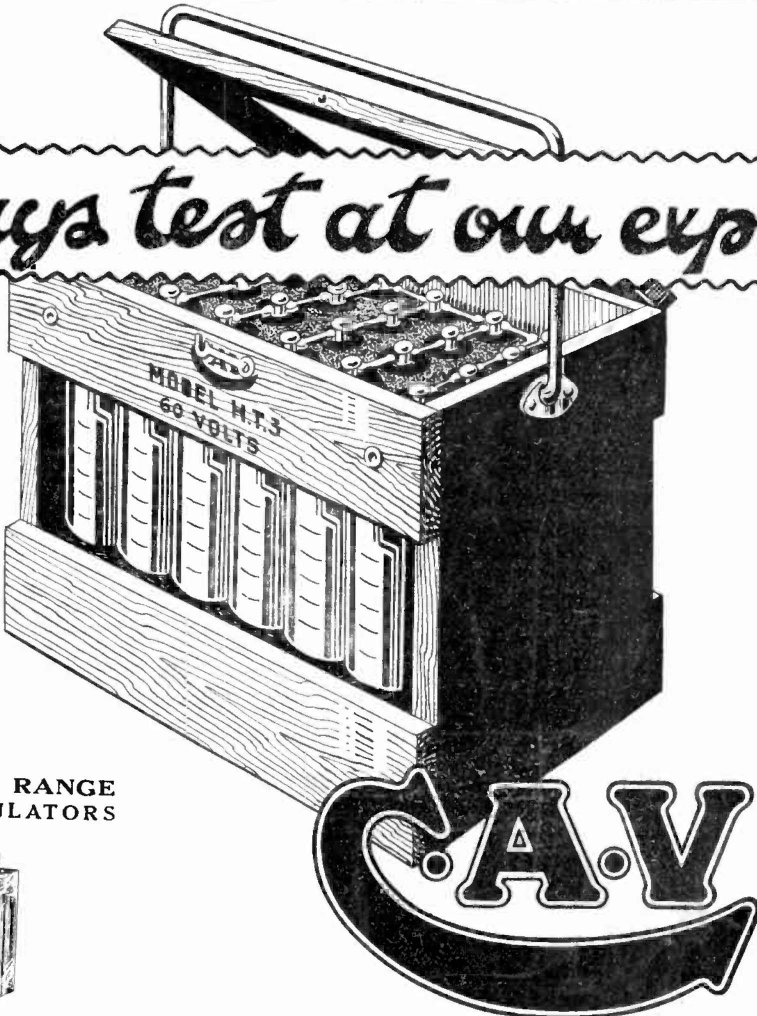

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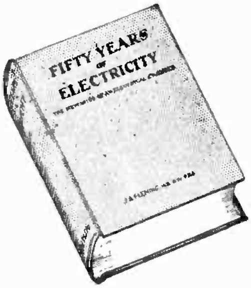

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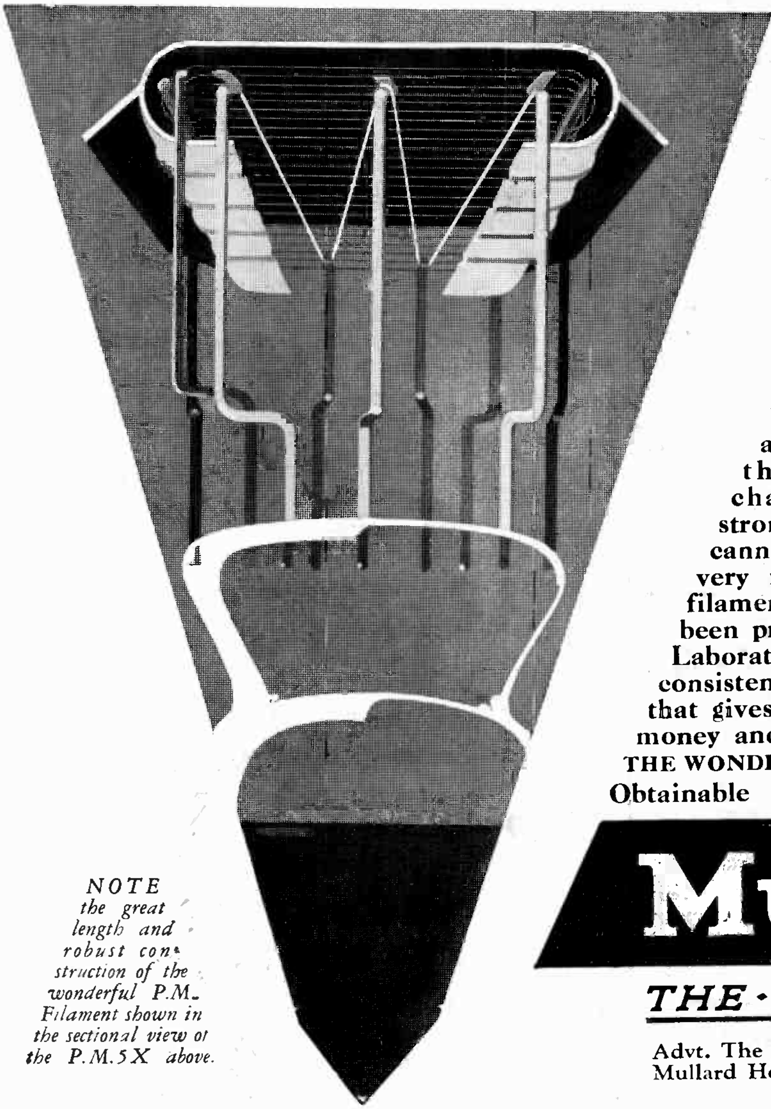

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