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& The WIRELESS ENGINEER

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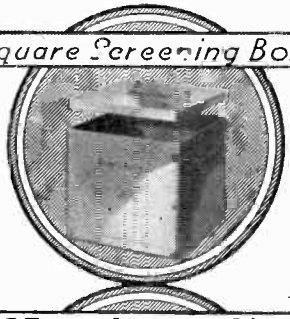

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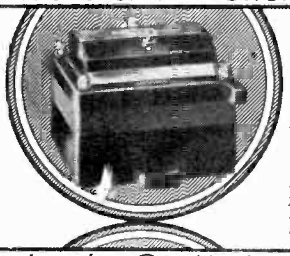

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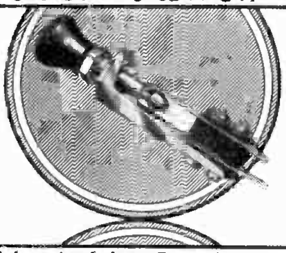

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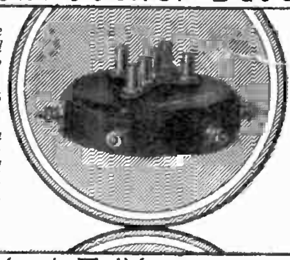

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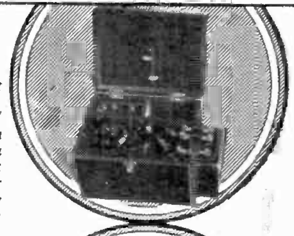

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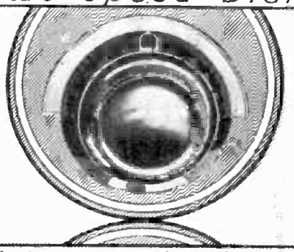

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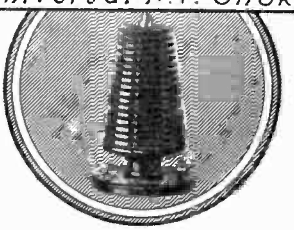

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A Journal of Radio Research and Progress

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EXPERIMENTAL WIRELESS & The WIRELESS ENGINEER

VOL. IV. SEPTEMBER, 1927. No. 48.

Editorial.

Short-wave Broadcasting.

A GREAT deal of attention is being focused at present on the subject of the application of short-wave transmission for the purpose of broadcasting from the home country to all parts of the Empire. The suggestion that an Empire broadcasting station should be established was, we believe, first put forward by our sister journal, *The Wireless World*, and the prominent position which the subject has taken in what we may describe as "broadcasting politics" is due to the persistence of that journal in advocating that a station should be established for this purpose.

The question which at first arose was naturally that of whose business it was to put up the transmitter, but the B.B.C. solved that difficulty for us by intimating that they had the project under way. In a letter to the *Times* recently the Chief Engineer of the B.B.C. has explained officially the policy of the Corporation on the subject, and from his letter it appears that the view adopted is that it is a matter to be undertaken only with the utmost caution and not to be essayed seriously until short-wave transmission and reception of broadcasting has developed to a stage approaching perfection. No doubt the Chief Engineer has some substantial reason (which he does not disclose) to justify this policy. For ourselves, we should think that short-wave broadcast transmission has reached a stage of development when the establishment of an Empire broadcasting station would not be premature. There is no doubt that a good deal of practical work remains to be carried out before anything like perfection of reception in remote parts of the Empire can be achieved, but we think that little will be done until a station is in operation as subject matter for the experiments.

We seem to recollect that in the early days of our broadcasting service in this country reception was by no means satisfactory, nor was the quality of the transmissions above suspicion. The broadcasting service is one which has developed gradually from an experimental stage. One hesitates to suggest it, but to be consistent in his policy our Chief Engineer would have preferred that we had waited, say, for the establishment of the regional scheme before any broadcasting was conducted here, rather than have begun with the Writtle experimental transmitter and its successors in the various stages of development.

High Frequency Resistance.

By A. G. Warren, M.Sc., M.I.E.E., F.Inst.P.

Inductance Coil in a High Frequency Circuit.

ALTHOUGH the quantities involved in high frequency work are usually the same as those of low frequency engineering, the differences of magnitude are so great that methods of measurement which are practicable in the latter case are often useless at radio frequencies. The difficulties encountered in high frequency measurement are mainly of two kinds: (1) that which has just been mentioned, viz., the inapplicability of methods which are capable of accuracy at low frequencies, and (2) what may be termed the "impurity" of the quantities to be measured.

Suppose we consider the second point first. Both the admittance of a condenser and the reactance of an inductance are proportional to the frequency. Capacities and inductances, therefore, whose magnitudes are negligible at ordinary frequencies, may become very important at high frequencies. This is a point to be noted by itself; but the point to be considered at the present moment is that a piece of apparatus often possesses, in a very marked degree, properties which it is not desired to possess. For low frequencies one may construct a resistance in which the effects of any associated inductance or capacity are negligible, or an inductance in which any capacity effects may be neglected. Although the property which the piece of apparatus is desired to have is always adulterated to a certain extent, the effects of such adulteration may be insignificant. As, however, the frequency increases this ceases to be the case and the effect of adulteration at high frequency may be so considerable that even definition becomes a matter of some doubt. Particularly is this the case when the applied frequency first approximates to, and then exceeds, the natural frequency of the piece of apparatus considered.

For example, let us consider an inductance coil. The turns of the coil possess capacity with respect to one another. At high frequencies part of the current entering a section of the coil, instead of traversing the conductor, proceeds as a displacement current. This is, of course, a distributed process, the total displacement current increasing as the centre of the coil is approached. This shunting effect does not reduce the current at the centre of the coil, as might appear at first sight, because the conduction current and the displacement current are almost opposite in phase. For frequencies below the natural frequency of the coil the current is a maximum at the centre and a minimum at the ends. Above the natural frequency of the coil the problem is more complicated and will be considered later.

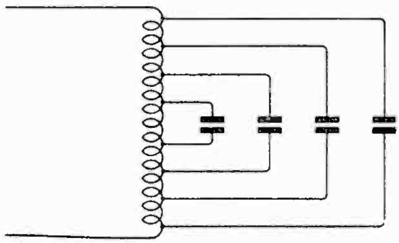


Fig. 1. *Condensers representing the self capacity of an inductance coil.*

The actual state of affairs could be represented somewhat as Fig. 1, where a large number of suitably chosen condensers are imagined shunting a coil which otherwise possesses no capacity. A rough idea of the behaviour of such a coil may be obtained by considering the circuit of Fig. 2. Here it is imagined that the actual coil may be replaced by an ideal inductance shunted by a single condenser. Such an approximation has been used by various writers (*e.g.*, Lindemann). Suppose it is possible to measure the current I flowing into the coil, the potential E across it, and the power P dissipated in it. Let I_L and I_C be respectively the inductive and capacitative components of I. The true resistance R of the coil is given by

$$R = P/I_L^2 \quad \ldots \quad \ldots \quad (1)$$

its apparent resistance from instrument readings is

$$R' = P/I^2 \quad \ldots \quad \ldots \quad (2)$$

whence

$$R/R' = (I/I_L)^2 \quad \ldots \quad \ldots \quad (3)$$

We have

$$E = (R + j\omega L)I_L \quad \ldots \quad \ldots \quad (4)$$

and

$$I_C = j\omega CE \quad \ldots \quad \ldots \quad (5)$$

whence

$$I = I_L + I_C$$
$$= E(1 - \omega^2 LC + j\omega CR)/(R + j\omega L) \quad (6)$$

and

$$I/I_L = 1 - \omega^2 LC + j\omega CR \quad \ldots \quad (7)$$

It is only the numerical value of this expression which is of importance. In most cases R is negligible in comparison with ωL and so except at or very near resonance (where $1 - \omega^2 LC = 0$), $j\omega CR$ may be neglected and

$$R/R' = (1 - \omega^2 LC)^2 \quad \ldots \quad (8)$$

At resonance

$$R/R' = \omega^2 C^2 R^2 = R^2/\omega^2 L^2 \quad \ldots \quad (9)$$

Very near resonance the expression (7) must be evaluated more exactly.

The above expressions may be illustrated by considering a coil of inductance 1mH having a capacity of 25.3$\mu\mu$F. We cannot define its resistance, as that changes rapidly with the frequency, but we shall assume it small compared with ωL. We may, however, examine the effect of resistance by assuming that at about 10^6 cycles, which is the resonant frequency of this coil, its resistance is 2 ohms. The following table is self-explanatory. It is seen that for the tabulated values the expression $j\omega CR$ is negligible except at the resonant frequency.

It will be seen that reasonable values for the resistance are obtained from equation (2), $R = P/I^2$, so long as the frequency is less than one-tenth of the resonant frequency of the coil. Above this, calculations from equation (2) give values increasingly too great until resonance is attained. Above resonance, values calculated from this expression are at first too great and later too small. No reliance can be placed on calculations from such instrument readings except below one-tenth of the resonant frequency.

TABLE I.

f	I/I_L	R/R'
0.1×10^6	0.99	0.980
0.5×10^6	0.75	0.562
0.8×10^6	0.36	0.130
0.9×10^6	$0.19 + .0003j$	0.036
10^6	$0 + .000318j$	10^{-7} approx.
1.1×10^6	$0.21 + .00035j$	0.044
1.2×10^6	0.44	0.194
1.3×10^6	0.69	0.476
1.4×10^6	0.96	0.922
1.5×10^6	1.25	1.562

Effect of Distributed Capacity of an Inductance Coil.

The circuit of Fig. 2 is only a very rough approximation and is not capable of affording reliable information when the frequency approaches or exceeds the natural frequency of the coil. If we consider the condensers shown in Fig. 1 to be representative of a large number of condensers of the correct magnitude, at least a qualitative insight into the behaviour of the coil can be obtained.

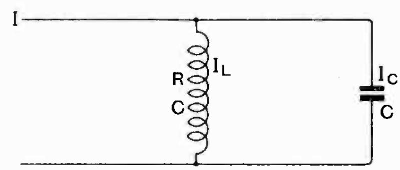


Fig. 2. *Rough approximation to self capacity of inductance coil.*

More than that will not be attempted at present. The exact solution of the problem is one of great difficulty and as far as the writer is aware has not been completely worked out. Here we shall only attempt to obtain an approximate idea of the current changes down the coil. For simplicity one may assume either (*a*) that condensers of suitable magnitudes are connected at equal intervals down the coil or (*b*) that a number of equal condensers are connected at suitable points, or what would offer greater difficulties from a quantitative point of view but is simpler in our case; or (*c*) that condensers are connected of such magnitudes and so disposed that they take equal currents (Fig. 3).

For frequencies below resonant frequency the current I_0 taken by the coil lags behind the voltage by practically 90 degrees (Fig. 4) the current $I_1 = I_0 - i_1$ and since i_1 leads the voltage by 90 degrees, I_1 is equal to the numerical sum of I_0 and i_1. Similarly $I_2 = I_1 - i_2$, etc. Fig. 4 shows how the magnitude of the current grows towards the centre of the coil.

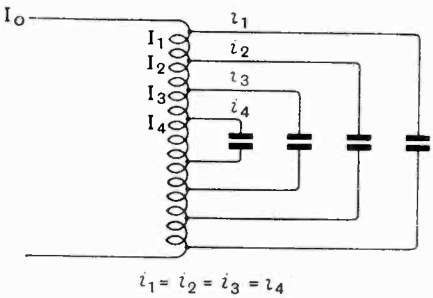


Fig. 3. *Imaginary condensers so disposed that they take equal currents.*

When the frequency exceeds that of the coil the case is very different. The current I_0 then leads the voltage by practically 90 degrees. (This is only true when the frequency does not exceed that of the coil by too great an amount. As the frequency is increased the phase of the current undergoes successive reversals. This point is

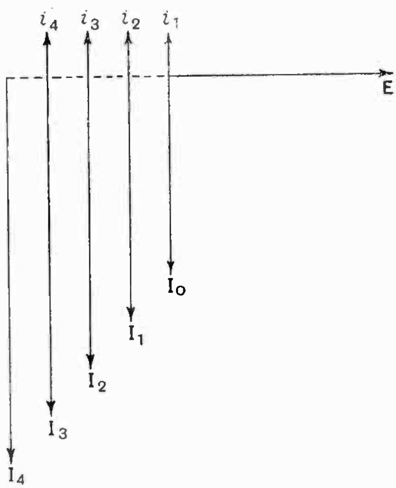


Fig. 4. *Vector diagram for circuit of Fig. 3.*

treated more fully later.) At some point down the coil there is a node of current beyond which the direction of flow is reversed. From this point the current grows until the antinode is reached, which may be at the centre of the coil. In the case of very long coils it is possible that there may be several nodes and antinodes at high frequencies. In any case, so long as the coil is symmetrical, and symmetrically disposed, an antinode of current will be at its mid-point. The current relations in a coil of moderate length are illustrated in Figs. 5 and 6.

It might now appear that the representation of the capacity of the coil by condensers distributed as in Figs. 3 and 5 does not indicate the true state of affairs. On very long coils some of the condensers will have voltages of opposite signs to others. A moment's reflection, however, shows that the representation is still correct: there are standing voltage and current waves upon the coil. The components i always lead the voltage by 90 degrees; this voltage varies in magnitude, and may be in the same

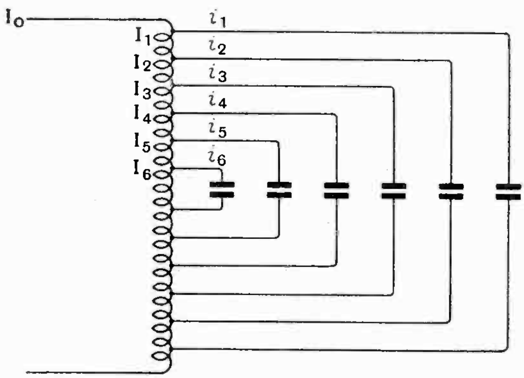


Fig. 5. *Approximate circuit assumed for a long coil at high frequency.*

direction or in the opposite direction to the voltage across the terminals of the coil. It would appear natural on very long coils to imagine the condensers connected to points equidistant from the antinodes of voltage of the same wave, such as AA'; no difference, however, occurs if they are imagined connected to points such as BB' which are at the same potential (Fig. 7). In the case of a short coil forming part of a tuned circuit oscillating at fundamental frequency, only part of a wave is situated upon the coil and the relations are as indicated in Fig. 8, the current being a maximum at the centre.

Resistance of an Inductance Coil.

At reasonably low frequencies there is no difficulty in defining with practical accuracy what is meant by the resistance of the coil. The current has approximately the same value at all parts and, leaving out of consideration any losses in the dielectric or losses due to radiation from the coil, the resistance may be defined as the power divided by the square of the current. If

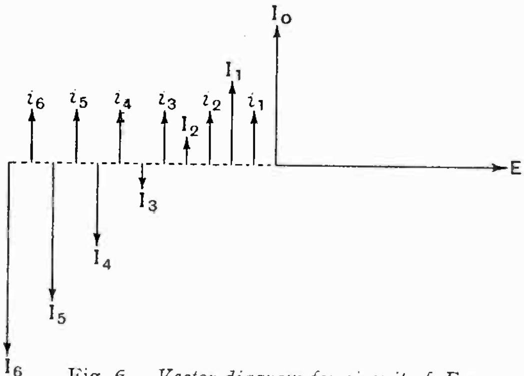


Fig. 6. *Vector diagram for circuit of Fig. 5.*

the power *dissipated* is measured, no error occurs due to any radiation which may take place. When, however, there are considerable differences in the value of the current at various parts of the coil the quantity given by the power divided by the square of the current at the *end* of the coil can hardly be said to be the resistance. If the current could be measured at all parts the resistance might be defined as the integral of dP/I^2 throughout the coil.

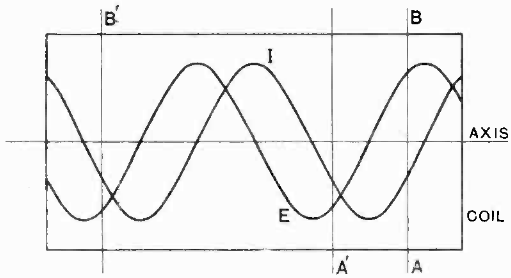


Fig. 7. *Showing distribution of current and voltage on a very long coil.*

From a scientific point of view the quotient, power/(input current)^2, is far too indefinite. If we take an extreme case, when the frequency is equal to that at which the coil will resonate, we have loss of power with practically no current, suggesting a nearly infinite resistance. This nearly infinite apparent resistance may be actually reduced by an increase of true resistance, or it may be actually reduced by an increase of true resistance, or it may be reduced by an increase in the length. (See equation (7) and Table I.) But such cases are rarely practical. Turning to actual practice we find that the problem with which the engineer is faced is this: Given a particular piece of apparatus what will its characteristics be at various frequencies? When the current in the circuit of which it forms a part is known in magnitude and frequency, what effective inductance and capacity has the apparatus, and what losses occur in it? If reduction

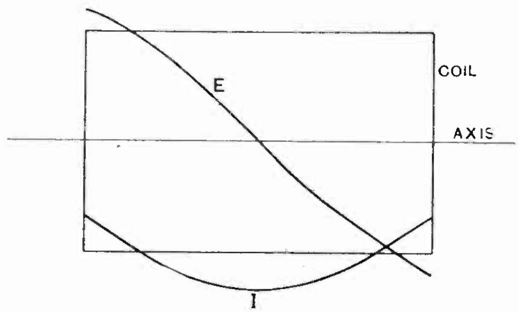


Fig. 8. *Current and voltage distribution on a short coil forming part of a tuned circuit.*

of loss is desirable, what is the distribution of the losses and how can such reduction be best effected? Towards the solution of such problems, a knowledge of the apparent resistance, as defined by the power divided by the square of the input current, offers one factor involved in the solution. So long as the frequency is reasonably lower than the resonant frequency, the apparent resistance does not differ greatly from the true resistance.

Effect of High Frequency Currents upon Resistance.

At high frequencies, as is well known, the current does not distribute itself uniformly over the cross-section of the conductor. In the case of a long straight wire the eddy currents caused by the flux within the conductor force the current towards the surface. The effect naturally increases with the frequency, until the current is practically confined to a thin surface layer. Another way of looking at the same effect (due to Howe)* is to consider the transmission of energy into the conductor from the surrounding dielectric. This transmission is governed by the same laws as the main transmission along the conductor. It is of a wave nature, the wavelength decreasing with the frequency. At low frequencies the current changes in phase and attenuates as the centre of the wire is approached, so that the total current is considerably less than it would be if it had the same density everywhere as it has at the surface. At higher frequencies the attenuation becomes greater, and the wavelength less, so that at a short distance within the conductor there may be a small reverse current flowing. The effect of a non-uniform distribution of current is clearly to increase the effective resistance, since the loss at every point is proportional

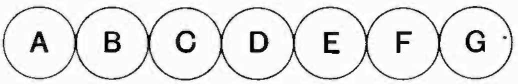


Fig. 9. *Parallel straight wires carrying equal currents.*

to the square of the current density. At high frequencies it is possible to reduce the effective resistance by making the wire hollow and eliminating the possibility of reverse current.

The case of a coil is much more complicated than that of a straight wire. The energy, instead of being propagated symmetrically into the conductor from all directions, is, for a conductor near the centre of the coil, propagated in the direction of the radius of the coil. The current is, in a single layer coil at high frequencies, confined almost entirely to a thin skin on the inside surface of the cylinder, there being practically no current at the outer surface. In general the coil resistance at a given frequency is considerably greater than the resistance of the wire of which it is composed, were the wire straightened out.

Notable contributions to an analytical solution of the problem have been made by Howe, who solved it for closely packed solenoids of square wire,† by Sommerfeld who obtained a solution for coils of large diameter of round wires in contact. In recent years the theory of the subject has been greatly developed by Butterworth. The reader is referred to his papers for a comprehensive analytical treatment of the subject.* Howe has assumed that the flux is parallel to the axis of the coil. This is true near the centre of long closely-packed solenoids, but it is far from true near the ends. The effect of obliquity of the field can be understood best by considering the eddy currents in any particular turn due to adjacent turns. We shall assume that the coil is being operated, as it most commonly is, at a frequency well below resonance, when we may assume with reasonable accuracy that the current is the same at all parts. Then the eddy currents produced in any particular conductor are due to the electromotive forces generated in it by the variation of its own internal flux and the variation of flux through it due to adjacent conductors. As a first approximation we may consider a number of parallel straight wires (Fig. 9). It is clear that the fields in D due to C and E largely cancel one another out, similarly the fields due to B and F and to A and G. If we consider the conductor B, the field due to the other conductors, at the instant when the current is flowing into the paper, is preponderatingly upwards. Still more is this the case for conductor A. One would therefore infer that the eddy currents produced in the end conductors would be much in excess of those in conductors near the centre, resulting in a greater heating loss, or a higher resistance at the ends. This is confirmed by the writer's experiments, described later.†

We see, therefore, that the resistance losses in a coil would be expected to be different in different parts. So long as the current is approximately the same at all parts of the coil, the losses will be much greater in the end turns. This represents a real increase of resistance to currents of the particular frequency. It is conceivable, however, that as the resonant frequency is approached the

* *Proceedings, I.E.E.*, Vol. 54, p. 473.
† *Ibid.*, Vol. 58, p. 152.

* See *Phil. Trans. A.*, Vol. 222, p. 57. 1921, for coils of greater diameter than length. Also *Proc. Roy. Soc. A.*, Vol. 107, p. 693, 1925, for closely wound coils. An excellent summary of much of this work appeared in *E.W.& W.E.*, April and May, 1926.)

† These experiments were carried out in 1921 before Butterworth's analytical work was available.

losses may become greater at the centre of the coil, when the current there is much greater than at the ends. The preliminary experiments which the writer has made call for repetition upon coils of all practical types; measurements near the resonant frequency would be of particular interest.

Practical Methods of Measuring Resistance.

Most methods which have been employed for high frequency resistance measurement have been subjected to considerable criticism. With any method of substitution or addition of resistance to a circuit it is extremely difficult to ensure that the general conditions of oscillation are unaltered. One of the chief sources of error is the effect of stray capacities. Bridge methods with coils of low power factor offer great difficulties. It "is equivalent to trying to weigh milligrammes with a 2 or 3 lb. weight on each side of the scale."* At high frequency the current is controlled almost entirely by the reactance of the circuit. Strict balance between two circuits can only exist when both the reactances and resistances are equal. Practical balances may, however, often be obtained when the quantities are fairly different. The calorimetric method, in spite of all the experimental difficulties, is not open to similar criticism. If the current into the coil can be measured, and the heat produced in it determined, the effective resistance can be readily calculated. There is no question of adjusting a circuit to a point of doubtful resonance or of balancing the coil against another circuit which more or less perfectly imitates it.

It has to be admitted that most calorimetric methods do not allow of rapid measurement, also that they are not capable of giving good results in unskilled hands. Often many corrections have to be applied, though these corrections can be made with a fair degree of accuracy and, when the final results are obtained, one can assume their approximate accuracy with confidence.

Objection has been raised to the calorimetric method on the ground that "it necessitates the use of much larger currents than the coils are often required to carry in practice."† The writer has not found this a serious objection. In the experiments described later the low frequency current through a coil of No. 20 S.W.G. copper wire rarely exceeded 5 amps. (The high frequency current was, of course, less.) The rise of temperature was never more than 5°C. Yet no difficulties occurred owing to the quantities being too small to measure. In the writer's second method this criticism is still less applicable.

There are many ways of applying the calorimetric method. One may actually measure the heat produced in the coil, and then from its thermal constants determine the resistance. It is usually more convenient to measure the heat produced by, first, a high frequency current and then by a low frequency or direct current. The ratio of the quantities of heat produced in unit time per ampere* in the two cases is the ratio of the high and low frequency resistances.

Methods may also differ in the thermal quantity that is measured. It may be the actual quantity of heat generated in the coil or it may be the rise of temperature which takes place in a specified time. Usually it is the latter. Temperature rise is usually determined by means of a thermojunction, though this is not the only means available.

Errors in Calorimetric Measurements.

The chief source of error in calorimetric measurements is the loss of heat from the conductor in which the heat is generated. A short time after the current is switched on we have copper, insulating covering, former and the surrounding air all at very different temperatures. Could these conditions be exactly reproduced on all occasions the calculated results at high and low frequencies would be strictly comparable and the determined ratio of the resistances at different frequencies would be correct. Unless very special precautions are taken, however, the repetition of circumstances cannot be assured. One day the cotton covering may be perfectly dry and the heat consequently retained much better by the copper than when the covering is damp. Dielectric losses occur in the covering and in the former.

* Fortescue, *Proceedings, I.E.E.*, Vol. 58, p. 163.
† Coursey, *Proceedings, I.E.E.*, Vol. 58, p. 164.

* Some objection may be taken to this expression; it is convenient, however; by it is meant the heat produced divided by the square of the current.

These tend to mask the resistance measurements and also result in the production of an amount of heat which may not be exactly reproducible even with currents of the same magnitude and frequency. Again, at fairly high frequencies, heat is generated at a greater rate at the ends of the coil than at the centre, whereas at low frequencies the heat is generated uniformly throughout the coil. It is hardly justifiable to assume that, when the same total quantities of heat are generated at high and low frequencies, the loss of heat is the same. In Howe's experiments the thermojunctions were situated near the centre of the coil and were only connected after the alternating current had been switched off. By this method errors due to capacity currents flowing along the thermojunction wires were obviated, but allowance was not made for the variation of temperature throughout the coil. In general, temperature measurements made upon a coil after a high frequency current has been passed through it for a definite time show that the heating is a maximum at the ends. Thermal conduction, however, tends to equalise the temperatures throughout the coil, and an estimation of the relative resistances of the various parts offers considerable difficulties.

At any instant the rate of rise of temperature of a conductor is determined by its thermal constants and the difference between the rate of heat generation in it and the rate at which heat is being lost. The rate of heat generation, which it is desired to measure, is thus the sum of two terms: (A) The *net* rate at which heat is being added; and (B) the rate of loss of heat. The second term is approximately proportional to the rise of temperature and is zero at the instant of switching on the current. It is, however, a somewhat variable quantity, even under apparently similar circumstances. Experiments of the writer show that the rate of loss of heat from a coil cannot be estimated with reasonable accuracy from the rate at which the coil cools after the current is switched off. The distribution of temperature during heating is very different to its distribution when cooling. In the first case heat is being given both to the surrounding air and to the former upon which the coil is wound. During cooling, heat is being received from the former at the same time as it is being lost to the air. One would expect, therefore, that the rate of loss of heat during cooling would be less than it is at the same temperature when heating. Experiment shows that it is actually less during cooling. Great reliance, therefore, cannot be placed upon calculations involving an estimate of the heat loss when that loss is comparable with the rate at which heat is generated.

Writer's Method of Determining Coil Resistance.

The distinguishing features of the method described below are :—

1. The *initial* rate of rise of temperature of different parts of the coil was measured, enabling

2. (A) The effects of variations of external thermal conditions upon different occasions to be eliminated ;

(B) The resistance of different parts of the coil to be determined.

Thermojunctions of very fine wire were soldered to various parts of the copper of which the coil under test was made. The initial rate of heating of these junctions was determined, by a method to be described later.

The initial rate of heating is dependent only upon the rate of heat generation. Loss of heat and thermal conduction between different parts of the coil are not appreciable until there are sensible differences of temperature between the various parts of the coil and between the coil and its surroundings. The rate at which the temperature of the part of the coil under observation changes immediately after switching on the current is therefore a true measure of the rate at which heat is being generated at the point in question. The chief feature of the method, however, is not that it reduces the errors incident to the estimation of the cooling loss, but that it permits of point measurements of resistance being made. The true resistance loss in the copper is determined apart from losses in the former and surroundings.

Test Coil and Junctions.

The coil tested consisted of 119 turns of No. 20 S.W.G. D.C.C. copper wire, wound upon a paper tube, the mean diameter of the coil being 10.8 cms., and its length 15.7 cms. Its low frequency resistance was about 1.04 ohms. Its inductance, calculated from Lorenz's formula, was 0.792 millihenries.

The coil was placed in the dummy aerial circuit of a ½kW Marconi valve transmitting set, capable of giving a high frequency current of 6 amps. High frequency currents greater than 3 amps, however, were rarely used. The coil was kept well removed from the generating plant. In fact, the two were in separate rooms, two pairs of leads connecting them—one in the high voltage circuit, the other in the grid-leak circuit. Adjustments were first made with the transmitting key closed, another coil exactly similar to the test coil being inserted in place of the latter. The transmitting key was then released and the test coil replaced. The junctions consisted of fine wires (2 mils.) of Eureka and platinum silver, soldered on to the bare copper. These wires in turn were soldered to No. 36 S.W.G. copper wires for connection to the junction terminals, the latter being carried upon a thin strip of ebonite supported at some distance from the coil. Both elements of the junctions were made of high resistance wire of very small diameter in order to reduce eddy currents in them. Approximate calculations, based upon the method employed by Howe in calculating the loss in stranded conductors, indicated that any heating of the junction wires due to this cause was negligible. Small pieces of cotton wool were pressed gently between the junction wires and over the joints between them and the copper terminal wires. The coil was supported in a double enclosure, consisting of two wooden boxes. This method of enclosing it was found very effective in protecting it from draughts, and it allowed the coil to be opened up very rapidly for inspection and for cooling between experiments. The junctions were connected in turn to a moving coil galvanometer of the single suspension type. The latter required about 7 microvolts to give 1 cm. deflection on the scale. It was suspended in an antivibration cradle from a bracket upon the wall. The junctions were calibrated by passing an alternating current of low frequency through the coil and measuring the initial rate of rise produced in each per amp.

Preliminary Investigations.

A number of preliminary investigations were necessary, the chief being the following:—

(i.) Means of measuring the high frequency current.

(ii.) The magnitudes and effects of stray capacity currents.

(iii.) Form of heating curves.

(iv.) Uniformity of heating of the wire over its cross-section.

These investigations will not be considered in detail, but the general results will be given. The measurement of the current within an accuracy of 1 per cent. presented little difficulty. Several instruments, whose readings were practically independent of frequency, were designed and constructed. It is not proposed to consider them here.

Stray capacity currents are often a source of considerable error in high frequency measurements. The instruments connected to the circuit often possess capacities which, though they may be neglected at low frequencies, are of importance at high frequencies. One advantage of the calorimetric method is that the results obtained are only in error to the extent to which the capacity currents obtrude upon the main current. With other methods it is possible that a balance may be rendered completely false by stray currents of this nature. It is desirable that, whenever possible, instruments should be connected at points of the circuit which are at approximately earth potential. Unfortunately this cannot always be done. The only course open then is to reduce the capacity of the instruments to a minimum. In the circuit used by the writer there were two points at which capacity leaks were possible, the first at the ammeter, the second at the galvanometer. The first leak was rendered insignificant by connecting the ammeter at a point of the circuit which was practically at earth potential. This could not be done in the case of the galvanometer, and a minute investigation of the possible errors that might occur had to be carried out. When current was passing through the test coil, it was clear that since the junction was not at earth potential a charging current would flow along the junction wires to the galvanometer. The effect of this current would be twofold: (*a*) to modify the actual current flowing into the coil, (*b*) to cause heating of the junction wires. Experimental investigation showed that both these effects were negligible.

A considerable number of experiments were carried out to determine the form of heating curves. These would be expected to be approximately of an exponental form (see later section). It was found that they were roughly of this nature but that the deviations were not negligible. But what was most remarkable were the variations that might occur between the observations of the rise of temperature of the same point upon different occasions. It was during these investigations that the writer came to the conclusion that great reliance could not be placed upon measurements involving any considerable rise of temperature of the coil—such measurements could not be repeated with sufficient accuracy. The explanation was obviously the variations in the conditions external to the conductor. Yet despite the variations in the rate of rise of temperature when the temperature was moderately different from that of the surroundings, the *initial* rate of rise was found to be remarkably constant for the same current.

The fourth point mentioned above is one of considerable theoretical complexity. Quite inconsistent assumptions have been made during the tests; it has been assumed that the initial rate of rise of temperature is determined by the rate of heat generation at a particular point of the coil; it has also been assumed that the conductor heats uniformly over its cross-section at a particular place. Actually, of course, heat is generated at very different rates over the cross-section of the conductor, the rates being very much more diverse than they are at different points of the coil. Yet calculation shows that it is justifiable to assume uniform heating in the one case and not in the other. Thermal conduction over the cross-section of the conductor is an extremely rapid process, whereas between different parts of the coil it is relatively slow.

Method of Determining the Initial Rate of Rise of Temperature.

The rate of loss of heat at any instant is approximately proportional to the rise of temperature, so long as that rise is not too great.

If a be the rate at which the temperature would rise if there were no loss of heat, and $b\theta$ be the rate at which the temperature would fall if no current were flowing and the coil were at a temperature θ above its surroundings, then

$$d\theta/dt = a - b\theta \qquad \dots \quad (10)$$

whence

$$\theta = \frac{a}{b}\,(1 - e^{-bt}) \qquad \dots \quad (11)$$

Actual heating curves were found to approximate closely, but not with mathematical accuracy, to this form. The approximation, however, was sufficiently exact for the equation to be assumed to apply rigidly in the neighbourhood of the origin. It could therefore be employed to determine a $(=Lt_{t=0}d\theta/dt)$, the initial rate of rise of temperature. If the unit of temperature be that causing a deflection of one galvanometer division, the deflection

$$\partial = \frac{a}{b}(1 - e^{-bt}) \quad \dots \quad \dots \quad (12)$$

whence

$$a = \frac{b\partial}{1 - e^{-bt}} = \frac{\partial}{t}\left(\frac{\log e^{bt}}{1 - e^{-bt}}\right) \quad \dots \quad (13)$$

∂/t is the average rate of rise of temperature during the interval. To obtain the initial rate of rise the average rate must be multiplied by a factor λ given by

$$\lambda = \log e^{bt}/(1 - e^{-bt}) \qquad \dots \quad (14)$$

This factor can be calculated from two successive determinations of deflection and time. In practice a double deflection method was found to be most convenient. A split seconds stop watch was used. One hand of the watch was stopped when the galvanometer deflection was ∂ (usually 10 cms.), the other when the deflection was 2∂. If the times be respectively t and T we have

$$\partial = \frac{a}{b}(1 - e^{-bt})$$

$$2\partial = \frac{a}{b}(1 - e^{-bT})$$

whence

$$(1 - e^{-bT})/(1 - e^{-bt}) = 2 \qquad (15)$$

From this relation a curve can be plotted enabling us to determine λ for any ratio of T/t. To obtain this curve, values are given to e^{-bt}, whence values of e^{-bT} can be calculated at once from equation (15). The corresponding value of T/t is given by

$$T/t = log\ e^{-bT}/log\ e^{-bt} \quad \ldots \quad (16)$$

λ is given by the relation

$$\lambda = log\ e^{bt}\ /\ (1 - e^{-bt}) \quad \ldots \quad (17)$$

The method is obvious from Table II.

In Fig. 10 the relation between T/t and λ is plotted.

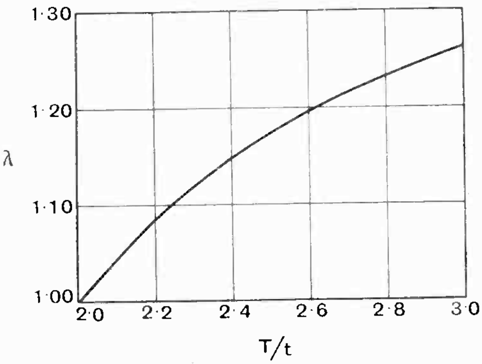


Fig. 10. *Graph for determining the initial rate of rise of temperature from the average rate of rise.*

As an example the following observations may be considered :—

Time for 10 cms. deflection = 9.4 secs., for 20 cms. = 21.0 secs., $T/t = 2.235$. From curve $\lambda = 1.097$. Average rate of rise in the first interval = 1.06, whence initial rate of rise is 1.16.

TABLE II.

e^{-bt}	e^{-bT}	λ	T/t
1	1	1	2
0.9	0.8	1.054	2.115
0.85	0.7	1.083	2.194
0.8	0.6	1.115	2.289
0.775	0.55	1.133	2.345
0.75	0.5	1.151	2.411
0.725	0.45	1.169	2.482
0.7	0.4	1.189	2.569
0.675	0.35	1.210	2.672
0.65	0.3	1.231	2.796
0.625	0.25	1.253	2.950
0.6	0.2	1.277	3.152

Typical Experimental Results.

One set of experimental observations is given here to illustrate the method adopted. After each reading the coil was exposed to the air to cool ; some time before the next reading was taken the boxes were closed and the whole apparatus allowed to assume a practically uniform temperature. Preliminary experiments showed that it was not necessary to wait until the galvanometer spot had returned to zero. Measurements made with the spot a few cms. from the zero (*i.e.*, coil a few tenths of a degree Centigrade above the surroundings) agreed very closely with those made initially from zero. It was considered desirable to make the actual tests of short duration and reduce inaccuracies in time measurements by taking the mean of a series of observations.

The method of taking an observation was as follows : After adjusting the current and wavelength to convenient values on the adjusting coil, the latter was replaced by the test coil. With the galvanometer spot deflected slightly less than the amount from which it was intended to work as a zero, the transmitting key was closed. As the spot passed the working zero the split seconds stop watch was started ; the first hand was stopped when the spot passed a deflection ∂ and the second hand stopped at a deflection 2∂. The current was read and then switched off. The procedure given above was adopted to eliminate inaccuracies due to the inertia of the moving coil of the galvanometer. Occasionally the wavelength was checked on the test coil before switching off the current. Typical log readings are given in Table III.

TABLE III.

JUNCTION III., WAVELENGTH 1,800 METRES.

Zero.	t_8	T_{16}	I	T/t	λ	a	I	a/I^2
2	7.8	20.0	2.90					
2	7.4	19.0	3.02					
2	7.6	19.0	2.99	2.51	1.176	1.239	3.02	.136
2	7.6	19.0	3.06					
2	7.6	18.6	3.06					
2	7.6	19.0	3.09					

t_8 = time for 8 cms. deflections; T_{16} = time for 16 cms. deflections. a/I^2 is the measure of the initial rate of heating per ampere.

This value divided by the corresponding quantity at low frequency gives the ratio R_c/R_0, where R_c is the high frequency resistance of the coil and R_0 its low frequency resistance.

Results Obtained.

The completed results for four different frequencies are recorded in Table IV. and are plotted in Fig. 11.

TABLE IV.

Junct.	L.F.	Wavelength.							
		3,500		3,000		2,500		1,800	
	a/I^2	a/I^2	R_c/R_0	a/I^2	R_c/R_0	a/I^2	R_c/R_0	a/I^2	R_c/R_0
I	.0427	.0864	2.02	.097	2.27	.102	2.38	.131	3.06
III	.0429	.0888	2.07	.099	2.30	.106	2.47	.136	3.17
IV	.0371	.0924	2.48	.104	2.80	.113	3.05	.141	3.80
V	.0336	.151	4.77	.175	5.24	.200	5.94	.242	7.22
VIa	.0325	.108	3.33	.120	3.69	.132	4.07	.165	5.07

Positions of junctions.

I turn 60 (middle of coil)
III turn 15
IV turn 9
V turn 1 (end of coil)
VIa turn 4

Examination and Criticism of Results.

Over the range of frequencies investigated the experiments were successful in demonstrating the approximate magnitude of the increase of resistance due to the end effect. Beyond this, it is claimed that the determination of the initial rate of rise of temperature is, in all cases, a more satisfactory way of carrying out a calorimetric test than the determination of the rise of temperature in a definite time. The experience is undoubtedly that the latter determination is open to many errors from which the former is free.

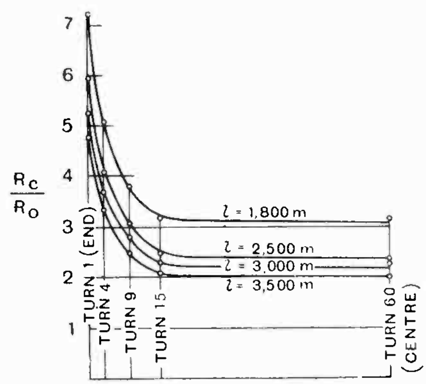


Fig. 11. *Distribution of loss in experimental coil.*

The magnitude of the end effect is considerable, as the curves of Fig. 11 show. It is, however, as might be expected, very localised. (The rise of temperature of junction III.—only one-quarter of the way from the end to the centre of the coil—was very little greater than the rise of junction I. From this point to the end the rise of resistance is most marked.) The total resistance of the coil is consequently increased—at the frequencies used—by about 12 per cent.

The generating set employed was limited in wavelength control and the range of frequencies actually used is too limited for extensive deductions to be made. The relations between the various curves, however, merit examination.

As far as the experiments go, no great variation (apart from the general rise of resistance with frequency) in the magnitude of the end effect was experienced. This is demonstrated in Table V.

TABLE V.

Wave-length.	R_c/R_0 at centre of coil—from curve.	R_c/R_0 average.	Ratio.
1,800	3.05	3.38*	1.11
2,500	2.35	2.66	1.13
3,000	2.18	2.44	1.12
3,500	2.00	2.24	1.12

Such a result would be expected if the field distribution were independent of the frequency. One would expect this for frequencies well below the resonant frequency of the coil, if the diameter of the wire is small compared with the dimensions of the coil, that is to say, so long as the field is not greatly modified by either variation of the current distribution along the length of the coil or by reaction of the eddy field upon the main field.

Again, the experimental results seem to indicate a lower actual resistance but a greater rate of rise of resistance with frequency than is suggested by theoretical investigations. Howe in his paper, "The High Frequency Resistance of Wires and Coils,"† gives a curve connecting R_c/R_0 and $\beta\tau$ (Fig. 6 of that paper, reproduced here as Fig. 12), where $\beta = 2\pi\sqrt{f\mu/10^9\rho}$ and τ = thickness of conductor, if rectangular. For round wires it is suggested that τ should be taken as .886d and μ as $\sqrt{S\tau}$ where S =

* The calculated value of R_c/R_0 average for this coil at 1,800 metres from Butterworth's formula is 3.41, a very good agreement.

† *Proceedings, I.E.E.*, Vol. 58, p. 152.

number of turns per cm. For the coil used by the writer $d=.0914$ cm., $\tau=.081$ cm., $S=119/15.7$, whence $S\tau=.613$, $\sqrt{S\tau}=.783$ and $\beta\tau=.00965\sqrt{f}$. The values of $\beta\tau$, therefore, for wavelengths 3,500, 3,000, 2,500, and 1,800 are respectively 2.82, 3.05, 3.34, 3.94. It will be seen from the curve that $R_c/R_0=\beta\tau$ when $\beta\tau>2.5$. The corresponding values obtained experimentally (at the centre of the coil) are 2.00, 2.18, 2.35, 3.05. Doubt has been expressed regarding the validity of the assumption that spacing is equivalent to a reduction in the permeability in the ratio $\sqrt{S\tau}$. The differences may be explained if this assumption is incorrect.

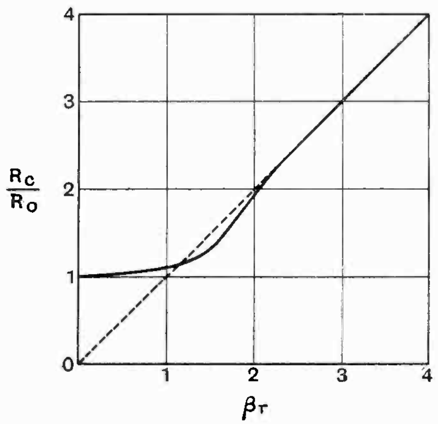


Fig. 12. *Curve from Howe's paper on "The High Frequency Resistance of Wires and Coils."*

The experimental results also suggest a rise of resistance more than proportional to the square root of the frequency. Comparing the values for wavelengths 1,800 and 3,500 we have $f_2/f_1=1.95$; $\sqrt{f_2/f_1}=1{,}396$; $R_2/R_1=1.525$; indicating a rise of resistance rather greater than the square root of the rise of the frequency.

It would perhaps be unwise to generalise from these results, although they differ somewhat from theoretical values. The experiments call for repetition upon coils of different shapes and sizes.

So long as one may assume that either the end effect is small or that the average resistance bears a constant ratio to the resistance at the centre, measurements upon the resistance of the coil as a whole (what one may call its "mass-resistance"), may afford valuable information. Thermojunctions placed at the centre may be assumed to give the resistance of long coils, if the initial rate of heating method is adopted. If, however, the coil is allowed to heat for a sensible length of time the reading of a thermojunction placed at the centre cannot give very reliable information. Junctions must, in this case, be placed at several points on the coil.

Another calorimetric method of test, evolved by the writer and described below, is capable of giving the mass-resistance much more expeditiously than thermojunctions.

Second Calorimetric Method of Determining High Frequency Resistance.

The resistance of a copper conductor to a direct current rises by about 0.4 per cent. for a rise of temperature of 1°C. This rise of resistance may be employed to determine the rise of temperature. The rate at which a conductor heats when an alternating current is passed through it is proportional to the square of the current and to the resistance which the conductor offers to the current. The same conductor may offer very different resistances at the same time to different currents. Thus the coil used in the tests already described, offered a resistance of about 3 ohms to a current at a frequency of 150,000. Had a direct current of 1 milliampere been superposed upon the alternating current, only about a millivolt direct pressure would have been required; its resistance to direct current is only about 1 ohm. This direct current resistance can be measured with a Post Office box even while the alternating current is passing through the coil; the galvanometer is not affected by an alternating current. Such an experiment, however, is not really practical. In the first place the high frequency voltage across the coil is considerable and the Post Office box would not stand this voltage being applied to it and, secondly, the connection of the box would modify the value of the current through the coil. The first objection may be met by the insertion of properly designed choking coils in the connections to the bridge; that, however, would add a considerable amount of undesirable resistance. It is clear that if satisfactory working is to be obtained the bridge must be connected to two points at the same, or practically the same, potential. In order to reduce capacity effects, these points should be at earth potential. Both of these conditions can, in general, be fulfilled.

We will assume for the present that two identical test coils are available. They are placed at some distance from one another, so that one coil cannot affect the current distribution in the other and they are connected as shown in Fig. 13. AB is a low resistance wire, CF and DF two equal high resistance wires having a negligible temperature coefficient, of sufficient section to carry the test current through one of the coils. (No. 22 S.W.G. Eureka wires, 3 metres long, were found satisfactory for the original test and adjustment coils.) If the high frequency current be passed between F and E it divides equally between the two branches, and points C and D are at the same potential and only a few volts, at the most, from earth. The Post Office box is connected between these two points. If R be the resistance of one of the coils and W the resistance of one of the wires, the measured resistance R' is $2RW/(R+W)$. If R increases by a small amount dR the change dR' in R' is given by

$$dR' = 2\left(\frac{W}{R+W}\right)^2 \cdot dR \qquad \dots \quad (18)$$

That is to say, so long as the change in R is small the change in R' is proportional to it. It is quite unnecessary for dR to exceed 1 per cent. of R and in this case the above expression is sufficiently accurate. It can be corrected if greater accuracy is required. Since the measurements are always relative, the constant can be neglected. The unit of temperature may be taken as that which causes a change of R' of, say, $1/n$ per cent.

The initial rate of rise of temperature method is still employed.

The arrangement was tested for two similar coils having a resistance of about 2 ohms each and consisting of 87 turns of No. 24 S.W.G. copper. Suitable Eureka wires were used and the resistance measured by the Post Office box between C and D was 3.83 ohms. (The plugs out were: ratio 1,000 and 10; resistance 383.) The balance was then disturbed by setting the bridge to 3.84 ohms, deflecting the galvanometer spot (a shunt was employed). The transmitting key was depressed and at the same instant the stop watch was started. The galvanometer spot immediately began to approach the zero; when it was sufficiently near, the shunt was removed and the exact instant of balance recorded by stopping the first hand of the watch. The shunt was replaced, the balance disturbed by setting the bridge to 3.85 ohms and the instant of balance recorded as before with the second hand of the watch.

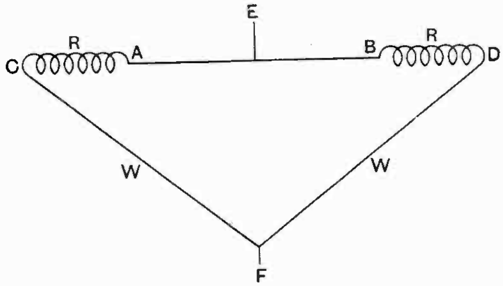


Fig. 13. *Circuit for second calorimetric method of determining high frequency resistance.*

Repeating with a low frequency current the ratio of high to low frequency resistance was determined.

Conclusion.

Time has not permitted the writer to pursue the experiments outlined in this article to the extent he would have wished. Sufficient has, however, been accomplished to show the practicability of the methods employed and to obtain certain results of value. It should be clearly recognised that the measurements made are of true loss in the copper conductor itself. The time of experiment was usually so short that there was no sensible exchange of heat between the conductor and its surroundings. It would be interesting to compare the results of such experiments with measurements of the effective resistance of coils determined, say, by the decrement which they introduce in an oscillating circuit. Measurements of the latter type would include incidental loss in the surroundings. The comparison should afford information of value in improvement in design, which must necessarily be hampered if the distribution of such losses as occur is unknown.

A Constant Frequency Source and its Frequency Measurement.

By S. W. C. Pack, Wh.Sch., A.C.G.I., B.Sc., D.I.C.

THE necessity for a reliable frequency standard for making accurate radio measurements in the laboratory is well known. Some measurements were recently made on the frequency drift of valve oscillators when variations took place in the circuit constants and other conditions, the L,C, values in the oscillatory circuit remaining the same. In this case it was essential to have a constant frequency source, the frequency of which could be relied on to within a few parts in a 100,000. A valve-maintained tuning fork at once presents itself to our minds, and it is proposed to describe in some detail the experimental arrangements of such a fork together with the difficulties encountered in successfully maintaining it, and the arrangement for the accurate determination of the frequency of the maintained fork. The experiments were carried out in the Radio Laboratories of the City and Guilds Engineering College under the supervision of Professor C. L. Fortescue, M.A., and Professor E. Mallett, D.Sc.

I. The Valve-Maintained Fork.

The question as to the suitability of a valve-maintained fork as a constant frequency source has been investigated by D. W. Dye* and also by H. Dadourian,† pretty thoroughly. Dye maintained a fork of 1,000 cycles in the manner first suggested by Eccles‡ but with slight modification.

The principle of maintenance is as follows: Two permanent magnets, each wound with a suitable number of turns, are placed one attracting each prong of a tuning fork the coils being connected into the anode and grid circuits of a thermionic valve as shown in Fig. 1. Now imagine the fork set in vibration. Suppose the prongs of the fork are on their outward traverse; then an E.M.F. will be induced in the grid coil and will be applied to the grid of the valve. This will vary the anode current, or in other words will produce a change of ampere-turns on the anode magnet. If the coil is connected up in the correct direction the anode magnet will be made to attract its prong and so assist in the outward traverse of the prongs. The same process occurs when the prongs are on the inward traverse the

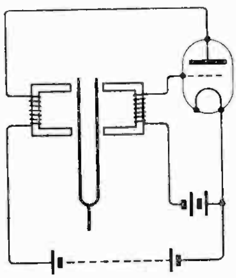


Fig. 1. *Simple circuit of valve-maintained tuning fork.*

anode magnet assisting its prong inwards, as the conditions are now reversed. Assuming therefore that we allow suitable constants in the circuit the fork will be maintained. One of the first difficulties that presents itself is the fact that we may not be able to get sufficient turns on the magnets; it is then necessary to adopt step-up transformers to be connected to each magnet coil and in this way we can match impedances very much better. The motional impedance of the fork is matched with the low impedance side of the transformer, and the high impedance side of the transformer is matched with the internal resistance of the valve. The arrangement for the transformers is indicated in Fig. 2.

The mathematical theory for the valve-maintained tuning fork has been dealt with very fully by Butterworth* and Hodgkinson†; a simple treatment as developed by Dr. Mallett is given later on in this article.

* *Proc. Roy. Soc. A.*, Vol. 103, p. 204, 1923.
† *Phys. Review*, Vol. 13, pp. 337-359.
‡ *Phys. Soc. Proc.*, Vol. 31, pp. 269.

* *Phys. Soc. Proc.*, Vol. 32, pp. 345-360, 1920.
† *Ibid.*, Vol. 38, pp. 24, 1924.

II. Constancy of the Valve-Maintained Fork.

Experiments were made by Dye and Dadourian on the valve-maintained fork to investigate the constancy of frequency under various conditions. Their results serve to show that the fork is really quite suitable as a frequency standard. The chief factor in causing variation is temperature and it is advisable to keep the mounted fork in a constant temperature cell. Dye found that the frequency decreased by 1.15 parts in 10,000 for an increase in temperature of 1° C. A 1,000-cycle fork was used in that

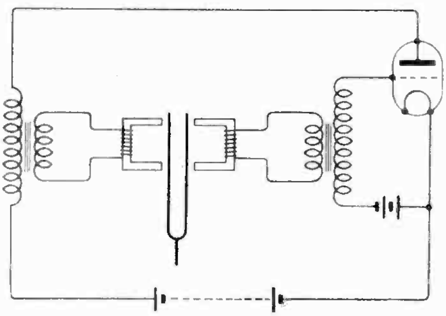


Fig. 2. *Circuit of valve-maintaining tuning fork using transformers.*

case. Other variations only made small alterations in the frequency. The anode and filament voltages could be suitably arranged so that a 10 per cent. change in either direction of the anode current or anode voltage caused less than 1 part in 1,000,000 change in frequency. Changing the valve produced a variation of only 1 part in 100,000. The flux density should be kept fairly constant as it was found that a change of only 1 per cent. gap flux for a B. 2,200, caused a frequency change of 6.5 parts in 1,000,000. The frequency of the fork also depends upon the power output from the system, and the method of taking the power varies to some extent the frequency variation. This matter of power output will be referred to later.

Dr. Mallet* has shown that there is considerable distortion in the resonance curve for an electrically driven fork at large amplitudes, so it is essential that the amplitude of the maintained fork should be kept moderately small in order to keep the frequency constant.

* *Phys. Soc. Proc.*, May, 1927.

III. The Selection and Mounting of Fork.

The most suitable frequency for the fork for use in comparing valve oscillator frequencies of a range varying from, say, a few hundred cycles upwards to the radio frequencies, was found to be 128 cycles. Maintaining a fork of such low frequency however is a matter which calls for careful design of the operating valve circuit, mainly because the induced E.M.F. at this frequency is so small. In addition the decay factor of low frequency forks is often just as high as in the case of the high frequency forks, though the fork used in the present case had quite a small damping when free. The dimensions of this 128-cycle fork were: $0.8 \times 0.47 \times 17$ cms., the distance between the prongs being 1.42 cms. For use as driving magnets some old phones were stripped and mounted on wooden blocks so as to bring the pole pieces to operate on the prongs of the fork, one to each prong. The method of mounting is illustrated in the photographs in Fig. 3. The picture also shows the bottom half of the constant temperature cell. This consisted of a cardboard box and lid made as airtight as possible and padded with cotton waste. A disused quarter plate was cleaned and inserted in one end so that a window was formed through which a thermometer inside the cell could be viewed. Leads were taken from the driving magnets to four terminals at the end on the outside of the box. The box with the fork inside was put inside a small cubicle which was in the laboratory and quite near to the bench supporting the other apparatus for the maintenance of the fork. The door of this cubicle could be kept shut and the temperature of the fork thus kept constant to within about .5°F. in normal weather. Leads were taken from the cell through holes in the cubicle walls to the transformers and apparatus on the bench. The position of mounting the driving magnets can be seen in the photograph. The phones with the terminals on top are the 120-ohm ones which were finally adopted as driving magnets, some smaller ones of 4,000 ohms were used but were not suitable for reasons explained later. Using a D.E.R. Marconi valve with either type of magnets and trying various values of grid bias and anode voltage the fork was not maintained nor did there seem to be any tendency towards maintenance.

The probability is that there were not enough turns on the low resistance magnets and not sufficient flux in the case of the high resistance magnets.

The phones had first been temporarily mounted near the extremities of the prongs the speed of a point near the extremity. If we take the phones right to the base of the prong the damping due to the magnets is then zero but there will be no attraction of the prongs. Hence there will be a compromise between the two factors of damping

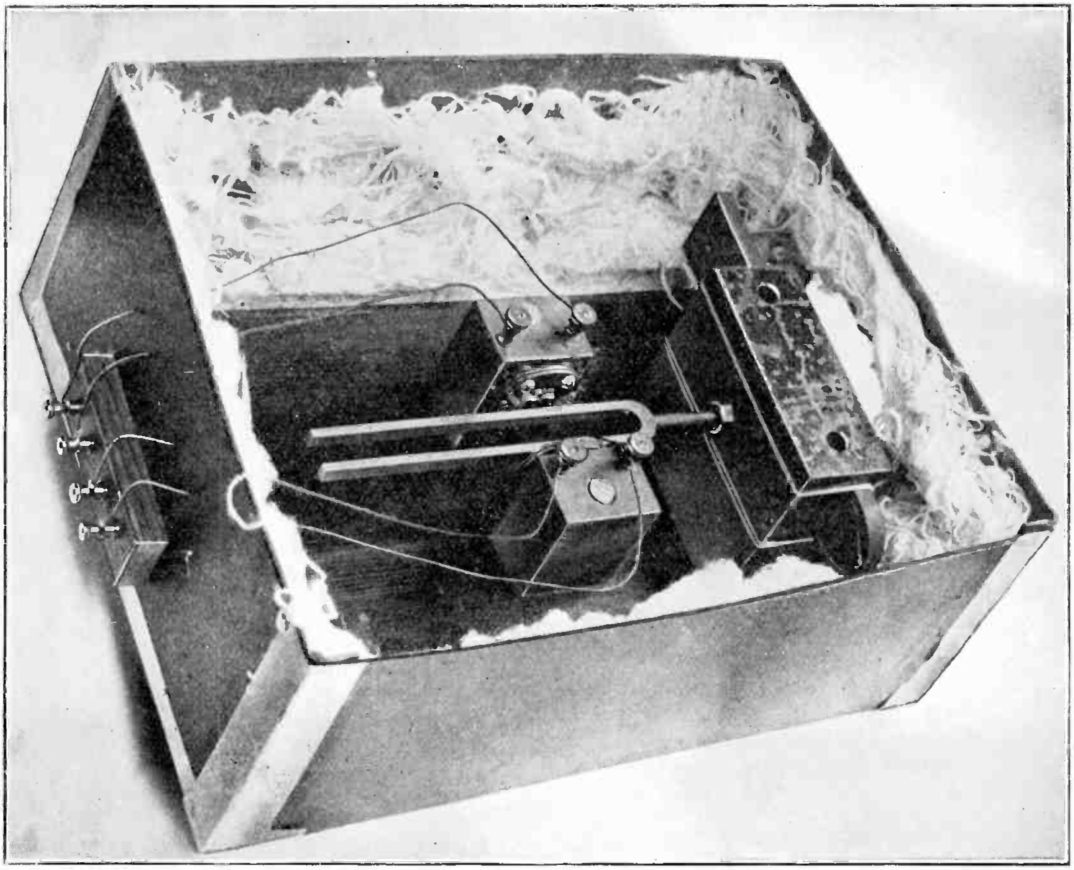


Fig. 3. *Mounted tuning fork and driving magnets enclosed in one-half of padded cell.*

but tests were now made to see the effect of moving the phones along the prongs. The effect was at once noticeable and by listening to some headphones inserted in the valve anode circuit one could adjust the position of the magnets to give the most satisfactory conditions. The reason for the improvement is due to the reduction in the damping of the vibrations, the nearer the phones are to the base of the fork. This is because the speed of a point of the fork near the prong base is relatively lower than and attraction. By experimenting the best position for the phones was found to be about two-thirds of the way along the prong towards the base and they were then permanently fixed in this position. There now seemed to be more of a tendency to maintain.

Various other valves were tried but without any improvement except for a Mullard P.M.1 H.F. which reduced the damping factor though not actually maintaining the fork. This may have been accounted for by the fact that the ratio μ/R_0 is high and this is important as may be seen in the following theory:—

IV. Theory of Maintained Fork.

The following simple treatment of the valve-maintained tuning fork has been suggested by Dr. Mallett and enlarged upon by the author, and enables us to obtain an idea of the limitations imposed in maintaining the fork.

The equivalent electrical circuit for the ordinary case is given in Fig. 4(*a*) and for the transformer case in Fig. 4(*b*).

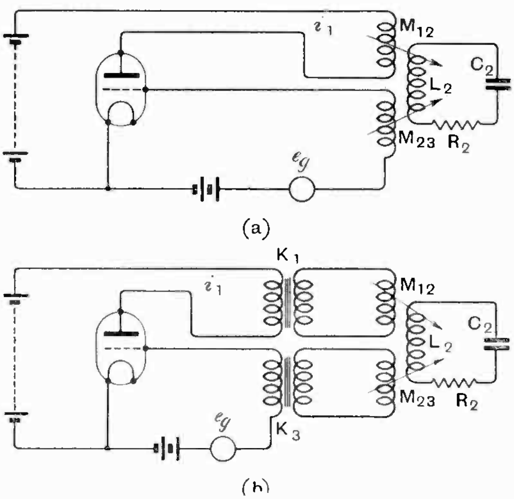


Fig. 4. *Equivalent electrical circuit of valve-maintained tuning fork,* (a) *without transformers,* (b) *with transformers.*

We will work out the transformer case as this applies to the ordinary case as well when the transformer ratios are put equal to unity.

Imagine an E.M.F. of value e_g injected into the grid circuit to maintain oscillations.

$\omega = 2\pi f$, where $f =$ frequency.
$v_g =$ E.M.F. applied to grid.
$i_2 =$ imaginary current in the tuning fork equivalent circuit.
$Z_2 =$ impedance of this equivalent circuit $= R_2 + jX2$.
$i_1 =$ anode current.
$Z_1 =$ impedance of anode coil $= R_1 + j\omega L_1$.
$R_0 =$ internal resistance of valve.
$\mu =$ amplification factor of valve.
$M_{12} =$ imaginary mutual between anode-coupled driving coil and tuning fork.
$M_{23} =$ imaginary mutual between grid-coupled driving coil and tuning fork.
$K_1 =$ transformation ratio of anode transformer.
$K_3 =$ transformation ratio of grid transformer.

Now $v_g = e_g + j\omega M_{23}.i_2.K_3$

and $i_2 = \dfrac{j\omega M_{12} i_1 K_1}{Z_2}$

$$\text{but } i_1 = \frac{\mu.v_g}{R_0 + Z_1 + \dfrac{\omega^2 M_{12}{}^2.}{Z_2} K_1{}^2}$$

$$= \frac{\mu\left(e_g - \dfrac{\omega^2.M_{12}.M_{23}.K_1.K_3.i_1}{Z_2}\right)}{R_0 + Z_1 + \dfrac{\omega^2 M_{12}{}^2 K_1{}^2}{Z_2}}$$

$$\therefore\ i_1\left(R_0 + Z_1 + \frac{\omega^2 M_{12}{}^2.K_1{}^2}{Z_2}\right) + i_1\left(\frac{\mu.\omega^2.M_{12}.M_{23}.K_1.K_3.}{Z_2}\right) = \mu.e_g$$

Now the condition for self maintenance is that $e_g = 0$.

Hence our condition is that

$$(R_0 + Z_1)Z_2 + K_1{}^2.\omega^2.M_{12}{}^2 + \mu.\omega^2.M_{12}.M_{23}.K_1.K_3 = 0 \quad \ldots \quad (1)$$

By equating the unreals we can determine the frequency of oscillation.

$$R_2.j\omega L_1 + (R_0 + R_1).j.X_2 = 0$$

We notice that this does not involve K_1 or K_3, hence the frequency is unaltered by inserting transformers.

$$X_2 = -\frac{R_2 . \omega L_1}{R_0 + R_1}$$

i.e.,
$$\left(\omega L_2 - \frac{1}{\omega C_2}\right) = -\frac{\omega R_2 L_1}{R_0 + R_1}$$

$$\omega^2\left(L_2 + \frac{R_2.L_1}{R_0 + R_1}\right) = \frac{1}{C_2}$$

Hence
$$\omega = \frac{1}{\sqrt{L_2 C_2\left(1 + \dfrac{R_2}{R_0 + R_1} \cdot \dfrac{L_1}{L_2}\right)}} \quad (2)$$

We must remember that R_2, L_2, and C_2 are all imaginary constants of the equivalent electrical circuit. Now from the equation for frequency derived as above and given in equation (2) we see that the correction term

$$\frac{R_2}{R_0 + R_1} \cdot \frac{L_1}{L_2}$$

is small and hence we may say approximately

$$\omega L_2 = \frac{1}{\omega C_2}$$

i.e., $X_2 = 0$

Thus simplifying the work and obtaining the following equation :—

$$(R_0 + R_1) R + \omega^2.M_{12}^2.K_1^2 + \mu.\omega^2.M_{12}.M_{23}K_1.K_3 = 0 \quad (3)$$

From this we get the all important fact that M_{12} and M_{23} must be opposite in sign. Hence the fork will only be maintained if the coils are connected up in the correct direction relatively to one another.

If the driving coils and magnets are similar to one another $M_{12} = M_{23} = M$ (numerically).

R_1 is small compared to R_0

Hence approximately

$$\omega^2.M^2.K_1(\mu.K_3 - K_1) = R_0R_2 \quad \ldots \quad (4)$$

From the point of view of maintaining the fork we want the critical value of ωM as small as possible.

$$\omega^2M^2 = \frac{R_0R_2}{K_1(\mu K_3 - K_1)} \quad \ldots \quad (5)$$

and should be as small as possible.

Mechanical Consideration.

We can work out the theory in much the same way from a consideration of the force factors at the prongs of the fork (the force per unit of current in the driving coils) and the mechanical impedance of the prongs.

The mechanical impedance of a prong is merely its opposition to motion when operated upon by a vibromotive force. The opposition consists of mechanical resistance and mechanical reactance. The mechanical resistance is composed of acoustic and frictional resistance which we may take as being proportional to the speed; hence it will be expressed in dynes per cm. per sec. or absolute ohms (*i.e.*, 10^{-9} ohms). The mechanical reactance is composed of the inertia and stiffness of the prong and will be expressed in the same units. Hence the mechanical impedance which is the vector sum of the mechanical resistance and reactance will be expressed in the same units.

If r = mechanical resist. in dynes/cm./sec.
m = equivalent mass of prong (referred to later) in grms. (or dynes/cm./sec²).
s = stiffness in dynes/cm.

Then Mechanical Impedance

$$= r + j(\omega m - s/\omega) \text{ dynes/cm./sec.}$$

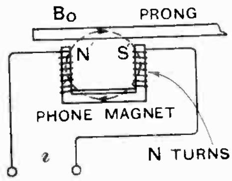


Fig. 5. *To illustrate mechanical consideration.*

Let B_0 = flux density due to permanent magnet (lines/cm²).
b = flux density due to current through coils.
N = total number of turns on poles.
$\mathcal{R}$ = reluctance of flux path (Oersteds).
a = cross sectional area of each pole (cm²).
i = current in coils, (absolute C.G.S. units).

The direction of b depends upon the direction of i. We will, however, consider it positive.

$$\text{Pull on prong} = 2 \times \frac{(B_0 + b)^2}{8\pi} \times a \text{ dynes.}$$

$$= \frac{a}{4\pi}(B^2 + 2B_0b + b^2) \text{ dynes.}$$

$$\text{Fluctuating pull} = \frac{a}{4\pi}(2B_0b + b^2) \text{ dynes.}$$

$$= \frac{a}{4\pi}.2B_0b + \frac{ab^2}{4\pi} \text{ dynes.}$$

Now, if $B_0 >> b$ the term involving b^2 is negligible.

Fluctuating pull due to current i

$$= a.B_0.b/2\pi \text{ dynes.}$$
$$= f_i \text{ (say).}$$

We will neglect fluctuation of $\mathcal{R}$ and assume it to be constant.

Total flux in one gap due to current i

$$= a.b = 4\pi.i.N/\mathcal{R} \text{ (Maxwells).}$$

neglecting the fluctuation of $\mathcal{R}$ with i.

Hence,
$$f_i = \frac{B_0}{2\pi} \times \frac{4\pi.i.N}{\mathcal{R}}$$
$$= \frac{2NB_0}{\mathcal{R}}.i$$
$$f_i = A.i \text{ dynes}$$

where A is the force factor (force per unit current).

Hence, $A = 2B_0N/\mathcal{R}$ for one prong.

We may liken the attracted prong to a mass "*m*" grms. attracted by a magnet and attached to a spring of stiffness "*s*" dynes/cm., there being a mechanical resistance to motion of "*r*" dynes per cm. per sec., the resistance varying with the velocity "*u*" of the mass. (See Fig. 6(*a*).) The electrical analogy is a circuit of inductance *L*, capacity *C*, and resistance *R*, with an applied E.M.F. of *e*. (See Fig. 6(*b*).)

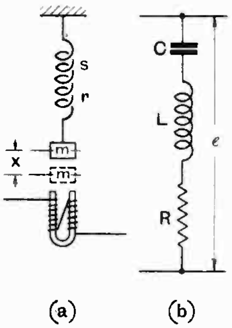


Fig. 6. (a) *Mechanical analogy.* (b) *Electrical analogy.*

In the electrical case the current
$$i = \frac{e}{R + j\left(\omega L - \frac{1}{\omega C}\right)} = \frac{e}{Z}$$

Now r is equivalent to R.
m is equivalent to L.
s is equivalent to $1/C$.

Hence velocity of prong
$$u = \frac{f_i}{r + j\left(\omega m - \frac{s}{\omega}\right)} = \frac{f_i}{z}$$

Where z is the mechanical impedance of prong. If x is the displacement of prong from the mean position, we have
$$\dot{x} = \frac{f_i}{z} = \frac{A.i}{z}$$
$$\dot{x} = \frac{A}{z}.i$$

Generated E.M.F.

The reluctance of the flux path will decrease when prong is displaced by a distance x towards the magnet poles.

i.e., Reluctance is $\left(\mathcal{R} - \frac{2x}{a}\right)$ (Oersteds).

Now, generated E.M.F. is the rate of change of linkages with respect to time.

$$\text{Generated E.M.F.} = N\frac{d\Phi}{dt}$$

where Φ = total flux (Maxwells).
N = total turns.

$$\text{Total flux} = \frac{\text{Magnetomotive force}}{\text{Reluctance}}$$

Hence,
$$\Phi = \frac{M.M.F.}{\mathcal{R} - \frac{2x}{a}}$$

Generated E.M.F.
$$= N\frac{d}{dt}\left[\frac{M.M.F.}{R}\left\{1 + \frac{2x}{\mathcal{R}.a}\right\}\right]$$

since $2x/a$ is small compared with R.

Generated E.M.F.
$$= N\frac{d\left(B_0.a\left\{1 + \frac{2x}{\mathcal{R}a}\right\}\right)}{dt}$$
$$= \frac{N.B_0a.2.\dot{x}}{\mathcal{R}.a}$$
$$= \frac{2B_0N}{\mathcal{R}}.\dot{x}$$

$\therefore$ Generated E.M.F. $= A.\dot{x}$

Motional Impedance.

Now, the effect of the prong vibrating in the magnetic field is equivalent to increasing the impedance of the magnet coil. The increase is referred to as the "motional impedance."

If the normal impedance of a magnet coil with current i is Z_1 then total E.M.F. across winding

$$= Z.i + A.\dot{x}$$
$$= Z.i + \frac{A^2.i}{z}$$
$$= \left(Z + \frac{A^2}{z}\right).i$$

Hence, motional impedance $= A^2/z$.

Now, returning to the complete circuit of the valve-maintained tuning fork and treating it in a somewhat similar manner as previously, we have :—

If

A_1 is the force factor of the anode-coupled prong,

A_3 is the force factor of the grid-coupled prong.

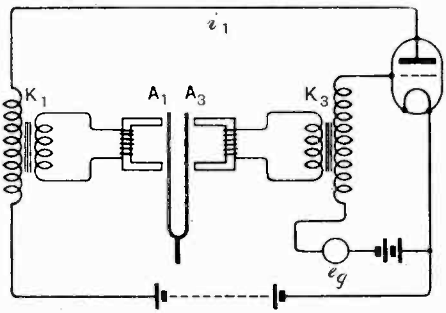


Fig. 7. *To illustrate mechanical consideration of valve-maintained tuning fork theory. False factors* A_1 *and* A_3.

Now

$$v_g = e_g + K_3 \times (A_3\dot{x})$$
$$= e_g + K_3 \times \left\{A_3 . \left(\frac{A_1.i_1}{z} . K_1\right)\right\}$$
$$= e_g + \frac{K_1K_3A_1A_3\,i_1}{z}$$

and $$i_1 = \frac{\mu v_g}{R_0+Z_1+K_1^2\left(\frac{A_1^2}{z}\right)}$$

$$i_1 = \frac{\mu\left(e_g + \frac{K_1K_3A_1A_3\,i_1}{z}\right)}{R_0 + Z_1 + K_1^2\left(\frac{A_1^2}{z}\right)}.$$

$$\therefore\ i_1\left(R_0+Z_1+\frac{K_1^2A_1^2}{z}\right) - i_1\left(\mu . \frac{K_1K_3A_1A_3}{z}\right) = \mu e_g$$

Now, the condition for self maintenance is that $e_g = 0$.

Hence our condition is that :—

$$(R_0+Z_1)z + K_1^2A_1^2 - \mu.K_1K_3A_1A_3 = 0 \qquad (6)$$

A_1, A_2, and z are complex quantities but if $A_1 = A_2 = A$ (say) as in the present practical case, that is the force factor at each prong in the same, we may say approximately that the numerical relationship is :—

$$A^2 = \frac{R_0.r}{K_1(\mu K_3 - K_1)} \qquad \ldots \quad (7)$$

by neglecting Z_1 which is small compared to R_0.

r may be defined as the mechanical impedance at resonance.

Equations (6) and (7) are analogous to equations (3) and (5) respectively.

From equation (7) we now know the limiting value of force factor A necessary to maintain the fork. Our actual A is given by substituting the values of the constants in

$$A = \frac{2B_0N}{\mathcal{R}}$$

We must then make B_0 and N sufficiently large and $\mathcal{R}$ sufficiently low to get a high enough value of A to satisfy the limiting condition.

For easy maintenance of course we want the critical value

$$\frac{R_0r}{K_1(\mu K_3 - K_1)}$$

to be as small as possible.

Now r is a constant and with a given valve μ, R_0 are constants. Hence $K_1(\mu K_3 - K_1)$ should be a maximum, K_1 and K_3 being two independent variables. The condition for this is :—

$$K_1 = \frac{\mu K_3}{2}$$

which gives us the best relations between the values K_1 and K_3.

V. Calculation on the Fork Constants.

Lord Rayleigh* has shown that the "equivalent mass" of a prong of a tuning fork may be taken as approximately equal to

* *Theory of Sound.* By Lord Rayleigh. Vol. I., p. 235.

one-quarter the total mass of the prong. The constants of a fork are analogous to those of a telephone diaphragm which have been dealt with by Kennelly.*

Hence equivalent mass " m "

$$= \tfrac{1}{4} \times (0.8 \times 0.47 \times 17) \times 7.8 \text{ grms.}$$

since the density of mild steel is 7.8 grms/c.c.

$$m = 12.5 \text{ grms.}$$

stiffness " s " $= m.\omega_0^2$

$$= 12.5 \times 128^2 \times 4\pi^2$$

$$s = 6.315 \times 10^6 \text{ dynes/cm.}$$

The amplitude of the fork was found to decrease to half of its initial value in about 6 secs.

If " Δ " is the decay factor

$$\therefore \quad \varepsilon^{-\Delta.6} = 0.5$$

$$\Delta = 0.115 \left[= \frac{r}{2m} \right]$$

Mechanical Impedance at Resonance " r."

$$r = \Delta \,.\, 2m$$

$$= 0.115 \times 25$$

$$r = 2.88 \text{ dynes/cm./sec.}$$

Minimum value of A necessary to maintain fork

$$= \sqrt{\frac{R_0 r}{K_1(\mu K_3 - K_1)}}$$

Without transformers

$$A = \sqrt{\frac{R_0 r}{\mu - 1}}$$

For a D.E.R. take $\begin{cases} \mu = 9 \\ R_0 = 32{,}000 \text{ ohms.} \end{cases}$

$$= 32{,}000 \times 10^9 \text{ abohms}$$

$$\text{minimum } A = \sqrt{\frac{32{,}000 \times 10^9 \times 2.88}{8}}$$

$$= 3.392 \times 10^6 \text{ dynes/abamp.}$$

Having found the minimum value of A necessary to maintain fork, if we know the flux density B_0 and the reluctance $\mathcal{R}$ of the flux path in each prong we can determine the number of turns which are necessary on the driving magnets.

The reluctance of the flux path is mainly composed of that of the two air gaps between the prong and the poles. Each air gap is 0.15 mm. long and the area of cross section of the pole pieces is 1×0.15 cm².

$$\text{Hence} \quad \mathcal{R} = \frac{2 \times 0.15}{1 \times 0.15} = 2 \text{ (Oersteds).}$$

Roughly the flux density of the air gap was found to be 600 lines/cm². Hence substituting in the equation

$$A = \frac{2B_0N}{\mathcal{R}}$$

we find that the number of turns necessary is

$$N = \frac{3.392 \times 10^6 \times 2}{2 \times 600} = 5{,}650 \text{ turns.}$$

The number of turns on the driving magnets used was about 1,000, which is well below the estimated need for 5 650 turns. It is obviously necessary therefore to use transformers. Some high resistance phones were tried as driving magnets, having a larger number of turns, but in this case the flux seemed very weak and owing to the small and flimsy construction of the magnets the reluctance was probably very high. The number of turns on these high resistance phones was not sufficiently high, apparently, to make up for the low flux and high reluctance, for the fork was not maintained when using them without transformers. With transformers the impedances did not match up suitably and fork was only weakly maintained. The low resistance phones were therefore adopted and various types of transformers which were available were tried.

From the theory we see also that it is best to use a valve with high " μ " relative to the " R_0 ". The effect of doing this will not be quite so advantageous as we might at first expect owing to the effect of the root sign in the term

$$\sqrt{\frac{R_0 r}{K_1(\mu K_3 - K_1)}}$$

Similarly when transformers are used the tendency for the K values to decrease the limiting value of " A " is minimised by the presence of the root sign. Again in using transformers we are introducing extra copper and iron losses, so that it is not just sufficient to introduce any transformers but we must also be careful in our selection.

After numerous trials with various types

* *Electrical Vibration Instruments.* By A. E. Kennelly. Chapters IV. to X.

the tuning fork was strongly maintained by using two fairly large transformers which may be seen in the photograph in Fig. 8. The one in the anode circuit is provided with a number of tappings. The best relation between the transformer ratios as found in the theory is $K_1 = \mu K_3/2$, but owing to

With small transformers there will be a risk of saturation and the permeability will drop to a low value. As there was not a big selection of large transformers available the relation $K_1 = \mu K_3/2$ could not be held to.

However, the fork was maintained quite

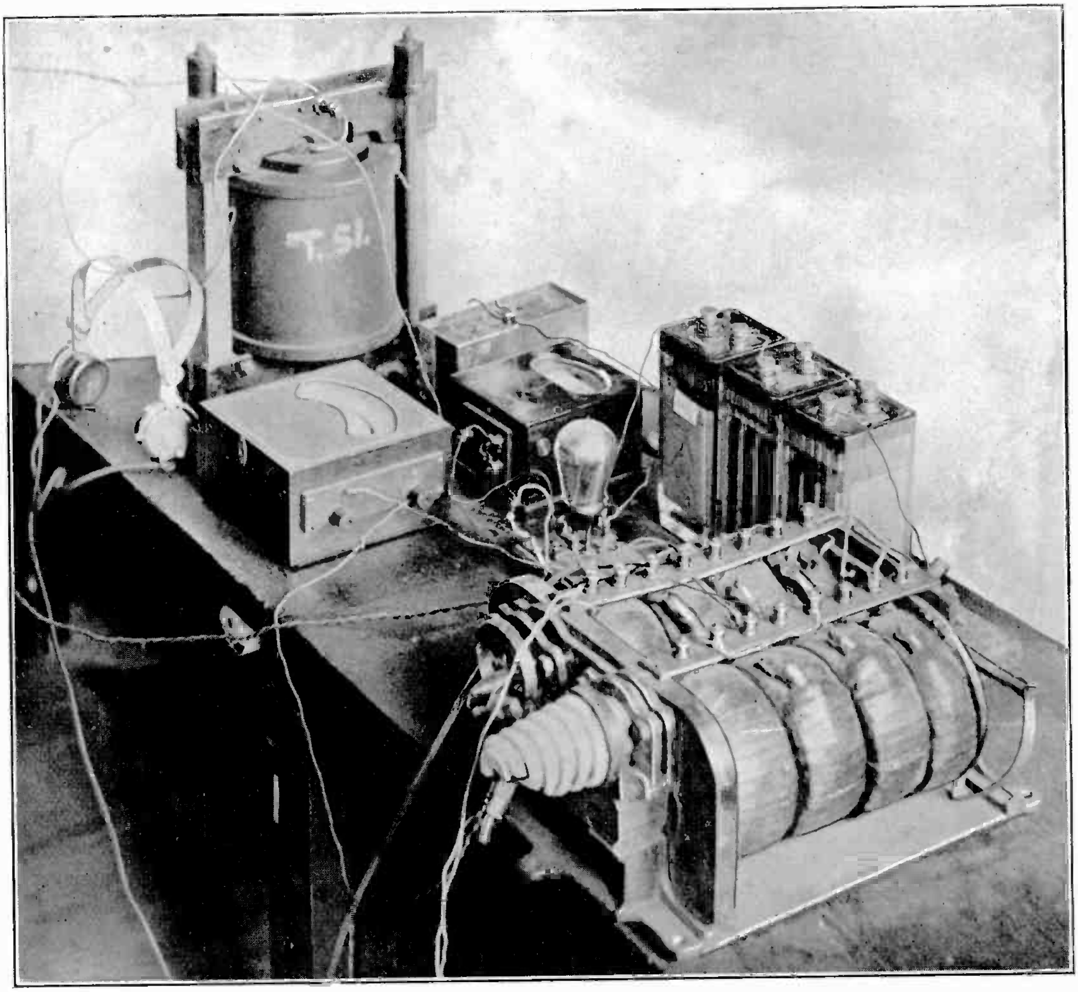


Fig. 8. *Transformers and apparatus for maintaining tuning fork.*

practical difficulties this relation could not be attained. It was found necessary to use rather massive transformers to reduce the power loss which would otherwise take place in a small transformer. This is because the frequency, 128 cycles, is fairly low, and to produce the necessary voltage we must have a suitable flux density.

strongly enough with the transformers shown in the photograph in Fig. 8, and if the relation between the K's had been held to strictly, the amplitude of vibration would have been so large as to lead to frequency distortion as mentioned previously. Actually the grid transformer ratio was about 70 to 1 and the tappings on the anode transformer were arranged to give the highest ratio, viz., 14 to 1.

With this arrangement and using a D.E.5B. Marconi valve having relatively small value of the ratio R_0/μ, the increase of anode current when fork was maintained was from 0.7mA to 2.7mA with 180 volts on the anode and a grid bias of 6 volts. The value of grid bias was found to be quite critical. At zero bias the fork would not maintain at all.

VI. Determination of Frequency of Maintained Vibrations.

The fork now maintaining well, the question arises as to how best to determine its frequency.

It was proposed to synchronise a small phonic motor with the fork, taking power from the fork circuit through a two-stage amplifier. For efficiency in supply of power our design must be such as to match the impedance of the motor with the last stage of the amplifier. After careful design the motor was wound to have as high an impedance as was practically possible, this amounting to about 2,500 ohms at 128 cycles. To match this the last stage consisted of two Western Electric 216A valves in parallel. The output from the fork circuit was taken direct across the transformer winding which is in the anode circuit of the maintaining valve. The diagram of connections is given in Fig. 9.

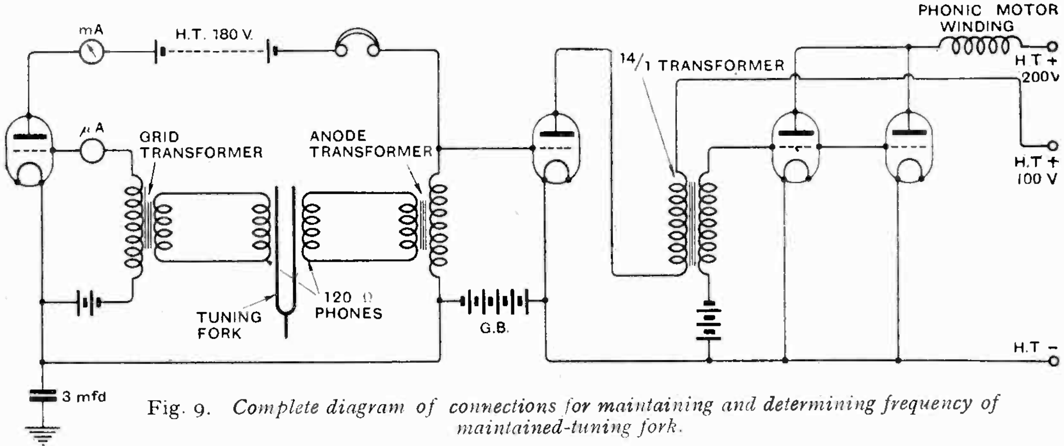


Fig. 9. *Complete diagram of connections for maintaining and determining frequency of maintained-tuning fork.*

The first stage of amplification was performed by a Cossor "Stentor 6" super power valve the input to the valve being taken across the transformer winding in the anode circuit of the valve maintaining the fork. It was essential to eliminate grid current as far as possible so that the conditions in the fork circuit were not changed.

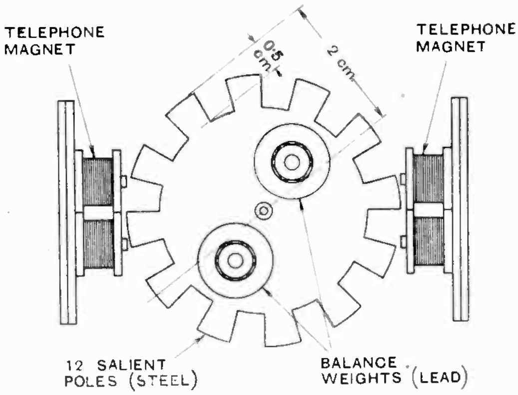


Fig. 10. *Diagram of synchronous motor.*

After various trials to synchronise the motor with the fork, all of which were unsuccessful, it was decided that in all probability the amplifiers were unable to supply a large enough voltage to run the motor at this frequency of 128 cycles. Tests were made on the motor using a variable A.C. supply and it was found that 150 volts A.C. output would be required to run the motor at the 128-cycle frequency. A very much smaller motor was, therefore, tried and this was found to pull into step with a 25-volt 128-cycles A.C. supply. This was evidently more suitable and was finally adopted. A view of the motor is given in Fig. 11, which also shows the starting gear and counting train. The motor consisted of a balanced wheel of mild steel with 12 salient-poles on a long steel spindle which we will call " *a* ". located below the counting train. The D.C. motor, also shown in the picture, is a 6-volt starting motor with a series winding, and a series resistance seen on the left of the box for speed control. This motor drives

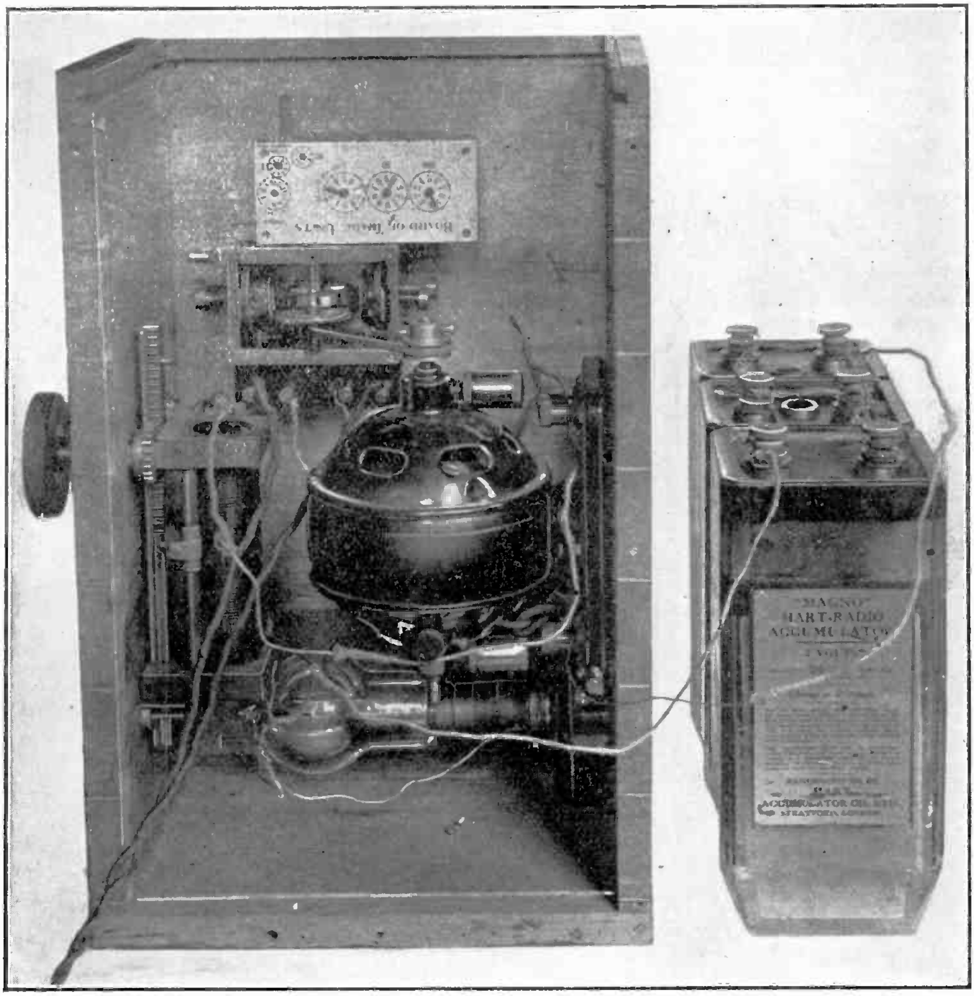


Fig. 11. *View of phonic motor, starting gear and counting train.*

Two old telephones were used as driving coils, being connected in series in the correct direction and being situated so that there was a very small air gap between the poles of the motor and the phone magnets (see Fig. 10).

In the photograph in Fig. 11 the poles of the motor can be seen just above the cog wheel within the brass rectangle which is directly by a belt on the spindle " *b* " with the large cog, seen in the brass rectangle. The top bar of the rectangle is a lever pivoted about its right end, which presses the spindle " *b* " downwards against a spring and engages the cog on spindle " *b* " with a cog on spindle " *a* ". The latter cog has a free wheel so that the phonic motor can pull into step even though the starting motor has exceeded the synchronising speed. This freewheel was not found to be successful, however, and it is a feature with these motors that the speed has to be adjusted very carefully before they will pull into step ; speeding the motor up and allowing to slow down through synchronous speed is not very effective. When synchronised the releasing of the pivoted lever disengages the cogs and the starting motor can be stopped leaving the phonic motor running in synchronism with the maintained fork. At the top of the long spindle "*a*" on the phonic motor is a small cog which engages with a counting train and the dials are thus made to record to a known reduced scale the number of vibrations of the fork. At the bottom of the box is a Neon lamp which, if connected to the phonic motor supply, indicates by a stroboscopic effect when the wheel is running synchronously. The wheel is looked at from above the box and the glow of the Neon lamp is visible below it through the poles of the wheel ; at synchronism the wheel appears to be stationary against the glow of the lamp. As the power supply was so limited in the present case the Neon lamp was disconnected and the wheel synchronised by trial.

This type of phonic motor was found to be quite suitable for its purpose of determining the frequency of the maintained fork. With practice synchronising the motor became an easy task. The motor was run for a considerable period of time extending over a number of hours and measured accurately by a chronometer, and the dials of the counting train recorded a number which when divided by a factor :—

$$[15 \times \text{Period of Trial (Hours)}]$$

gave the accurate frequency of the maintained fork.

Thus not only have we a constant frequency source but in addition we know the actual value of this frequency to many places of decimals and we are now ready for any experiment which calls for comparison of one unknown frequency with that of a standard known source. If the harmonics of this known frequency are amplified by some device, such as a multivibrator, we have a comparison standard of a range extending from the audio frequencies up to radio frequencies.

The Performance of Reflexed Valves.

By D. Kingsbury.

WHEN recently testing the relative performance of two audio-frequency intervalve transformers in a reflex receiver, the writer noticed certain peculiarities in the results obtained which called for further investigation. The conclusions reached are, to the best of his knowledge, novel and are therefore offered in the hope that they may be interesting to others.

The circuit of the receiver, a " one-valver," is shown in Fig. 1, from which it will be noted that R.F. step-up transformers with tuned secondaries are used in both the grid and anode circuits of the valve. A third winding, having the same number of turns as the primary, has been placed between the primary and secondary of the anode transformer and is arranged to perform three functions simultaneously :—

1. To provide R.F. stabilising E.M.F. ;
2. To balance out the A.F. component of the valve output within the transformer; and
3. To provide an earth screen between primary and secondary to A.F. voltages.

The object of functions (2) and (3) is to prevent the transfer of A.F. energy to the detector circuit and is attained with the connections shown. The remainder of the circuit represents standard practice.

The set was adjusted to absolute stability before the commencement of operations. By absolute stability is meant that, without the use of magnetic reaction, produced by moving the second R.F. transformer away from the normal 55 degrees from the horizontal, it is not possible to produce oscillation even with the aerial disconnected and the contact wire removed from the crystal. Further, with the aerial connected but with the crystal disconnected, it is not possible to hear the local station although the same is more than pleasantly loud on a horn type loud-speaker when the crystal is restored to service. The subject of stability in reflex receivers has been dealt with by the author elsewhere* and it will suffice to say in passing that unless a high degree of stability is obtained such investigations as those about to be described, where A.F. transformers are changed and their connections reversed indiscriminately without sensible alteration to the R.F. portion of the circuit, are practically impossible.

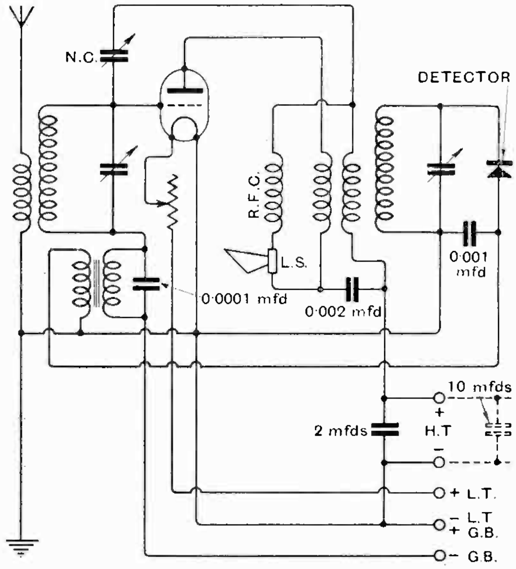


Fig. 1.

The two transformers under test were an R.I. 4 : 1 and a Marconi Ideal 6 : 1 which differ widely in construction and tonal characteristics. Two valves were used in turn, a Burndept L525 and a Marconi Osram D.E.5, the former having a somewhat lower impedance, lower self-capacity and longer " straight " than the latter. The anode volts in both cases ranged from 130-200 and the grid bias from $-4\frac{1}{2}$ to $-13\frac{1}{2}$ in steps of $1\frac{1}{2}$ volts. Two different loud-speakers, one horn type and the other diaphragm type, were also employed.

The foregoing details have been given to dispel at the outset any suggestion that the following reasoning is based on the peculiarities of one particular piece of apparatus. Substitution made no essential difference to the effects observed.

In the first place it was noticed that with

* " Reflex Receivers," *Wireless World*, p. 21, 7th July, 1926.

either transformer a rough and slightly deeper tone was obtained with one set of connections than with another.

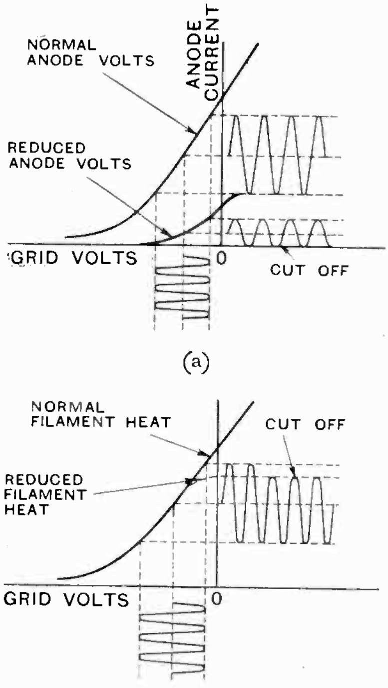
The arrangement of connections will be called "straight" and "crossed" for easy reference. In the case of the R.I. "straight" indicates I.P. to earth, O.P. to crystal contact wire, I.S. to grid and O.S. to bias battery, while with the Marconi "straight" indicates I.P. to earth, O.P. to crystal contact wire, O.S. to grid and I.S. to bias battery. The crossing of *either* primary *or* secondary corresponds to the arrangement called "crossed." (The crossing of both primary and secondary retains the original "straight" arrangement and effect.)

The "straight" connections gave the rough results; the Marconi being the louder, gave very rough results. This seemed to indicate valve distortion, but it was not possible to cure the trouble within the safe limits of voltage for the valves in use. It was noticed that if the filament current was decreased slowly, tone steadily improved up to a point at which signals were fast disappearing. Further, on switching off the rectifier which supplies the anode current from A.C. mains and which has about $12\mu F$ shunted across its output terminals a howl similar in pitch to the parasitic roughness was heard from the loud-speaker as the voltage collapsed.

The "crossed" connections gave smooth and eminently satisfactory results on both transformers, but it was noticed that the roughness and howl mentioned above now appeared as the filament was slowly dimmed and that when switching off the rectifier the music died a natural death.

The effects on the output of the valve of reducing anode volts and reducing filament current can perhaps best be appreciated by examining the typical valve characteristic curves shown in Fig. 2. Fig. 2(a) indicates that the negative half cycles suffer first if the anode voltage be gradually reduced and from Fig. 2B we see that the reverse is the case if the filament be dimmed.

Now the essential difference between the "straight" and "crossed" connections is the reversal of polarity of the A.F. impulses applied to the grid of the valve in respect to the modulations in the incoming R.F. wave, and since a suppression of the negative half cycle of the composite input wave (by reducing the anode volts) causes a howl with the "straight" connections while a suppression of the positive half cycles (by reducing filament current) causes the same howl with "crossed" connections, we are led to the conclusion that the input to the



(b)

Fig. 2.

valve is asymmetrical and that only one half-cycle is markedly susceptible to curvature in the valve characteristic.

Let us, therefore, consider in detail the conditions under which the valve has to operate. Fig. 3(a) represents C.W. modulated by a simple note and will be taken as representing the R.F. input. Now this input is amplified and passed on to the crystal for rectification after which it is reapplied to the valve grid by means of an A.F. transformer. In relation to the modulation in the input wave, the voltage wave occurring at the terminals of the secondary of the A.F. transformer may be in the form of 3(b) or 3(c). 3(b) has a positive maximum when the R.F. input is greatest whilst 3(c) has a positive maximum when the R.F. input is at a minimum. Just exactly which wave we do obtain depends on at least three factors:—

1. The R.F. transformer connections;
2. The crystal connections;
3. The A.F. transformer connections.

There is a further factor, namely, transformer phase shift which is assumed not to be

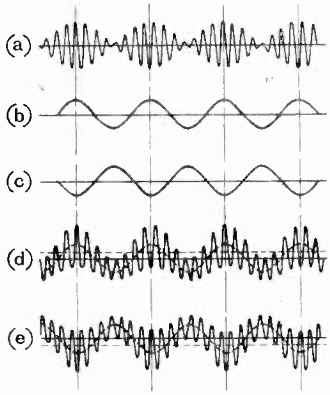


Fig. 3.

of sufficient magnitude under the present circumstances to warrant consideration since the frequency (*i.e.*, pitch) of the phenomenon does not vary greatly with any given transformer.

If we combine the A.F. waves 3(b) and 3(c) in turn with the R.F. wave 3(d) we shall obtain waves 3(d) and 3(e) which show quite clearly that asymmetry does exist. In the case of 3(d), since the amplitude of R.F. wave is a maximum during the positive half-cycle of the A.F. wave and a minimum during the negative half-cycle, the mean of the combined wave (dotted line) is positive in respect to the mean of the basic A.F. or R.F. waves (full line). The opposite occurs with the wave 3(e) where the mean of the combined wave is negative in respect to the basic waves.

Fig. 4 shows the case of 3(e) supplied to a valve, and the main point to be noted is that the valve is no longer working at the mean potential applied by the bias battery. This gives us a clue as to how to find out whether this curve is produced with the "straight" or the "crossed" connections. If we suddenly short-circuit the A.F. transformer secondary while signals are being received, there should be, under the conditions depicted in Fig. 4, a rise in anode current. This actually occurs with "crossed" connections the reverse (a fall in current) happening with the "straight" arrangement. Now since a howl takes place on reducing the filament current with "crossed" connections (see Figs. 2(b), 3(e) and 4) and also occurs on reducing the anode volts with "straight" connections (Figs. 2(a) and 3(d) we may draw our second conclusion, viz., that the particular howl and roughness only occur when valve characteristic curvature is allowed to interfere with the lesser half-cycle of the composite wave, *i.e.*, that period during which the R.F. wave is most depressed by the modulation of the transmission.

And so to the inevitable "Why?" Fortunately the characteristic howl can be produced with the "crossed" connections on the unmodulated carrier of the local station (providing a really excellent spot on the crystal be obtained) if the filament be slowly dimmed. No effect is obtained when mistuned or when the station is shut down. This makes examination of the subject simpler and we will proceed with the case of filament dimming.

In order fully to understand the "mechanics" underlying this phenomenon

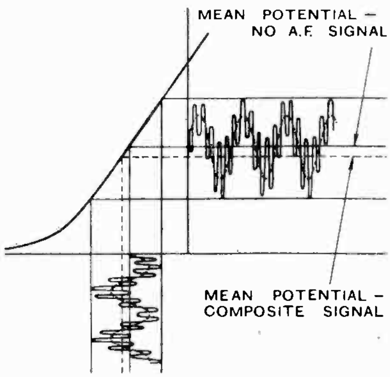


Fig. 4.

it is necessary to bear two facts in mind: Firstly, that on the input side of the valve there is an A.F. transformer secondary between the R.F. transformer and the bias battery, instantaneous positive or negative potential from which will carry the R.F. wave bodily higher up or lower down the characteristic curve of the valve than the region we choose when setting the bias battery and secondly, that filament dimming lowers the upper limit of the useful part of the valve characteristic curve.

Consider now normal conditions when receiving the unmodulating carrier of a broadcast station. The R.F. wave is being applied to the grid of the valve, which, after amplification passes it on to the crystal. The crystal, by reason of its unilateral conductivity and the blocking condenser, passes a steady current through the A.F. transformer primary. Because this current is steady no voltage is generated in the transformer secondary.

We then modify these conditions by dimming the filament which has the effect, already described, of reducing the R.F. output of the valve owing to partial cut off of the positive half-cycles (see Fig. 2(a)). Now this reduction in R.F. output is accompanied by a reduction in steady current passing through the transformer primary which causes a momentary positive potential from the secondary in accordance with our previous findings for "crossed" connections (see Figs. 3(a), 3(c), 3(e) and 4). But this momentary positive potential from the transformer secondary carries the whole R.F. wave further up the characteristic curve of the valve, the upper limit of which has been fixed by the reduction in filament current and so further suppression of the positive half-cycles takes place and therefore a still greater reduction in the steady current in the transformer primary and therefore further positive potential from the secondary which in turn causes still more cut off. A state of change, tending towards the complete extinction of the positive half-cycles of R.F. wave exists, which change obviously cannot continue indefinitely and so the positive potential being generated in the A.F. transformer secondary commences to die away.

As soon as this happens, however, the R.F. wave is allowed to move down the curve and the cut off becomes less severe. This allows an increase in the rectified current which is accompanied by a negative potential across the A.F. transformer secondary terminals. This negative potential will carry the R.F. wave down the characteristic curve tending to allow it to grow to its normal value (*i.e.*, that value obtaining before we reduced the filament current).

Again this condition cannot last indefinitely and the negative potential commences to die away so that conditions eventually become as they were when we had first dimmed the filament. This cycle will be repeated continuously, in fact, the arrangement is unstable and oscillates at a frequency depending almost wholly upon the constants of the A.F. transformer and the magnitude of the R.F. wave. Fig. 5 is an attempt to show the state of affairs.

Following the same reasoning for the filament dimming case with "straight" connections (wave 3D) it will be seen that a reduction of the R.F. wave "cut off" produces a negative voltage from the transformer which tends to enlarge the R.F. wave to its former value at once and thus limits the generated A.F. voltage. Stable conditions are thus assured. Exactly the same argument holds good for the opposite cases of reduced H.T. voltages.

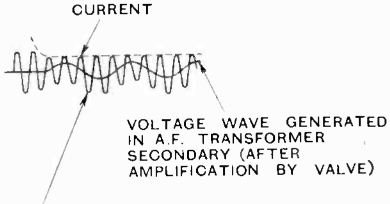


Fig. 5.

Our third conclusion is, therefore, that in order to ensure freedom from parasitic howls and A.F. reaction effects, it is necessary to provide a good straight portion of the valve characteristic for the lesser half-cycles of the incoming R.F. and A.F. wave previously shown to be asymmetric. A curvature in that part of the characteristic on which the greater half of the wave operates may actually be an advantage as it tends to limit the loudest notes only, although introducing slight even harmonics which the author has not yet been able to recognise aurally. These results are best obtained by working under the conditions shown in Fig. 4 (which give an increase in anode current if the A.F. transformer secondary is suddenly shorted while receiving broadcast) and if necessary by decreasing the H.T. voltage slightly whilst retaining adequate filament heat and grid bias.

Somewhat insufficient negative grid bias will produce the howl already observed owing to partial suppression of the R.F.

wave by grid current but the effect is different as only notes above a certain intensity are affected. With much too little or no grid bias it is not possible to produce the note, presumably owing to heavy damping, also it is not possible to demonstrate the effect with a feeble R.F. input, in fact the author has come to consider the phenomenon as indicative of a healthy set and suitable operating conditions.

Having established the cause of his howl let us give it a name. It is, of course, a species of A.F. reaction but the author proposes to call it the reflex interference note to distinguish it from true R.F. or A.F. oscillation, which are quite different both in cause and effect.

The reflex interference note is—like mechanical friction, electrical resistance, etc.—at first sight highly undesirable but really quite useful. We may set the crystal with it by firstly tuning the local station to the greatest apparent loudness, then tuning the filament down to the point at which a sharp decline in anode current sets in and then trying a number of places on the crystal. Some spots will produce no note, others a mediocre and erratic note while a few will produce quite a loud, steady and rather low pitched note; these are the good spots. We may very fairly judge the merits of a crystal by the number of good notes we obtain out of, say, twelve contacts. Similarly, we have a crude but useful way of indicating if the crystal is ageing.

One may tune the local station the absolute maximum loudness with this interference phenomenon. Having obtained a good spot of the crystal with its aid, a slight adjustment of both anode and grid condensers may increase the loudness of the note and in this respect tuning is quite sharp.

The relative suitability of valves for the circuit may be quickly estimated by seeing which produces the loudest note and the comparative excellence of two valves of the same type but different manufacture may similarly be estimated. The author has found that there are appreciable differences in this direction, probably due to the better bases used by some makers.

The note gives audible indication should the L.T. accumulator fail while in use; a useful point. In the same way failure of emission of a valve has on two occasions been shown up.

The question as to how many volts negative grid bias are required can be answered quite easily by listening for traces of the interference and in this connection it is remarkable what a large swing is produced by the low notes of the piano and harp and by certain drums.

The author has tried some six different A.F. transformers in the set and found that the pitch of the note is different for each transformer, and the lower the note, the better the transformer is on music, provided the loud-speaker in use is capable of dealing with low notes. The now famous "nearly perfect" transformer (Ferranti) gives an interference note estimated at 150 cycles. The smaller of the two transformers mentioned at the beginning of this article gave a note estimated at 1,500 cycles. A small French transformer tested as a matter of interest either could not muster enough output to produce a note or the note was above audible frequency (it was *not* sold to the author as a supersonic instrument).

Loading a transformer with by-pass condensers makes a slight difference to the note, but not so much as is obtained between two transformers of different makes.

Finally, a word in support of the reflex set. It should be noted that the roughness which gave rise to these investigations only occurred when obtaining loud-speaker strength at nine miles from 2LO without a trace of reaction. Further, as has been shown, this roughness is curable until the limit of the valve has been reached. In the author's opinion far too little serious thought has been applied to this class of receiver with the result that its reputation is anything but good. Only the other day his attention was drawn to a circuit just published and announced as likely to have an important bearing in reflex design in the future. The first glance showed a variable condenser consisting of two $.0005\mu F$ sections so connected that amongst other things it shunted the *secondary* of the associated A.F. transformer. In other words, anything up to $.001\mu F$ was applied at a point where $.0001\mu F$ is by design and selection* ample and from the point of view of quality possibly too much.

* "Bypass Condensers in Reflex Receivers," by D. Kingsbury, *Wireless World*, 20th October, 1926, pp. 546-550.

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

By *W. A. Barclay, M.A.*

(*Continued from page* 466 *of August issue.*)

Part II.

In the previous part of this paper we considered the derivation and use of certain curves obtained from the grid current characteristic of a valve, to which the writer gave the name of *grid signal characteristics*, and an example was given of the use to which such curves may be put in determining the mean voltage on the grid during the rectification of a C.W. signal. The method of use was shown to be analogous to that employed in the determination of the initial conditions from the ordinary characteristic. The *raison d'être* of the grid signal characteristics being thus established, we shall now proceed to consider a means whereby, in the majority of practical cases, the actual drawing of these curves is rendered unnecessary and may be dispensed with. It will further appear that in these cases the required values of mean grid voltage during signal reception may be ascertained directly from the original characteristic.

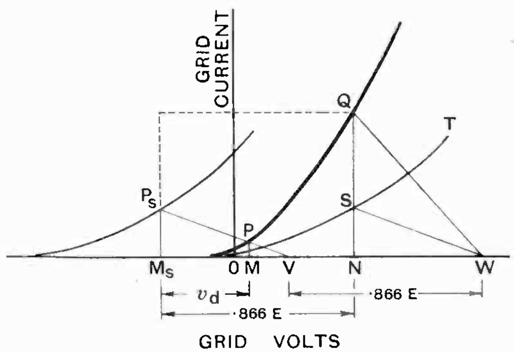


Fig. 7. *Method of deriving mean grid signal voltage from the original characteristic. The length* M_sM *represents* v_d*, the grid voltage shift owing to rectification.*

In the diagram of Fig. 7, let the curve PQ denote the grid current characteristic, whose equation, when referred to suitable axes, may be written—

$$i_g = f(v_g)$$

Let ST be the curve whose ordinates are one-third those of PQ, its equation being—

$$i = \tfrac{1}{3}f(v_g)$$

Take the point V to represent the value v of grid voltage, and let VP be the slope line for resistance R and bias voltage v. Then M, the projection of P on the voltage axis, represents the pre-signal voltage of the combination. We have seen that the grid signal characteristic of amplitude E is, for all that part of the diagram in which the ordinates of PQ are negligible, a replica of the curve ST, transferred horizontally to the left through a distance of $.866E$ along the voltage axis. This curve having been drawn in, let P_s be the point of its intersection with the leak line VP. Then the required value of mean grid voltage during the passage of the signal is given by the abscissa of P_s, represented by the point M_s.

Let us now consider an alternative method of finding M_s. Take a point W on the voltage axis at a value $v+.866E$, and through it draw a line parallel to VP to meet the curve ST in S. Then, since the two curves are horizontally apart by $.866E$, the parallel lines VP_s and WS, also at the same horizontal distance apart, will meet them in the two points P_s and S, whose ordinates M_sP_s and NS are equal, and whose distance apart is also $.866E$. But—

$$P_sS = M_sN$$

Therefore—

$$M_sN = .866E \text{ volts,}$$

so that the point M_s may be found by setting off this distance to the left of N. Having obtained N by means of the gradient line WS and the curve ST, the value of v_s is found by subtracting $.866E$ from the value of the voltage represented by N.

Consider, further, the derivation of the point N. The ordinates of the curve ST being one-third those of PQ, it will be obvious that a line through W, whose gradient is three times that of WS, will meet the original characteristic PQ in a point Q whose abscissa will be the same as that of S. It will not be necessary, therefore, even to draw the curve ST. *The original characteristic may be made to serve,* provided the line WQ used to intersect it have three times the gradient of WS, *i.e.*, of VP, and that it pass through a grid voltage point W representing a value equal to $v+.866E$. The gradient of the slope line WQ will therefore be that corresponding to a leak resistance of one-third the value of the given leak R, and is thus easily plotted. As already stated, there falls to be deducted from the value of grid voltage found at N the amount $.866E$, in order to obtain the required value of mean grid voltage during signal reception.

We may now shortly summarise the procedure to which we have been conducted. To obtain the mean grid voltage during the rectification of a signal of amplitude E with a leak resistance R and fixed bias voltage v we have the simple rule :—

From a point on the voltage axis situated at $v + .866E$, draw a line of gradient corresponding to a leak of $R/3$. From the intersection of this line with the curve measure back $.866E$ volts. The resulting voltage is that of the grid under the signal conditions; subject to its position being on that part of the diagram for which the original characteristic has zero ordinates.

(If the mean voltage under signal conditions is not on this part of the diagram, recourse must be had to the actual plotting of the signal characteristics as previously described.)

An interesting verification of this procedure is shown in Fig. 8. The grid characteristic there given is the exponential curve found by Mr. Colebrook for an Ediswan dull-emitter valve.* When plotted to a suitable scale, reckoning in microamperes and volts, its equation may be written

$$i_g = 3.16\epsilon^{5.55v_g}$$

With a leak resistance of 1.89 megohms and zero bias voltage, Mr. Colebrook finds the initial voltage on the grid to be —.461. This value is, of course, the abscissa of the intersection of the curve with the line whose equation is

$$i_g = -\frac{v_g}{1.89}$$

which is the lower line plotted on the diagram.

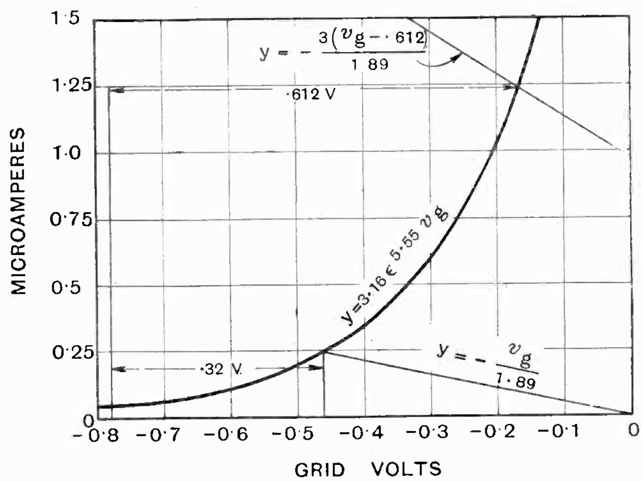


Fig. 8. *Exponential grid current characteristic.*

Assuming now a signal amplitude of .707 volt, he proceeds to calculate, by means of curves applicable to the exponential form of characteristic, a mean change of grid potential equal to .329 volt. (In passing, it should be remarked that accuracy of this order is entirely contingent upon the degree of approximation of the characteristic to the assumed exponential form. In this case, of course, the assumption of this form is explicitly made, and there is no limit,

*See *E.W. & W.E.*, Nov., 1925, p. 871.

theoretically, to the accuracy obtainable under this hypothesis.)

On our diagram (Fig. 8) the upper resistance line has been drawn in accordance with the preceding rule to intersect the voltage axis at the value $O+(.866 \times .707)$ volts, while having a gradient three times that of the other line. Its equation will therefore be

$$i_g = -\frac{3(v_g - .612)}{1.89}$$

from which it may be readily plotted.

On setting back a distance corresponding to .612 volt from the abscissa of the new intersection, we obtain —.78 as the value of mean grid voltage during the signal, corresponding to a change of .32 volt. A useful check is thus afforded on the accuracy of the new method, which, it is to be remembered, is applicable with equal ease to other forms of characteristic besides the exponential.

It might be anticipated that in the above simple construction for the derivation of the mean grid voltage change in signal reception, the subject had, from the computer's point of view, been "reduced to its lowest terms." This, however, is not the case, and the writer believes that an account of a device which he has elaborated to simplify yet further such calculations will be found of service to many experimenters interested in the statistics of grid detection. Especially will the device be useful where many such calculations are required to be done in bulk, *e.g.*, when it is desired to study the effect of varying any particular factor, such, for instance, as signal amplitude or leak resistance.

The foundation of the method consists in the use of semi-logarithmically ruled paper, the utility of which to the serious experimenter, though little known, can scarcely be over-estimated. This paper, which can be obtained very reasonably from several scientific instrument makers, is graduated logarithmically along one axis only, the other being divided at equal intervals in the usual way. It is a simple matter to replot the i_g—v_g characteristic curve upon such paper, taking values of i_g upon the logarithmic and v_g upon the linear axis. The values of grid current, as is known, increase rapidly with positive grid voltage, and for this reason the logarithmic paper will show them more conveniently than the ordinary diagram. For negative values of grid voltage, the grid current becomes negligible in comparison with its higher values, so that we may stop our representation of it when it falls below, say, .2μA. Such a representation of a grid current characteristic is shown in Fig. 9, in which the horizontal axis is divided to represent integral values (both positive and negative) of grid potential in volts while the vertical axis is graduated logarithmically to represent positive values of grid current from .2 to 20μA. The characteristic shown is a portion of that of the Edison D.R.2 valve previously illustrated at Fig. 5.

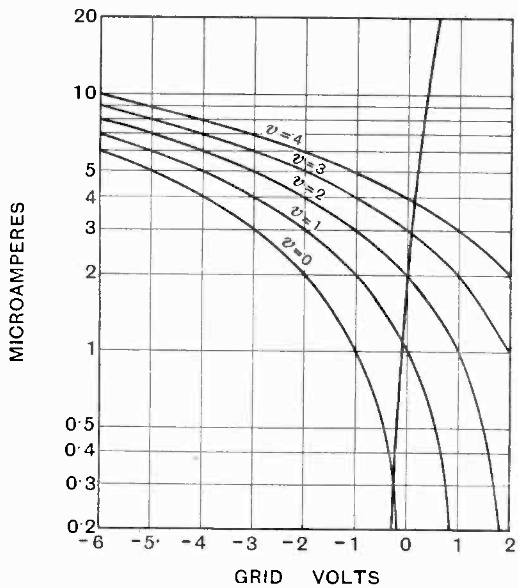


Fig. 9. *Logarithmic grid characteristic diagram, with portion of Edison D.R.2 characteristic.*

We now develop the diagram by plotting in a series of curves which are to represent various values of fixed bias voltage v. The law of their construction will become apparent from the following examples: For the curve representing $v=0$, we join all the points the algebraic sum of whose co-ordinates (expressed in the units, volts and μA) is zero. Thus, the points ($v_g=-2$, $i_g=2$) and ($v_g=-0.5$, $i_g=0.5$) will lie on this curve. For the curve $v=1$, we join all points the algebraic sum of whose co-ordinates is 1, and similarly for the other values of v, integral or fractional, in which we are interested. In the diagram of Fig. 9, these curves are shown for steps of 1 volt from $v=0$ upwards. They will be found exceedingly simple to construct upon the ruled network, as their course is marked by the intersections of vertical and horizontal lines already ruled upon the diagram throughout their length. In practice —owing to the decimal graduation of the logarithmic paper—sub-divisions of $\frac{1}{10}$ volt in v are readily drawn in.

Finally, prepare a cursor cut from stiff paper in the form of a T as shown in Fig. 10. The head of the T is graduated logarithmically to the same scale as used in the diagram of Fig. 9, from which the markings may be readily copied. These graduations are to represent values of leak resistance, measured

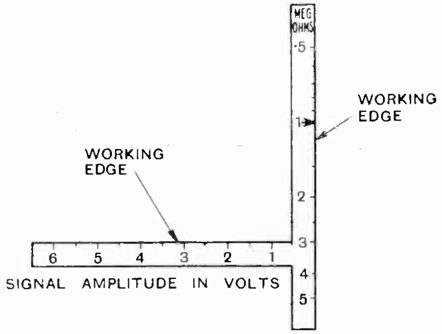


Fig. 10. *Cursor for use with Fig. 9.*

in megohms, the graduation for 1 megohm being distinguished by an arrow-head. Perpendicular to this scale, and forming the stem of the T, is a scale of signal amplitudes which meets the scale of resistance at the value 3 megohms. This scale is linear, the graduations being at .866 of the distances between the vertical voltage lines of Fig. 9 and are measured from a zero on the resistance scale. In applying the cursor to the diagram, it is to be oriented as shown in Fig. 10; the T is to be placed on its side, the stem being always kept horizontal and to the left of the head. The logarithmic graduations for leak resistance should then run in the opposite sense to that of the current graduations on Fig. 9.

The method of using the cursor on the diagram is twofold, solving the double problem of obtaining mean grid voltages (*a*) before, and (*b*) during signal reception. In both cases, the cursor is placed so that the resistance scale is parallel to the vertical lines on the diagram, while the graduation corresponding to the leak resistance in use is placed over the characteristic curve. The cursor is now at liberty to slide in this position along the characteristic.

(*a*) For pre-signal conditions, slide the cursor thus until the arrow-head is on the curve corresponding to the required value of v, interpolating by eye where this is necessary. The initial grid voltage is then read from the diagram at the position occupied by the resistance scale.

(*b*) For signal conditions, still keeping the resistance graduation upon the characteristic, slide the cursor until the signal amplitude graduation is over the same v curve. The voltage read from the diagram *at this point* is now the mean grid voltage during reception of the signal.

It thus appears that by two applications of the cursor to our logarithmic characteristic we can obtain immediately the mean grid voltages both before and during signals and this for any signal amplitude and using any desired values of leak resistance and bias voltage. The advantages obtained by the use of this simple device are obvious. The diagram of Fig. 9 with its network of lines and v-curves is available for use with any grid characteristic, and need not, therefore, be redrawn in order to contrast the detecting performance of different valves. The widest facility is also afforded for comparing results using different or varying values of the circuit constants concerned without either calculation or graphical construction. In particular, the applicability of the method to every grid characteristic, irrespective of its mathematical form, should commend it to the attention of the computer.

The limitations imposed on the method are the same as those implied in the method previously derived for use with the ordinary characteristic, *i.e.*, the value found for the mean signal voltage on the grid must be such that the corresponding grid current is negligible in comparison with other values to which this current may attain during the cycle of oscillation. This, in effect, precludes the use of the method for very small amplitudes of signal voltage, as with these the current corresponding to the mean voltage of the grid tends to become equal to the mean value of the total current during the oscillation. In these cases, as already remarked, recourse to the grid signal characteristic curves becomes necessary.

A short mathematical proof of the properties of the logarithmic characteristic and cursor will now be given. Referring to the diagram of Fig. 7 in which suitable units of length were taken on the axes to represent volts and microamperes, we saw that if the original grid characteristic has the equation

$$i=f(v_g) \quad \ldots \quad \ldots \quad (14)$$

the curve ST has the equation

$$i=\tfrac{1}{3}f(v_g) \quad \ldots \quad \ldots \quad (15)$$

while the grid signal characteristic of amplitude E has the equation

$$i=\tfrac{1}{3}f(v_g+.866E) \quad \ldots \quad (16)$$

Using a grid bias of v volts and a leak of R megohms, the equation of the line VP is

$$i=\frac{v-v_g}{R} \quad \ldots \quad \ldots \quad (17)$$

If v_0 denotes as usual the pre-signal voltage on the grid, while v_s denotes the mean grid voltage during the signal, the values of v_0 and v_s may be determined as the result of eliminating i between (14) and (17), and between (16) and (17) respectively. Hence v_0 is the solution of

$$f(v_g)=\frac{v-v_g}{R} \quad \ldots \quad \ldots \quad (18)$$

considered as an equation in v_g, while v_s is the solution of

$$\tfrac{1}{3}f(v_g+.866E)=\frac{v-v_g}{R} \quad \ldots \quad (19)$$

similarly considered.

In the logarithmic diagram, Fig. 9, let the axes of co-ordinates be the horizontal line representing 1μA, and the vertical representing zero grid volts. Choosing a suitable scale for representation along each of these axes, we may write the equation of the characteristic as now plotted,

$$y=\log i=\log f(v_g) \quad \ldots \quad (20)$$

where y, the distance from the 1μA. line, is to be reckoned positive or negative according as $f(v_g)$ is greater or less than 1μA. With the same convention, we find that the equation to the family of curves representing grid bias voltage may be written

$$y=\log(v-v_g) \quad \ldots \quad \ldots \quad (21)$$

to each curve corresponding to its appropriate value of v.

If, now, the head of the cursor be slid over the characteristic, the graduation corresponding to R being always over the curve, the arrow-head at the value 1 megohm will obviously describe the curve

$$y=\log f(v_g)+\log R \quad \ldots \quad (22)$$

When the arrow-head in its travel meets the desired v-curve, the value of v_g will then be obtained by eliminating y between equations (21) and (22), giving

$$\log(v-v_g)=\log f(v_g)+\log R \quad \ldots \quad (23)$$

an equation which is seen to be identical with equation (18) already obtained for the determination of v_o, the initial grid voltage.

In finding v_s, the head of the cursor is again slid while maintaining the graduation for R over the characteristic. The zero of the signal amplitude scale, situated at the value 3 megohms on the head of the cursor, will then describe the curve

$$y=\log f(v_g)+\log R-\log 3 \quad \ldots \quad (24)$$

Hence the graduation on the cursor corresponding to signal amplitude E, distant to the left of this zero point by $.866E$, will describe the curve

$$y=\log f(v_g+.866E)+\log R-\log 3 \quad (25)$$

When this graduation arrives over the v-curve of equation (21) the two values of y are equal. Equating them we have

$$\log(v-v_g)=\log f(v_g+.866E)+\log R-\log 3 \; (26)$$

which, after rearrangement, is seen to be equivalent to equation (19) from which the grid signal voltage v_s is derived. Thus the construction is proved.

The logarithmic characteristic used in conjunction with the cursor as above described furnishes us (within the limits of its operation) with a convenient means of estimating the detecting performance of valves, a desideratum noticed at the outset of this paper. (It may be well here to remark that in speaking of "detecting efficiency" we are here confining ourselves solely to the grid circuit of the valve, and are ignoring the very importantly associated anode circuit.) In Fig. 11, let the right angles ABC and DEF represent the initial and final positions of the cursor. In the first of these the arrow-head (at 1 megohm) is on the curve $y=\log(v-v_g)$ while the point A, corresponding to resistance R, is on the characteristic. In this position the abscissa of the line AB is v_0, the initial voltage. Substituting this value for v_g in the equation of the v-curve, we obtain for the ordinate of the arrow-head $\log(v - v_0)$. Subtracting (algebraically) the distance equal to $\log R$ between the arrow-head and the point A, we may write the co-ordinates of the latter $\{v_0, \log(v - v_0) - \log R\}$. In the position DEF, the point F on the horizontal stem of the cursor marks the graduation for signal amplitude E, which appears over the curve $y = \log(v - v_g)$, the abscissa of the point being v_s. The ordinate of F may thus be written $\log(v - v_s)$. At the same time the resistance graduation for leak R occupies

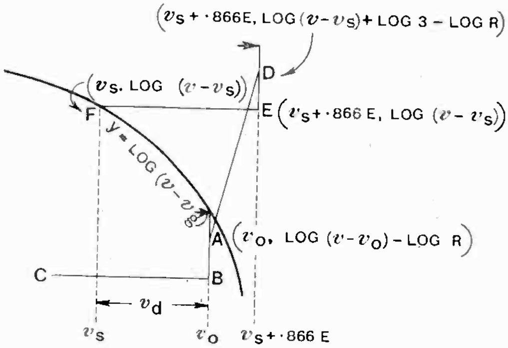


Fig. 11. *Showing dispositions of cursor upon the logarithmic diagram of Fig. 9.*

the position D on the characteristic. Since the point E, the zero of the scale of signal amplitude, is at a distance from F representing $.866E$ volts, the co-ordinates of E are $\{v_s + .866E, \log(v - v_s)\}$, whence, again, those of D are

$$\{v_s + .866E, \log(v - v_s) + \log 3 - \log R\}.$$

The course of the characteristic is approximately shown by the straight line joining the points A and D. If the characteristic conforms to the exponential type, it will actually follow the line AD. For the usual type of rectifier valve, the course of the characteristic between working points such as A and D may be regarded as approximately linear. Whatever be the departure from the linear form, however, there will be a much smaller discrepancy between the slope of the line AD and the actual average gradient of the curve between these points. Indeed, we may in all cases regard the gradient of AD as a fairly accurate estimate of the average slope of the characteristic over the working range. If, then, we represent by G this average gradient, we have, from Fig. 11,

$$G = \frac{\log(v - v_s) + \log 3 - \log(v - v_0)}{v_s + .866E - v_0} \qquad (27)$$

If by v_d we represent the difference $v_0 - v_s$ between the initial and signal grid voltages, while by V we represent $v - v_0$ the initial potential difference across the leak, we may write :—

$$G = \frac{\log 3 + \log\left(1 + \frac{v_d}{V}\right)}{.866E - v_d} \quad \ldots \quad (28)$$

Now it is obvious from Fig. 7 that, for all values of E suitable for the application of the method (*i.e.*, such that the current ordinate at resulting v_s is negligible), v_d will be less than $.866E$. Thus, for a given signal amplitude E, the value of G is seen to increase with increase of v_d, *i.e.*, other things being equal, *the greater the gradient of the logarithmic characteristic, the greater the rectifying efficiency of the grid circuit of the valve.*

It may be of interest to indicate a convenient means of correlating geometrically the magnitude of G with the other three variables of equation (28). Writing this in the form

$$G = \frac{\log 3 - \left\{-\log\left(1 + \frac{v_d}{V}\right)\right\}}{.866\,E - v_d} \quad \ldots \quad (29)$$

it is seen that if on the diagram of Fig. 21 we take two points P and Q whose co-ordinates with respect to the cartesian axes OX and OY are

$$\{.866\,E,\ \log 3\}$$

and

$$\left\{v_d, -\log\left(1 + \frac{v_d}{V}\right)\right\}$$

the value of G will be represented by the gradient of the line PQ. All the points P are seen to lie along the horizontal line of ordinate equal to $\log 3$ in a linear scale of values of E. The positions of the Q points are determined by the values of the two variables v_d and V. The abscissa of each Q point is the corresponding value of v_d; hence are drawn a series of vertical lines to represent that variable. The curves shown for V are then the result of eliminating v_d between the equations

$$x = v_d \text{ and } y = -\log\left(1 + \frac{v_d}{V}\right)$$

i.e., they are the curves

$$y = -\log\left(1 + \frac{x}{V}\right)$$

The position of any given Q point will thus be found at the intersection of its appropriate v_d line and V curve. If both the scales taken for the horizontal and vertical measurements in Fig. 12 are the same (or in the same proportion) as the corresponding scales in Fig. 9, the values obtained for G by means of the two diagrams will be identical. In Fig. 9 we are dealing with the actual values of grid bias, initial and signal grid voltages. In Fig. 12 we deal directly with the change of grid voltage due to the signal, and relate it to the pre-signal value of the P.D. across the leak V, the signal amplitude E, and the value of G. The two diagrams are thus complementary, but whereas Fig. 9 necessitates the use of the cursor described, Fig. 12 may be used as it stands.

To illustrate the use of Fig. 12, suppose the average value of G for the working portion of the logarithmic characteristic is known, and also the value V of the initial P.D. across the leak, then, by sliding a set-square so as to preserve the constant slope of gradient G, we can correlate values of E with the corresponding values of v_d, and this without reference to the actual values of grid bias and leak resistance. As the sliding edge of the set-square passes through successive values of E, it simultaneously intersects the given V curve at the required values of v_d. The $E - v_d$ characteristic of the valve may thus be readily graphed for various values of V for all except small values of E.

An interesting confirmation of Fig. 12 may be obtained by reference to the diagram of Fig. 6. On Fig. 12 the line PQ has been drawn of slope equal to the average of that of the logarithmic characteristic shown in Fig. 9, the signal amplitude E being taken as 2 volts. From Fig. 6, which shows the original and signal characteristics of the same valve, it is seen that for a leak of 1 megohm and positive bias of 4 volts, we have $v_0 = .12$. Further, for signal amplitude

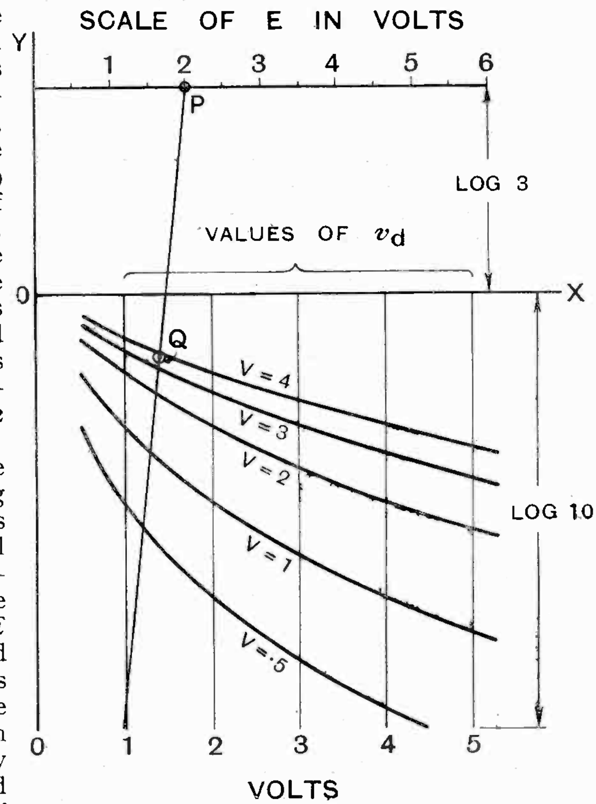


Fig. 12. *Chart relating the quantities* E, V *and* v_d *to* G, *the slope of the logarithmic characteristic. The point* P *corresponds to* E = 2 ; *the point* Q *corresponds to* V = 3.88, v_d = 1.34. *The gradient of* PQ *is that of the characteristic shown in Fig.* 9 ; *the horizontal and vertical scales of Figs.* 9 *and* 12 *being in a fixed ratio.*

$E = 2$, we obtain $v_s = -1.22$. Hence $V = 3.88$, while v_d, the required voltage shift, is 1.34. On Fig. 12 the slope line passes through a point Q satisfying these values.

Mathematics for Wireless Amateurs.

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

(Continued from page 492 of August issue.)

PART III (CONTINUED).

7. Rules for Differentiating Combinations of Functions.

THIS section deals with technique rather than principles. As such it is likely to be dullish reading but will repay attention.

(A) *Differentiation of the Sum of a Number of Functions.*

Suppose it is required to differentiate

$$y = 4x^3 + 3x^2 + 2x + 10$$

The best method is essentially that indicated by Æsop in the fable about the bundle of sticks. The above function can be regarded as a sum of the simpler functions $4x^3$, $3x^2$, etc. Now it is fairly easy to show from the definition of a limit that the limit of the sum of a finite number of terms is equal to the sum of the limits of the separate terms. From this it follows at once that if u, v, w, etc., are functions of x, and

$$y = u + v + w + \text{etc.}$$

then

$$\frac{dy}{dx} = \frac{du}{dx} + \frac{dv}{dx} + \frac{dw}{dx} + \text{etc.}$$

Applying this to the example given,

$$dy/dx = 12x^2 + 6x + 2$$

Disappearance of the Constant Term.

Notice that in the above differentiation the 10 disappears. The disappearance of any constant term is inherent in the process of differentiation. This important fact must be borne in mind when the process is reversed. For example, if n is a positive integer, it has been shown that the d.c. of x^n is nx^{n-1}. But so also is the d.c. of x^n+C, where C is any constant number whatever. If, therefore, we are told that y is a function of x such that

$$dy/dx = nx^{n-1}$$

then we can only infer that

$$y = x^n + C$$

where C is some unknown "arbitrary" constant for the determination of which further information is required.

(B) *The Differentiation of a Product of Functions.*

If $f(x)$ and $g(x)$ are two functions of x, and

$$y = f(x)g(x)$$

then by definition,

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

$$= \underset{h\to 0}{lt.}\ \frac{f(x+h)g(x+h) - f(x)g(x+h) + f(x)g(x+h) - f(x)g(x)}{h}$$

$$= \quad g(x)\frac{df(x)}{dx} + f(x)\frac{dg(x)}{dx}$$

or, putting this in a form which is rather easier to remember,

$$\frac{duv}{dx} = u\frac{dv}{dx} + v\frac{du}{dx}$$

Consider for example the two functions x^n and x^{-n}, n being a positive integer. The product of these functions is 1, and the d.c. of the product is therefore zero, *i.e.*,

$$\frac{dx^{-n}x^n}{dx} = x^{-n}\frac{dx^n}{dx} + x^n\frac{dx^{-n}}{dx} = 0$$

or

$$nx^{n-1}x^{-n} + x^n\frac{dx^{-n}}{dx} = 0$$

$$\frac{dx^{-n}}{dx} = -nx^{n-1}x^{-n}x^{-n}$$

$$= -nx^{-n-1}$$

which shows that the formula for the d.c. of x^n is true for negative indices.

It is easy to extend the above result to products of more than two terms. It will be found that

$$\frac{duvw}{dx} = uv\frac{dw}{dx} + uw\frac{dv}{dx} + vw\frac{du}{dx}$$

and so on.

(C) *The Differentiation of a Quotient.*

This can be derived from the preceding, just as the idea of a quotient is derived from that of a product.

If $y = u/v$ then $u = vy$.

The right-hand side can be differentiated by the rule for a product, and in this way it is easy to show that

$$\frac{dy}{dx} = \frac{1}{v^2}\left\{v\frac{du}{dx} - u\frac{dv}{dx}\right\}$$

(D) *The Differentiation of a Function of a Function.*

This sounds tautological, for a function of a function of x is a function of x. However, in a case such as

$$y = 3(x^2 + 2x + 5)^2 + 7(x^2 + 2x + 5) + 8$$

it will generally be more convenient to treat y as a function of the variable (x^2+2x+5), which variable is itself a function of x. The function $y = log\ (sin\ x)$ is another instance. The general form is

$$u = f(x)$$

and

$$y = \phi(u) = \phi\{f(x)\}$$

Suppose x increases to $x+h$, in consequence of which u increases to $u+k$ and y to $y+m$. Then

$$\frac{du}{dx} = \underset{h\to 0}{lt.}\ \frac{k}{h}$$

and

$$\frac{dy}{du} = \underset{k\to 0}{lt.}\ \frac{m}{k}$$

Further, since the functions are assumed to be continuous, k will tend to zero as h tends to zero, so that

$$\frac{dy}{du} = \underset{h\to 0}{lt.}\ \frac{m}{k}$$

Therefore

$$\frac{dy}{du}\frac{du}{dx} = \underset{h\to 0}{lt.}\ \frac{m}{k}\ \underset{h\to 0}{lt.}\ \frac{k}{h}$$

It is easy to show from the definition of limit that the product of the limits of two terms is equal to the limit of the product of the terms so that

$$\frac{dy}{du}\frac{du}{dx} = \underset{h\to 0}{lt.}\ \left\{\frac{m}{k}\frac{k}{h}\right\}$$
$$= \underset{h\to 0}{lt.}\ \frac{m}{h}$$

since the quantities m, k, and h are not zero. But

$$\underset{h\to 0}{lt.}\ \frac{m}{h} = \frac{dy}{dx}$$

Therefore

$$\frac{dy}{dx} = \frac{dy}{du}\frac{du}{dx}$$

For instance, taking the first example quoted above

$$y = 3u^2 + 7u + 8$$

and

$$u = x^2 + 2x + 5$$
$$dy/du = 6u + 7$$
$$du/dx = 2x + 2$$

Therefore

$$dy/dx = \{6(x^2 + 2x + 5) + 7\}(2x + 2)$$
$$= 12x^3 + 36x^2 + 98x + 74$$

An important special case is that in which y is that function of x which makes

$$y^q = x^p,\ i.e.,\ y = x^{p/q}$$

The differentiation of y^q by the above rule gives

$$qy^{q-1}\,(dy/dx) = px^{p-1}$$

By substituting in this the value for y in terms of x and rearranging, it is easy to show that

$$dy/dx = (p/q)x^{(p/q)-1}$$

We can therefore say that

$$dx^n/dx = nx^{n-1}$$

for all real values of n, positive or negative, integral or fractional.

8. Standard Forms.

In order to acquire fluency in the applications of the calculus it is advisable to learn off by heart the differential coefficients of a number of the most common functions, just as one learns off by heart the multiplication tables at an earlier stage of one's mathematical education. With these standard forms and the above rules for dealing with simple combinations of functions the differentiation of any ordinary function is a comparatively simple matter. The more important of these standard forms will now be detailed.

(A) x^n.

It has already been shown that

$$dx^n/dx = nx^{n-1}$$

for all values of n.

(B) ε^x.

On account of its great importance, this case will be given in full. If $y = \varepsilon^x$ then by definition,

$$\frac{dy}{dx} = \underset{h\to 0}{lt.} \frac{\varepsilon^{x+h} - \varepsilon^x}{h}.$$

$$= \underset{h\to 0}{lt.} \ \varepsilon^x \frac{\varepsilon^h - 1}{h}$$

$$= \varepsilon^x \ \underset{h\to 0}{lt.} \frac{\varepsilon^h - 1}{h}$$

Now

$$\frac{\varepsilon^h - 1}{h} = 1 + \frac{h}{2}\left\{1 + \frac{h}{3} + \frac{h^2}{3\cdot 4} + \frac{h^3}{3\cdot 4\cdot 5\cdot} + \text{etc. etc., } ad\ inf.\right\}$$

For values of h less than 1 the sum to infinity of the series in the brackets is less than

$1 + h + h^2 + h^3 + h^4 +$ etc., etc., *ad inf.* $= 1/(1-h)$

(by Sect. 9 of Part I). Therefore the series in the brackets can be put equal to $K/(1-h)$, where K is less than 1 as long as h is less than 1. Therefore

$$\underset{h\to 0}{lt.} \frac{\varepsilon^h - 1}{h} = \underset{h\to 0}{lt.} \ 1 + \frac{Kh}{2(1-h)}$$

$$= 1$$

so that $\quad dy/dx = d\varepsilon^x/dx = \varepsilon^x = y$

(It might appear that this could be proved more simply by differentiating term by term the series for ε^x. The series so obtained, however, is not necessarily equal to the differential coefficient of the sum of the original series, for the sum of the limits of an infinite number of terms is not necessarily equal to the limit of the sum. It generally is but it quite often isn't, and the assumption may never be made without question.)

Note that if

$$y = a\varepsilon^{mx} = a(\varepsilon^x)^m$$

then by the rule for the differentiation of a function of a function

$$dy/dx = am(\varepsilon^x)^{m-1}\varepsilon^x = am\varepsilon^{mx} = my$$

Thus the function $a\varepsilon^{mx}$ has the remarkable property that its rate of change is proportional to itself. Further, it is the only known function which has this property. In other words the most general solution of the differential equation

$$dy/dx = my$$

is

$$y = a\varepsilon^{mx}$$

where a is an arbitrary constant number for the determination of which further information is required. This is the reason why the curious and rather awkward number $\varepsilon = 2.71828$ . . . . is always turning up in applied mathematics and physics.

The rather more general case

$$y = a^x$$

can be derived at once by writing the constant a in the form ε^m, *i.e.*, m is $log_\varepsilon a$ Then

$$y = a^x = (\varepsilon^m)^x = \varepsilon^{mx}$$

and

$$dy/dx = m\varepsilon^{mx} = m(\varepsilon^m)^x = a^x \ log_\varepsilon a$$

(C) $Log_\varepsilon x$.

This case can be derived from the preceding for if

$$y = log_\varepsilon x$$
$$x = \varepsilon^y$$

and the differentiation of both sides (the right-hand side being a function of a function of x) gives

$$1 = \varepsilon^y (dy/dx)$$

so that

$$dy/dx = d \ log \ x/dx = 1/\varepsilon^y = 1/x.$$

An obvious extension is

$$\frac{d \log f(x)}{dx} = \frac{1}{f(x)} \frac{d f(x)}{dx}$$

(D) *Sin x*.

The reader should have no difficulty in showing from the trigonometrical formulæ derived in Sect. 16, Part II, that

$$sin \ A - sin \ B = 2 \ cos \ \frac{(A+B)}{2} \ sin \ \frac{(A-B)}{2}$$

so that

$$sin \ (x+h) - sin \ x = 2 \ cos\left(x + \frac{h}{2}\right) sin \ h/2.$$

Therefore, if $y = sin \ x$

$$\frac{dy}{dx} = \underset{h\to 0}{lt.} \ cos\left(x + \frac{h}{2}\right)\frac{sin \ (h/2)}{h/2}$$

$$= cos \ x$$

for, as already shown in Part II, the limit of $(sin \ \theta)/\theta$ when θ tends to zero is 1.

In a precisely similar manner it can be shown that

$$d\,(cos \ x)/dx = - sin \ x$$

Notice that

$$d\,(sin \ mx)\,/\,dx = m \ cos \ mx,$$

by the rule for the differentiation of a function of a function.

The other trigonometrical functions are derived from these two, the sine and the cosine, as shown in Part II, and the d.c.s can therefore be calculated from the above rules relating to combinations of functions. Space will not permit of their being detailed individually but they are listed below for reference.

Function.	Differential Coefficient.
$\tan x$	$\sec^2 x$
$\cot x$	$-\mathrm{cosec}^2 x$
$\sec x$	$\sec x \tan x$
$\mathrm{cosec}\, x$	$-\mathrm{cosec}\, x \cot x$

So much for what may be called the ABC of the calculus. Not enough, perhaps, some may think. It certainly is rather concentrated, but the essence of the matter is there. Familiarity with the ideas involved can only be had by practice, and then more practice, and then some more. A few examples are given, but many more need to be worked by a beginner. A good plan is to express a function in two ways and differentiate each form. Work can be made more or less self checking in this way. (Examples: $(a+x)^3$ and $a^3+3a^2x+3ax^2+x^3$; $\tan 2x$ and $(2 \sin x \cos x)/(\cos^2x-\sin^2x)$; and so on.)

9. Successive Differentiation.

This does not introduce any new ideas, but only some more "shorthand." If y is a function of x, then in general dy/dx will also be a function of x and as such can be differentiated with respect to x, giving

$$\frac{d}{dx}\left(\frac{d}{dx}y\right)$$

Since this is rather cumbersome to write, it is abbreviated to

$$d^2y/dx^2$$

the d's and dx's being, so to speak, multiplied together as if they were numbers (which of course they aren't). It is merely a convenience of notation. The process can obviously be extended, giving d^3y/dx^3, d^4y/dx^4, etc., d^ny/dx^n being referred to as the nth differential coefficient of y with respect to x, or sometimes as the nth derivative. As an example, if

$$\begin{aligned} y &= ax^3 \\ dy/dx &= 3ax^2 \\ d^2y/dx^2 &= 2.3ax \\ d^3y/dx^3 &= 2.3a \end{aligned}$$

and $\quad d^4y/dx^4=0$

so that the process terminates. On the other hand a function such as $\sin x$ can be differentiated for ever. In this matter the trigonometric functions have a peculiar property which can be illustrated by

$$\begin{aligned} y &= a \sin mx + b \cos mx \\ dy/dx &= am \cos mx - bm \sin mx \\ d^2y/dx^2 &= -am^2 \sin mx - bm^2 \cos mx \\ &= -m^2 y \end{aligned}$$

No other function can be found which has this property that the second differential coefficient is equal to the function multiplied by a negative number. In other words the most general solution of the differential equation

$$d^2y/dx^2 = -m^2y$$

is $\quad y=a \sin mx+b \cos mx$

where a and b are constant numbers which can only be determined by additional information. Suppose, for instance, we are given that

$$\begin{aligned} d^2y/dx^2 &= -169\, y \ (i.e., -13^2 y) \\ y &= 10 \text{ when } x=0 \\ dy/dx &= 26 \text{ when } x=0 \end{aligned}$$

Then the general solution is

$$y= a \sin 13x+b \cos 13x$$

so that

$$dy/dx=13a \cos 13x-13b \sin 13x$$

Therefore when x is 0 we have

$$(y)_0=10=b$$

$$(dy/dx)_0=26=13a,\ i.e.,\ a=2$$

giving as the complete particular solution

$$y=2 \sin 13x+10 \cos 13x.$$

10. Partial Differentiation

Here again there is no new idea but only additional notation. As already pointed out in Part I, two or more independently variable numbers can be combined in a variety of ways to give another number. For instance if x and y are independent variables,

$$z = ax^2 + bxy + cx^2$$

is a function of the two variables x and y. Such a function could be represented geometrically by taking x and y as rectangular co-ordinates and z as the vertical height above the x, y plane at the point x, y. The equation would then define a surface. Now in general the rate of change of z, *i.e.*, the slope of the surface, will depend on the direction in which it is measured, a fact which is demonstrated afresh every time the driver of a wagon zig-zags up a hill which is too steep for his horses. The term "differential coefficient" is therefore indefinite unless the direction is specified in some way. There are two directions which naturally suggest themselves and which are generally of more interest than any others —the directions of the x and y axes. Moving in the direction of the x axis means that y is kept constant. (If this is not immediately obvious, the reader should draw the axes. Then it will be.) As long as y is kept constant z is in effect a function of the single variable x and has a differential coefficient with respect to x, *i.e.*, a slope in the direction of the x axis. That is what is meant by dz/dx in such a case, only it is written $\partial z/\partial x$ in order to distinguish it from the case in which z is a function of x only, in the full ordinary sense of that phrase. It is called the partial differential coefficient of z with respect to x. Similarly for $\partial z/\partial y$. For instance, in the above case, *i.e.*,

$$z = ax^2 + bxy + cy^2$$
$$\partial z/\partial x = 2ax + by$$

since cy^2 is by definition a constant as far as this rate of change is concerned. Similarly

$$\partial z/\partial y = bx + 2cy.$$

Both these partial differential coefficients will in general be functions of x and of y, as they are in the above case, and will therefore themselves have further partial differential coefficients, defined in the same way. Thus

$$\frac{\partial}{\partial x}\left(\frac{\partial z}{\partial x}\right)$$

which is written for shortness $\partial^2 z/\partial x^2$ is $2a$, and

$$\frac{\partial}{\partial y}\left(\frac{\partial z}{\partial x}\right)$$

which is abbreviated to $\partial^2 z/\partial y \partial x$ is b. Notice that $\partial^2 z/\partial x \partial y$ and $\partial^2 z/\partial y \partial x$ have different meanings as defined above. It can be shown, however, that if they both exist they will be equal, as they are in the present instance. The proof is rather beyond the scope of this work.

The reader should have no difficulty in showing that if z is a function of a function of x and y, *i.e.*,

$$z = f(u)$$

where $$u = \phi(x, y)$$

then $$\frac{\partial z}{\partial x} = \frac{df(u)}{du}\frac{\partial u}{\partial x}$$

and

$$\frac{\partial z}{\partial y} = \frac{df(u)}{du}\frac{\partial u}{\partial y}$$

The proof follows exactly the same lines as for the rule for the differentiation of a function of a function and is omitted to save space. Consider, for instance, the anode current of a triode valve, which, using the usual symbols, can be expressed in the form

$$i_a = f(v_a + \mu v_g + a)$$

where a is a constant. The quantities v_a and v_g are independent variables and have probably been varied independently by readers of this paper on many occasions. The relation can be put in the form

$$i_a = f(V) \text{ where } V = v_a + \mu v_g + a$$

which gives i_a as a function of a function of the two variables. The slope of the anode current—grid voltage characteristic is

$$\frac{\partial i_a}{\partial v_g} = \frac{df(V)}{dV}\frac{\partial V}{\partial v_g} = \mu\frac{df(V)}{dV}$$

and of the anode current—anode voltage characteristic

$$\frac{\partial i_a}{\partial v_a} = \frac{df(V)}{dV}\frac{\partial V}{\partial v_a} = \frac{df(V)}{dV}$$

so that

$$\frac{\partial i_a}{\partial v_g} = \mu\frac{\partial i_a}{\partial v_a}$$

Notice that $df(V)/dV$ is the slope of what is sometimes called the "lumped volts" characteristic.

11. Critical Values.

Given a circuit or some other combination of apparatus the performance of which depends on, or, in other words, is a function of, some variable condition of operation, it is generally desirable and sometimes very important to know what condition of operation will give the best performance. Suppose, for instance, that a battery is to supply electrical power to some variable load resistance. What will be the magnitude of the resistance which will absorb the maximum power from a battery of given characteristics? Such problems are of frequent occurrence in applied electricity, and the technique of the differential calculus finds one of its most valuable applications in the solution of such problems.

First, let us examine a little more closely the example quoted above in order to get a

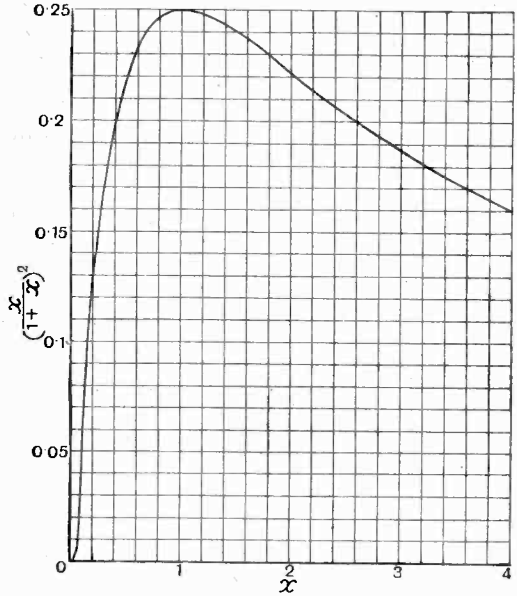


Fig. 30.

clearer idea of the nature of the problem. If the "open circuit" E.M.F. of the battery is e volts, its internal resistance R_0 ohms, and the resistance of the load R ohms, then the current will be

$$i = e/(R_0 + R)$$

amperes, by Ohm's Law. The power absorbed by the load will be

$$p = i^2 R = \frac{R}{(R+R_0)^2} e^2$$

and is thus a function of R for given constant values of e and R_0. It is therefore also a function of the ratio R/R_0, and for the present purpose is more conveniently expressed in terms of this ratio. Putting x for R/R_0,

$$p = \frac{x}{(1+x)^2} \frac{e^2}{R_0}$$

and the variation of the power p with R is seen to be essentially the variation with x of the function $x/(1+x)^2$. Calling this function y, the variation of y with x is shown in Fig. 30. This is the simplest form of "efficiency curve" and in most practical cases the variation of electrical efficiency will be of this character. It appears from the diagram that y reaches a pronounced maximum value of $\frac{1}{4}$ when x is 1, *i.e.*, when $R=R_0$. Therefore in this particular case the maximum power obtainable from the battery is $e^2/4R_0$, and the "optimum" load corresponding to this output is a load equal to the internal resistance of the battery.

Now let us see how this same conclusion could be reached without the trouble of drawing the curve of the function, by applying the technique of the differential calculus.

In Fig. 31 the point P_1 is assumed to correspond to the maximum value reached by y in the range 0 to x_1 of x, y being a continuous function of x in the range illustrated in the diagram. Up to P_1, y increases with x so that dy/dx is positive. From P_1 to P_2 y decreases with x so that dy/dx is negative. The point P_1 therefore separates positive and negative values of dy/dx. It will be assumed that the variation of dy/dx is continuous. Then the point of separation of positive and negative values is the value

$$dy/dx = 0$$

(*i.e.*, the tangent at P_1 is parallel to the x axis). Notice that from 0 to x_2, dy/dx

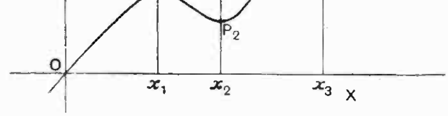


Fig. 31.

decreases continuously. This means that $d(dy/dx)/dx$, or d^2y/dx^2 is negative throughout this range and therefore negative at P_1. Thus for the maximum value at P_1 (corresponding to the value x_1 of x)

$$dy/dx = 0$$
$$d^2y/dx^2 < 0 \text{ (\textit{i.e.}, is negative)}$$

or, another way of writing it,

$$dy/dx_1 = 0$$
$$d^2y/dx_1^2 < 0$$

In a precisely similar manner, the point P_2 will be a minimum if

$$dy/dx_2 = 0$$
$$d^2y/dx_2^2 > 0 \quad (i.e., \text{ is positive}).$$

It is important to notice that the condition $dy/dx=0$ alone will not necessarily determine a maximum or minimum value of y. At P_3, for instance, the tangent is parallel to the axis of x, so that $dy/dx=0$. However, dy/dx is positive on both sides of P_3. Therefore zero is a minimum value of dy/dx, and d^2y/dx^2 passes through zero at P_3. This is known as a point of inflection.

The example already considered will serve as an illustration of a maximum value.

If $$y = x/(1+x)^2$$

$$dy/dx = \{(1+x)^2 - 2x(1+x)\}/(1+x)^4$$

which reduces to

$$dy/dx = (1-x)/(1+x)^3$$

so that

$$dy/dx = 0 \text{ when } x = 1$$

Also it is easy to show that

$$d^2y/dx^2 = -2(2-x)/(1+x)^4$$

which is negative when $x=1$. Therefore y passes through a *maximum* value ($\frac{1}{4}$) when $x=1$.

The following is a very useful practical point in connection with maximum and minimum values. It frequently happens that the quantity to be investigated can be regarded as a function of a function, *e.g.*,

$$y = \phi(u)$$

where

$$u = f(x)$$

The critical condition is then

$$\frac{dy}{dx} = \frac{d\phi(u)}{du} \cdot \frac{du}{dx} = 0$$

so that either

$$\frac{d\phi(u)}{du} = 0$$

or

$$\frac{du}{dx} = 0$$

and in the majority of cases it will be the second condition that counts. Take, for instance, the case

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

where R, L, and ω are constant numbers and C is variable. This is in effect

$$y = 1/\sqrt{u}$$

where

$$u = R^2 + (\omega L - 1/\omega C)^2$$

There is no critical condition for dy/du, but

$$du/dC = 2(\omega L - 1/\omega C)/\omega C^2$$

which will be zero when $\omega L = 1/\omega C$. There is no need to write out the whole differentiation in full in this or similar cases.

Examples.

1. Find the first, second and third derivatives of
   i. $ax^2 + bx + c$.
   ii. $a + b/x + c/x^2$.
   iii. $30 \sin x + 15 \sin 2x + 10 \sin 3x$.
   iv. $\varepsilon^{ax} \sin bx$.
   v. a^x.
   vi. $a^x \log(\sin x)$.

2. Solve the equation

$$dQ/dt = -Q/CR$$

where C and R are numbers, given that Q is 10 when t is 0.

3. Solve the equation

$$d^2i/dt^2 = -25m^2t$$

where m is a number, given that i is 0 when t is 0 and that i is 10 when t is $\pi/2m$.

4. Find

$\partial z/\partial x$, $\partial z/\partial y$, $\partial^2 z/\partial x^2$, $\partial^2 z/\partial y^2$, $\partial^2 z/\partial x\partial y$, $\partial^2 z/\partial y\partial x$

for

$$z = ax^2 + bxy + cy^2$$

and

$$z = \varepsilon^{ax+by} \sin xy.$$

5. Discuss the critical values of
   i. $x/(1 + 2ax + x^2)$.
   ii. $x/(1 + x^2)$.

Answers to Examples in August Issue.

1. If θ is the angle between the two vectors the area of the parallelogram is

$$ab \sin\theta = ab\sqrt{1 - \cos^2\theta}$$
$$= \sqrt{(ab)^2 - (\mathbf{a.b})^2}$$

2. Use formula

$$c^2 = a^2 + b^2 - 2ab\ cos\ \gamma\ .\ c = 20.09 \text{ cms.}$$

3. $Tan\ 60^\circ = sin\ 60^\circ / \sqrt{1 - sin^2 60^\circ} = 1.732.$

$Sec\ 60^\circ = 1/\sqrt{1 - sin^2\ 60^\circ} = 2.0.$

4. i. Express $tan\ (A+B)$ as $sin\ (A+B)/cos\ (A+B)$ and divide top and bottom by $cos\ A\ cos\ B$.

ii. Put $A = B = \theta$ in the preceding result.

iii. and iv. Expand $(cos\ \theta + j\ sin\ \theta)^3$ and equate to $(cos\ 3\theta + j\ sin\ 3\theta)$.

i. 5; 6.403; 7.81.

ii. $r = 19.21\quad \theta = 51^\circ 21'$

iii. $r = 3.606\ \theta = 56^\circ 18'$

iv. $r = 1.46\quad \theta = 1^\circ 56'$

v. $r = 0.484\ \theta = -50^\circ 36'$

6. These vectors are not parallel and their sum is zero.

7. $1.59 + .626j;\ -1.339 + 1.065j;\ -.541 - 1.621j.$

8. Since $ds/dt = 50 + 100t$, $s = 50t + 50t^2 + C$, where C is an unknown constant. Therefore time travelled in an hour from instant $t = 0$ is

$$50 \times 3{,}600 + 50 \times 3{,}600^2 \text{ cms.} = 6{,}482 \text{ kilometres.}$$

9. $ds/dt = 500 - 10t$. This is 0 when $t = 50$ seconds. Putting t=50 in the original equation gives a distance of .125 kilometre. It will return to starting point in 100 seconds.

Book Reviews.

NAVIGATIONAL WIRELESS. By S. H. Long, D.Sc., M.I.E.E. 164 pp.+xi. with 156 Figs. Chapman & Hall. Price 12s. 6d. net.

This book is written with a double object, viz., to enlighten the radio operator on the subject of navigation and to enlighten the navigating officer on the subject of radio direction-finding and thus to develop a much-to-be-desired close co-operation between them. We can say at once that the book is well written and well illustrated and admirably adapted to fulfil its object. It devotes the first two chapters to elementary electrical theory and the principles and application of the 3-electrode valve, then follow two chapters on the principles of direction-finding by the various methods which have been devised. A chapter is devoted to the practical installation of a single-frame aerial on a ship, with special reference to the apparatus made by Siemens Bros., the author being connected with this firm. The sixth chapter deals in a very thorough and practical manner with the errors due to the metal mass of the ship, other errors such as those due to night effect and coastal refraction being dealt with in a later chapter. Three chapters are devoted to maps and the navigational side of direction-finding and a concluding chapter to beacon stations and under-water acoustic methods of signalling and sounding. There are five appendices of assorted information. In looking through the book we noted a few points which might have been put more clearly. For instance, on page 2, where it is stated that a drift of $10^{19}/1.57$ electrons per second would produce a charge of 1 coulomb, and on page 5 where we read that "the number of changes of direction per second is termed the *half frequency*. Frequencies up to 1,000 reversals per second are usually considered as low frequencies." The italics are in the original and they emphasise the confusion. If one is ever unwise enough to call the number of changes of direction per second anything at all, we trust that it will be something less misleading than the half frequency, seeing that it is twice the frequency. On page 14 the author seems to have a confused idea as to what constitutes the primary and secondary of a transformer when he says that "the transformer should be of the step-down type, *i.e.*, one in which the large voltage and small current in the *secondary* is transformed into a small voltage and comparatively large current in the *primary*"; this is not a misprint as the same mistake occurs elsewhere on the same page.

The treatment of the E.M.F. induced in an oscillatory circuit on page 33 is far from clear, the idea being apparently that the E.M.F. induced in the aerial increases as the aerial is tuned. We doubt whether it is quite correct to say on page 55 that the Robinson or Cranwell system of direction-finding works on positions of maximum signals; the reversal of the auxiliary coil is equivalent to swinging a single coil over a large angle and thus balancing the signals on either side of the maximum but considerably removed from it. These are minor criticisms and the book is one which can be recommended to those interested in the subject.

G.W.O.H.

EXPERIMENTAL RADIO. By R. R. Ramsey. Second Edition, 109 pp. Published by the author at the University Book Store, Bloomington, Indiana, U.S.A. Price 2 dollars.

The author is Professor of Physics at the University and the book is a mimeographed collection of laboratory instructions for carrying out 85 experiments dealing with radio work. Very complete instructions are given together with the underlying theory where necessary, and references given with each experiment to the relevant pages of several of the best known text books. The experiments cover all the practical work which a student would normally do in any course in radiotelegraphy. We have one adverse criticism to make and that is that the diagrams are in many cases very badly drawn; if the author replied that they were good enough for their purpose we should retort that they were calculated to cultivate an untidy habit in the writing up of experimental results, and in the setting up of apparatus. Apart from this we have nothing but praise for the book which should prove invaluable to those who have to plan and conduct a laboratory for radio instruction.

G.W.O.H.

A Reed Rectifier for Battery Charging.

The Construction of a Simple, Silent and Non-sparking Instrument.

By C. O. Browne, B.Sc.

A GREAT many amateurs are desirous of doing their own accumulator charging from the public lighting mains, but are confronted with the difficulty that their supply is alternating. Many resort to the Nodon cell or some other form of chemical rectifier, and others have arranged systems of mechanical rectifiers, but unfortunately very often have given them up in disgust. It is hoped, therefore, that the following somewhat detailed description of a vibrating reed rectifier and charging board built by the author will provide fresh stimulus to those who are anxious to have some economical means of charging accumulators from A.C. mains.

Details of the action of reed rectifiers have been published previously in *E.W. & W.E.* and the apparatus to be described is one of the simpler types employing only half-wave rectification. A modification is suggested, however, whereby both halves of the wave are rectified. Unlike the usual run of reed rectifiers, that possessed by the author has a mercury break and has the advantage that when properly adjusted it is absolutely

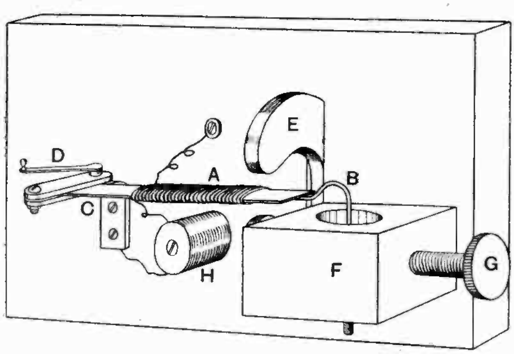


Fig. 1.

silent in operation. Again, the apparatus is far more economical than the Nodon or Tantalum rectifier, as the transformer supplying the current steps down to ten volts only, there being practically no loss due to the internal resistance of the rectifier.

Details of the reed system may be gathered largely from the perspective diagram Fig. 1. The reed *A* consists of a piece of stalloy iron wound with 200 turns of 42 D.S.C. wire, to which is soldered the dipper *B* consisting of a short length of iron or platinum wire.

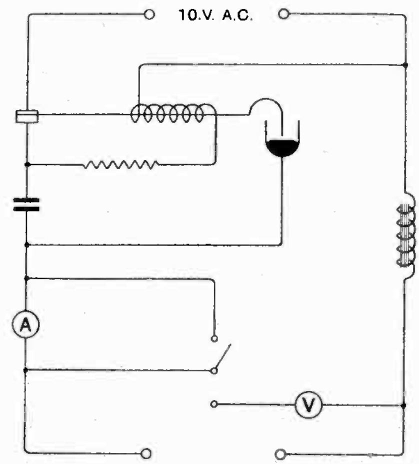


Fig. 2.

The other contact is a mercury cup *F* cut in a block of ebonite ; provision being made to adjust the level of the mercury by the screw *G*. A clamp *C* made from a few pieces of odd brass and two screws serves to hold the end of the reed. The rough adjustment of the period of vibration of the reed to that of the mains is provided by slipping the reed in the clamp, and the fine tuning obtained by loosening or tightening one of the clamp screws mentioned by means of the lever *D*. A permanent magnetic field is maintained across the end of the reed by the telephone magnet *E*. Connections are made as in Fig. 2, the winding on the reed being in series with a resistance (*H*, Fig. 1) to limit the amplitude of vibration to 3 or 4 mm. and the whole shunted across the input.

Other necessaries to complete the equipment are a 2μF condenser bridged across the mercury break to prevent sparking, and a small choke consisting of about 40 turns of thick wire wound on an iron core in series with the output. The ammeter and voltmeter do not call for any particular attention, but it should be noted that since only half-way rectification is employed, if the ammeter is of the moving iron variety it will not indicate the mean value of the charging current. To obtain the mean value the current indicated must be multiplied by the factor $2/\pi$ or .64 approximately. The same factor applies to the readings of a moving iron voltmeter when there is not an accumulator connected to the output. Moving coil instruments will indicate the mean values. Although a rheostat has not been included in Figs. 2 and 3, this accessory may be inserted in the lead from the reed to the ammeter. The single pole double-throw switch cuts out the meters when they are not required.

Fig. 3 suggests an arrangement for a rectifier for full-wave rectification, the two reeds being held under one clamp situated in the same magnetic field and provided with independent mercury cups. The windings on the reeds should be so arranged that there is a phase difference of 180 degrees between their movements. Thus, by adjusting the levels of the mercury in the cups, the two reeds could be prevented from making contact at the same time. A certain amount of latitude might be expected in this adjustment since the contacts are made and broken when the current from the secondary of the transformer is zero.

For a trial the half-wave rectifier was left running continuously day and night without attention for a week at 6 volts and 1.5 amps,

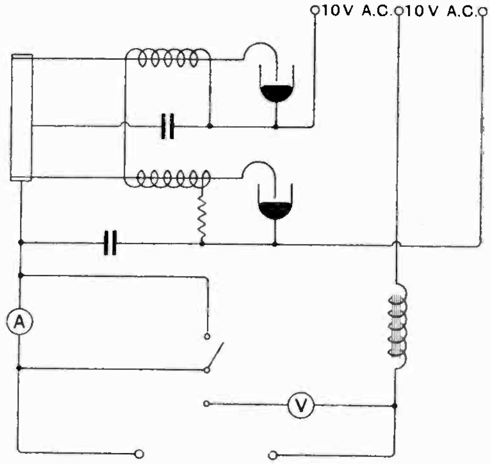


Fig. 3.

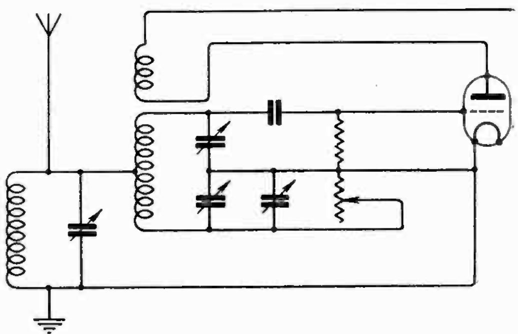
as read on moving iron instruments, and has now been in use for two years charging for 24 hours each week. The only renewal necessary has been that of the mercury every three or four months, and the initial cost apart from that of the condenser and meters was nothing.

Design and Construction of a Superheterodyne Receiver.

CORRECTION NOTE.

Our attention has been drawn to an error which appeared in Fig. 13 illustrating the article on "Design and Construction of a Superheterodyne Receiver," by P. K. Turner, A.M.I E.E.

The corrected figure is here reproduced and should replace that on page 339 of the June, 1927, issue.



Note on the Measurement of Dielectric Losses and Permittivity at Radio Frequencies.

By Raymond M. Wilmotte, B.A.

IN measuring the loss and permittivity of a solid dielectric, it is usual to place the sample between two electrodes (which may be of mercury), thus forming a condenser, which is measured by any of the usual methods. The permittivity is then calculated from the size of the electrodes and their distance apart.

This calculation, however, is liable to error due to the edge effects, which are not wholly accounted for in the formulæ. Thus, suppose the two electrodes are made of equal circular plates of radius r and kept at an average distance b apart, if we neglect the edge effects, the capacity will be given by

$$c = \frac{Kr^2}{3.6b}\mu\mu\text{F} \quad \ldots \ldots \quad (1)$$

where K is the permittivity of the dielectric.

Kirchhoff has calculated the case to allow for the edge effect, when the thickness and the distance apart of the electrodes is small compared with their radius. The capacity that has to be added to formula (1) to give the true geometric capacity between the electrodes is

$$\delta c = \frac{Kr}{3.6\pi}\left[\log_\epsilon\frac{16\pi(b+t)r}{b^2} + \frac{t}{b}\log_\epsilon\frac{b+t}{t} - 3\right] \quad (2)$$

where t is the thickness of the electrodes (of equal radius r).

When the capacity to be measured is of the order of 100 or 200$\mu\mu$F, as often occurs, and mercury is used, it will often be found that this correction on formula (1) represents 5 per cent. or even more of the total. Even this correction, however, is only a rough approximation, for the thickness of the mercury electrodes can hardly be less than 2 mm., which will be comparable with the thickness of the dielectric, so that the stray field will pass partly through the dielectric and partly through air. There will also be a direct capacity of the insulated electrode to earth, which cannot be calculated in practical cases. Tinfoil may be used instead of mercury to make the electrodes thin and the correction given by equation (2) apply more exactly; but the contact between the electrodes and the dielectric will not be so good, unless a conducting liquid be inserted between the two. This will generally take the form of an electrolyte, but the water may be absorbed by the dielectric and thus alter its properties. All these errors will gain in importance, if the sample under test is thick.

To obtain true results, the use of a guard ring and a screen appear desirable, when equation (1) will hold together with a small correction given by Maxwell to allow for the small distance between the guard ring and the electrode. This correction is given by

$$\delta c = \frac{r\omega}{3.6\,(b+0.22\omega)}\left(1 + \frac{\omega}{2r}\right)\mu\mu\text{F} \quad \ldots \quad (3)$$

where ω is the width of the channel between the guard ring and the electrode. The ratio of r to b can have any value so long as this is large compared to ω and the width of the guard ring is at least 4 or 5 times b.

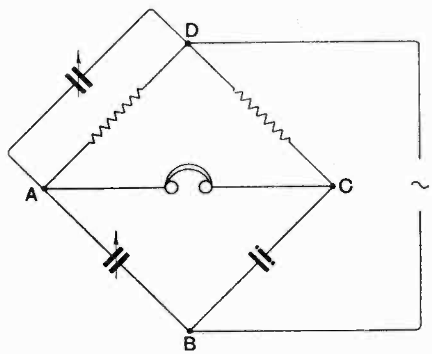


Fig. 1.

At low frequencies, where bridge methods of measurement can be used, there should be no difficulty in using a guard ring and keeping it at the potential of the insulated electrode. Thus in the equal armed bridge, Fig. 1, the guard ring can first be connected to A and then to C. Let C_1, C_1' be the readings of the condenser in the arm AB, and C_0, C_2 be the capacities of the guard ring and plate respectively to the other electrodes.

Hence $C_1 + C_0 = C_2$

and $C_1' = C_0 + C_2$.

Therefore $C_2 = \frac{1}{2}(C_1 + C_1')$.

The condenser in the arm AD is to balance the resistance component of the condenser undei test.

Otherwise a system can be adopted similar to a Wagner earth having the neutral point connected to the guard ring as shown in Fig. 2.

At high radio frequencies bridge methods have not yet been found satisfactory, so that the methods suitable for low frequencies will not apply. The following method should, however, prove satisfactory. The E.M.F. is induced in a stranded coil B (Fig. 3). One of the strands is connected to the guard ring and to the earthed electrode of C. The

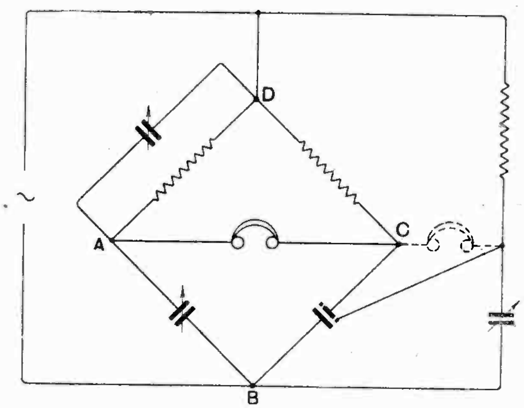


Fig. 2.

other strands are connected as usual to the condenser C and the condenser to be measured. In this way the guard ring is always at the same potential (except for the small ohmic drop) as that of the insulated plates of condenser C. The circuit is tuned with the plate D in and then out of the circuit. If K_1 is the difference in the two readings of the condenser C, and C_0 is the capacity representing the tubes of force from the shield to the upper side of plate D, then the capacity required is $(K_1 - C_0)$. Let this be C_1.

It will be seen that the ammeter A in Fig. 3 does not measure the current through the guard ring, so that measurements of the effective resistance of the condenser can be made in the usual way by the resistance variation or other method.

The value of C_0 can be found in the following way. Once found, it can be used for all cases, for it will not vary appreciably with the thickness of the electrode or of the dielectric.

Let C_2 be the geometric capacity between the shield and the lower electrode including the earth capacities.

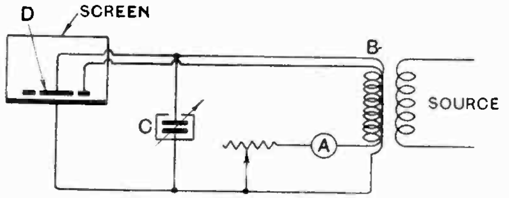


Fig. 3.

The capacity between the electrode D and the lower electrode with the screen disconnected from the lower electrode is measured as before, keeping the guard ring at the same potential as D. Let K_2 be the capacity measured. The screen is then connected to the electrode D and the capacity again measured. Let this be K_3.

Hence $K_1 = C_1 + C_0$

$$K_2 = C_1 + \frac{C_0 \ C_2}{C_2 + C_0}$$

$$K_3 = C_1 + C_2.$$

From these three equations we find—

$$C_0 = K_1 - K_2 + \sqrt{K_2^2 + K_3K_1 - K_1K_2 - K_2K_3}$$

The guard ring could be cut out of a brass sheet with a metal ring about 0.5 cm. in height along the inner circumference. A thin rubber band just overlapping the lower edge of the ring could be stuck on to it. (A section is shown in Fig. 4.) The sample

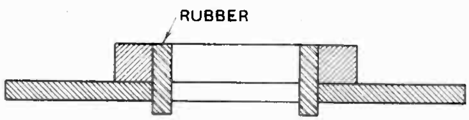


Fig. 4.

would be floated on mercury, the guard ring put on and the mercury poured within the ring, thus forming the insulated electrode. The whole would then be covered by the metal screen.

It is necessary to allow the rubber to overlap the guard ring slightly in order to allow for any irregularities in the surface of the sample.

Abstracts and References.

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PROPAGATION OF WAVES.

ON THE NATURE OF WIRELESS SIGNAL VARIATIONS —I.—E. V. Appleton and J. A. Ratcliffe. (*Proc. Roy. Soc., A*, 115, pp. 291-305, July, 1927.)

The paper is summarised as follows:—

1. Two methods of measuring the angle of incidence of downcoming wireless waves are described. The two methods have different ranges of applicability. Both involve photographic registration. The first method utilises the ordinary night-time signal variations and can be employed in connection with any steady transmitting station. It only yields useful results if the natural signal variations are small. The second method requires a controlled wavelength change at the transmitter, but may be used even when the natural signal variations are large.

2. The mean values of the angle of incidence, as measured by these two methods, for the periods immediately following sunset and preceding sunrise, show a close agreement, and lead to an effective height of 90-100 kilometres for the atmospheric deflecting layer.

3. Observations of the angle of incidence, made by these methods, indicate a diurnal variation in the height of the ionised layer, which is found to be higher in the middle of the night than during the sunset and sunrise periods.

4. Comparatively rapid fluctuations have been observed in the angle of incidence of downcoming waves. Such fluctuations are not considered as being due to variations in the height of the ionised layer, but are explained by supposing that "reflection" takes place at different points on a layer the mean height of which is sensibly constant. Such variations might be expected if the layer were not of sensibly uniform horizontal stratification.

ON THE NATURE OF WIRELESS SIGNAL VARIATIONS —II.—E. V. Appleton and J. A. Ratcliffe. (*Proc. Roy. Soc., A.*, 115, pp. 305-317, July, 1927.)

The paper is summarised as follows:—

1. An account is given of experiments designed to yield information on the nature of the variations of downcoming wireless waves, which are responsible for nocturnal signal variations. By employing a receiving assembly which is a combination of a loop and vertical aerial, it has been possible to eliminate the effects of the ground waves at the receiving station and to study the characteristics of the downcoming wave directly. Large variations in the intensity of the downcoming waves are found.

2. It is pointed out that fading may be due to changes in any of the following variables which determine the nature of the downcoming waves:—

(*a*) Angle of incidence;
(*b*) Intensity;
(*c*) Phase;
(*d*) Polarisation.

It is shown that for wavelengths of about 400 metres and distances of about 80 miles, fading is chiefly due to changes in the intensity of the downcoming waves. Variations in the phase relation between ground and sky waves are a secondary cause of fading. Changes in the angle of incidence or polarisation of the downcoming wave are not responsible in any very marked degree for signal variations.

3. The downcoming ray has been shown to be of complex polarisation, having electric vectors both in, and at right angles to, the plane of propagation. Similar intensity variations are found in both these vectors.

4. The use of a suppressed atmospheric ray system in reception for the minimisation of fading, and in transmission, for preventing the emission of upward rays, is discussed. Such a system may be used to find the angle of incidence of downcoming rays in the absence of direct rays.

SHORT-WAVE WIRELESS TELEGRAPHY.—T. L. Eckersley. (*Journ. Inst. Elect. Engineers*, 65, pp. 600-644, June, 1927.)

A paper read before the Wireless Section, 2nd March, 1927.

Abstracts of the paper were published in *E.W. & W.E.*, of April, pp. 213-222, and in the *Electrical Review*, of 17th June, pp. 996-997.

TRANSMISSION OF ELECTRIC WAVES THROUGH THE IONISED MEDIUM.—T. L. Eckersley. (*Philosophical Magazine*, 4, 20, pp. 147-165, July, 1927.)

A mathematical investigation showing that in a medium containing free electrons there is a certain critical frequency characterised by the fact that waves of lower frequency than this cannot travel through the medium.

The physical reason for the existence of such a critical frequency is shown to be connected with the fact that the electrons in the medium rob the wave of its momentum, and at the critical frequency also rob this momentum completely so that the wave can travel no farther.

This fact is shown to be connected with the theory of Compton scattering, in which an individual quantum gives up its momentum in collision with an electron. The wave is brought to a standstill when all the quanta (per unit volume) are brought into collision with the electrons, which event occurs when the critical frequency is approached.

SUR LES PROPRIÉTÉS DIÉLECTRIQUES DES GAZ IONISÉS ET LA PROPAGATION DES ONDES ELECTROMAGNÉTIQUES DANS LA HAUTE ATMOSPHÈRE (On the dielectric properties of ionised gases and the propagation of electromagnetic waves in the upper atmosphere).—H. Gutton and J. Clément. (*L'Onde Electrique*, 6, 64, pp. 137-151.)

Description of experiments undertaken with a view to observing the apparent diminution of the dielectric constant of an ionised gas predicted by Eccles' theory. This diminution was verified by the authors with the gas at low pressure, but was found to cease as the ionisation becomes greater, a sudden increase occurring when the ionisation reaches a certain value, which is the lower the longer the wavelength. Eccles' theory does not predict this increase, but the theory does not take into consideration the mutual action between the ions. The experimental results are completely explained if this mutual action introduces quasi-electric forces which determine the existence of a period of resonance. It is shown how this resonance can account for the reduced range and irregularity of signals transmitted on wavelengths in the neighbourhood of 200 metres (*cf. Comptes Rendus*, 184, pp. 441 and 676; these abstracts *E.W. & W.E.*, May and June, 1927, pp. 312 and 368 respectively).

PENETRATION OF RADIO WAVES.—A. Eve and D. Keys. (*Nature*, 2nd July, 1927, p. 13.)

Information as to the extent to which wireless waves penetrate into the ground has become of special interest owing to there now existing two or three geophysical methods of ore prospecting which definitely attempt to use wireless waves for the detection of ore beneath the earth.

While experiments with submerged submarines prove that radio waves will not pass more than about 50 or 60 feet into seawater, no matter what the wavelength, the question of penetration into fresh water, damp rock and dry rock remains very uncertain.

This letter is written to express the hope that some experimenters may be able to carry out investigations underground in a cave, tunnel, or mine which is absolutely devoid of wires or other conductors, and where the windings from the entrance are sufficiently devious to preclude the passage of waves down to the receiver through air.

LA PROPAGATION DES ONDES ELECTROMAGNÉTIQUES (Propagation of electro-magnetic waves).—Com. Metz. (*Q.S.T. Français et Radio Electricité Réunis*, 8, 36 and 37, pp. 63 and 25 respectively.)

A brief historical summary of the work done on wave propagation, reviewing the ideas that are to-day accepted, and their application to the employment of very short waves to meteorology and direction-finding.

EXPÉRIENCES SUR LA PROPAGATION DES ONDES RADIOTÉLÉGRAPHIQUES EN ALTITUDE (Experiments on the propagation of radio waves at an altitude).—P. Idrac and R. Bureau. (*L'Onde Electrique*, 6, 66, June, 1927, pp. 266-267.)

A paper that appeared in *Comptes Rendus*, of 14th March, an abstract of which is to be found in *E.W. & W.E.*, of June, 1927, p. 368.

ATMOSPHERIC ELECTRICITY.

LOI DE DISTRIBUTION DES ORAGES MAGNÉTIQUES ET DE LEURS ELÉMENTS. CONSÉQUENCES À EN TIRER SUR LA CONSTITUTION DU SOLEIL (Law of distribution of magnetic storms and their elements. Inferences to be drawn regarding the composition of the sun).—H. Deslandres. (*Comptes Rendus*, 185, pp. 10-14, 4th July, 1927.)

The author finds that magnetic storms can be divided into groups, in each of which the intervals between the maximum points of the storms, expressed in solar longitudes, are exact multiples of 15 degrees. Successive points of the same storm indicate influxes of electrified particles of different velocity which, emitted at the same time, are deviated by a different angle and separated by the sun's exterior magnetic field. It is as though the corpuscular and even also the undulatory emissions emanated from a deep invisible layer which rotates like a solid body and presents at least 24 permanent volcanoes, of variable activity, distributed uniformly around the axis of rotation. This emitting layer would be the first cause of all the phenomena observed in the sun and what depends on it, and subject at the same time to the great undecennial oscillation. All the magnetic disturbances must therefore be carefully followed during at least one whole period of 11 years. The present article presents an analysis of the eight principal storms of the years 1917, 1918 and 1919, that for the years 1920-1926 having been given previously.

LE CHAMP MAGNÉTIQUE TERRESTRE ET LES PROPRIÉTÉS ELECTROMAGNÉTIQUES INTERNES DU GLOBE (The terrestrial magnetic field and internal electro-magnetic properties of the globe).—M. Brillouin. (*Comptes Rendus*, 184, 13th June, 1927, pp. 1381-1385.)

ON CERTAIN AVERAGE CHARACTERISTICS OF WORLD-WIDE MAGNETIC DISTURBANCE.—S. Chapman. (*Proc. Roy. Soc. A.*, 115, pp. 242-267, July, 1927.)

CURRENTS CARRIED BY POINT-DISCHARGES BENEATH THUNDERCLOUDS AND SHOWERS.—T. W. Wormell. (*Proc. Roy. Soc. A.*, 115, pp. 443-455, July, 1927.)

MÉSURES SUR LES GROS IONS À PARIS.—J. MacLaughlin. (*Comptes Rendus*, 184, 20th June, 1927, pp. 1571-1573.)

Certain results of these observations have already been given (*Comptes Rendus* 184, p. 1183, these abstracts, *E.W. & W.E.*, August, 1927). The present paper summarises some new results concerning the absorption of solar radiation by the ions, their relation to the meteorological elements, and the excess of ions of one sign.

PROPERTIES OF CIRCUITS.

GITTERGLEICHRICHTUNG (Grid rectification).—Y. Groeneveld, B. v.d. Pol, jr., and K. Posthumus. (*Zeits. f. Hochfrequenz.*, 29, 5, pp. 139-147, May, 1927.)

The purely rectifying properties of a triode in the grid rectification circuit-arrangement depend practically exclusively upon the shape of the grid characteristics and the grid circuit constants. It is shown by means of characteristics that the anode tension has very little influence.

The grid current characteristic is exponential over a wide range, and the inclination of the logarithmic grid-current curve is determined entirely by the temperature. For a given triode the lighting up tension has little influence on this inclination, since the temperature of the emitting part alters little as a percentage.

The increase in grid tension necessary to raise the grid current e fold (where e is the electronic charge) is called the *temperature tension*.

From the calculation it follows that the rectifying effect is numerically the same for all triodes, if all tensions are expressed in terms of temperature tension: if the rectifying effect is expressed as a percentage of the high frequency tension, then this relation is the same for two triodes with different temperature tensions in the case where two signals are observed that behave like temperature tensions. From this it follows, that for the rectification of weak signals, triodes with small temperature tension are advantageous. Miniwatt valves are therefore to be preferred in this respect to thorium and wolfram valves (bright emitters).

For strong signals the rectifying effect is always about equal to the peak tension of the signal, whatever the type of triode.

LIEFERT EIN ABREISSENDER MODULIERTER UNGEDÄMPFTER SENDER MODULIERTE HOCHFREQUENZ? (Does a modulated I.C.W. transmitter yield modulated high frequency?) —F. Fischer. (*Zeitschr. f. Hochfrequenz.*, 29, 6, pp. 191-194.)

With short waves, it often appears desirable to work, not with an absolutely undamped wave, but with a broader frequency band. In this way the effect of small deviations in the receiver can be eliminated. With beat reception, however, it is not sufficient to modulate the transmitter, since then the heterodyne note always reproduces the variation of the carrier wave or a wave in the side band. Only complete modulation of the transmitter, that can be attained with certainty most simply by working the transmitter with anode alternating current, achieves this end. Then a pure heterodyne note no longer results, the transmitter sounding like a quenched spark transmitter. The theory of this experimental fact is considered here. It is found that a modulated I.C.W. does not in general yield modulated high frequency; beat reception of the complicated oscillation phenomenon that arises producing no heterodyne note, but a noise.

ÜBER SCHWINGUNGSERZEUGUNG MITTELS ELEKTRONENRÖHREN-SYSTEMEN, WELCHE SELBSTINDUKTION NICHT ENTHALTEN (On the generation of oscillation by valve systems containing no self-inductance).—K. Heegner. (*Zeitschr. f. Hochfrequenz.*, 29, 5, May, 1927, pp. 151-154.)

The manner of working of the "multivibrator" (Abraham and Bloch, *Ann. de Physique*, 1919, p. 237) is discussed, and the instability of the direct current state is represented by a diverging infinite series. The influence of capacities connected in parallel with the anode resistances is more closely investigated. It is shown that the self-excited oscillation can be adjusted to any desired back-coupling, but also that it is possible for the amplitude to vanish or jump to a finite value, depending on the grid potential. The theory of the coupling of the system is developed and it is shown that this fails on the general theory when the coupling is loose. A geometrical construction, given earlier, is described more exactly.

L'AMPLIFICATION À RÉSONANCE AVEC LES BIGRILLES (Resonance amplification with four-electrode valves).—R. Barthélémy. (*L'Onde Electrique*, 6, 64, pp. 152-160.)

The author explains the employment of four-electrode valves to avoid undesired reaction in resonance amplifiers, making a series of stages of high-frequency amplification easily possible.

UNE MÉTHODE SIMPLE DE CALCUL DE L'INDUCTANCE DE MODULATION (A simple method of calculating the modulation inductance).—C. Krulisz. (*L'Onde Electrique*, 6, 66, pp. 255-262, June, 1927.)

The author shows the effect of different factors on the modulation obtained by means of a "constant current" system. Given the fidelity of reproduction to be attained, he deduces a simple formula for determining the modulation inductance.

GRID SIGNAL CHARACTERISTICS AND OTHER AIDS TO THE NUMERICAL SOLUTION OF GRID RECTIFICATION PROBLEMS.—PART I.—W. Barclay. (*E.W. & W.E.*, August, 1927, pp. 459-466.)

UNTERSUCHUNG EINES SCHWINGUNGSKREISES MIT EISENKERNSPULE BEI GERINGER SÄTTIGUNG DES EISENS (Investigation of an oscillatory circuit with an iron-cored coil, the iron being feebly saturated.)—H. Winter-Günther. *Zeitschr. f. Hochfrequenz.*, 29, 5, pp. 148-150, May, 1927.)

DREI DEMONSTRATIONS VERSUCHE AUF DEM GEBIETE DER SCHWINGUNGSTECHNIK (Three demonstration experiments in the range of oscillation technique).—H. Sell. (*Zeits. f. techn. Physik*, 8, 6, pp. 222-230.)

The demonstrations described concern :—

1. A mechanical electrical analogy of the "pull" phenomena in coupled oscillatory circuits.

2. The sound nozzle as a highly sensitive method of electrical measurement.

3. Experiments on the vibration of light membranes.

TRANSMISSION.

ON THE CONSTANTS OF RECEIVING AND TRANSMITTING ANTENNÆ.—R. Wilmotte. (*Philosophical Magazine*, 4, 20, pp. 78-91, July, 1927.)

It is found theoretically that, if the distribution of the constants of an antenna is the same for transmission as for reception, the effective resistance, reactance, and the effective height are also the same in the two cases. The radiation resistance, however, is slightly different.

Experimental evidence down to about 100 metres wavelength showed that the difference in the reactance in the two cases was undetectable, while there was strong evidence that there was a small difference in the resistance, that for reception being slightly greater than that for transmission.

DER GEGENTAKT-RÖHRENGENERATOR FÜR MODULIERTE SCHWINGUNGEN (The "push-pull" valve generator for modulated oscillations.)—P. Schmakow. (*Zeitschrif. Hochfrequenz.*, 29, 6, pp. 171-177.)

The fundamental circuit of the push-pull modulating system requires one oscillation and two speech valves. This paper describes a circuit-arrangement which combines the speech and oscillation adjustments and requires only two valves. The paper considers :—

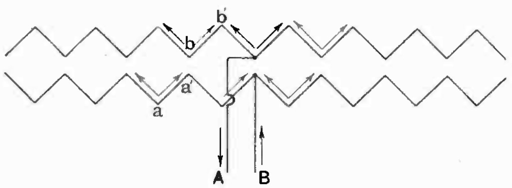
1. The working principle of a two-valve push-pull generator for modulated oscillations.

2. The graphical method of the grid modulating principle; the conditions for undistorted modulation are that the no-load current must be a quarter of the saturation current and the note frequency curve must lie in the region of negative grid potential.

3. The graphical method of the push-pull modulating principle; the conditions for undistorted modulation are given for different no-load cases, distortion occurring when the note frequency curve encroaches into the region of positive grid potential.

NOUVELLE ANTENNE DIRECTIVE SIMPLE POUR ONDES COURTES (New simple directional antenna for short waves).—H. Chireix. (*Q.S.T. Francais et Radio Electricité Réunis*, 8, 37, pp. 43-46.)

In the Bulletin Technique of *Radio Electricité*, 25th July, 1924, the author investigated combinations of transverse and longitudinal alignments and recalls here the practical conclusions drawn. Further consideration has led to the development of a new alignment of antennæ in phase, shown diagrammatically below.



An element such as *aa'*, *bb'* constitutes an antenna of one complete wavelength comprising two doublets of the same sign having the effect of increasing the directivity in the plane of the zenith. This system has been employed for communication between France and the Argentine on a wave of 14 metres 50 with favourable results.

A PROPOS DE L'ANTENNE DE HERTZ (Concerning the Hertz antenna).—J. Balta Elias. (*L'Onde Electrique*, 6, 64, pp. 173-177.)

Since for the transmission of short waves linear antennæ are now frequently employed, without earth, operating in a way that recalls the Hertz oscillator, the author here gives the results of experiments he made last year with a view to clearing up some obscure points in the functioning of these antennæ.

SUR LES OSCILLATIONS DE BARKHAUSEN OBTENUES AVEC DES LAMPES FRANÇAISES (On the Barkhausen oscillations obtained with French valves).—E. Pierret. (*Comptes Rendus*, 184, 13th June, 1927, pp. 1428-1430.)

Description of experiments with wavelengths mostly less than 50 centimetres when certain anomalies were observed which are enumerated here.

SHORT-WAVE TRANSMISSIONS.—*Wireless World*, 29th June, 1927, p. 816.

A list of stations in all parts of the world which transmit fairly regularly on short waves.

RECEPTION.

THE PERFORMANCE OF AN INTERMEDIATE FREQUENCY AMPLIFIER.—M. Scroggie. (*Journ. Inst. Elect. Engineers*, 65, pp. 644-647, June, 1927.)

The paper gives the results of measurements carried out on an intermediate-frequency amplifier forming part of a commercial supersonic heterodyne receiver designed for broadcast reception. The amplifier is described, with special reference to the coupling transformers. Slight modifications of the circuit are necessitated by the method of test, but it is concluded that the conditions of measurement approximate closely to those of normal use.

Three representative types of valves are employed in turn and it is shown that, for a prescribed standard of cut-off at the extremes of the side-bands, the amplification obtainable increases with the mutual inductance of the valves. The best type of valve to use in various circumstances is deduced from the results obtained.

ÜBER DIE EINEM EMPFÄNGER DURCH ERDUNG ZUGEFÜHRTE ENERGIE (On the energy conducted to a receiver through the earthing).—A. Szekely. (*Zeitschr. f. Hochfrequenz.*, 29, 5, May, 1927, pp. 155-158.)

Measurements are described which show that fluctuating tensions are introduced into a receiving circuit, that do not enter by way of the antenna, but through the earth connection. The measurements were carried out not far from the transmitter, and it remains to be discovered whether at greater distances as well the conduction of energy through the earth connection is still noticeable compared with the arrival *via* the antenna, which the author was prevented from investigating for want of a suitable receiver.

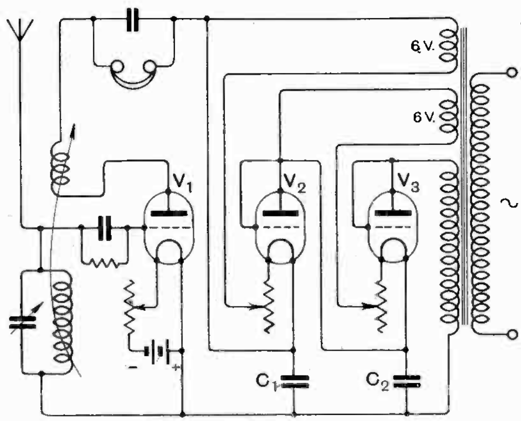
To explain the observations described, the view is expressed that the energy introduced through the earth connection arises from the ground field which sets the buried earth leads in stationary oscillation. This view is supported by the marked variation of the energy arriving through the earth connection. If this view is correct, care will have to be exercised in interpreting the variations of signal strength with earthed receivers, for distinction will have to be drawn between variations due to change of the atmospheric field and those caused by change of the ground field.

NACHTRAG ZU DER ARBEIT: "EIN BEITRAG ZUR THEORIE DER NIEDERFREQUENZ—VERSTARKUNG MIT WIDERSTANDSKOPPLUNG" (Supplement to the paper: "A contribution to the theory of low-frequency amplification with resistance coupling").—H. Kafka. (*Zeitschr. f. Hochfrequenz.*, 29, 6, p. 190.)

In the above paper (*Zeitschr. f. Hochfrequenz.*, February, 1927, these abstracts, *E.W. & W.E.*, May, 1927, p. 308) the frequency dependence of the amplification ratio $\mathcal{E}_{g_1}/E_{g_1}$ of a stage of amplification with resistance-capacity coupling, taking account of the valve capacities, is represented by a locus diagram. It is shown here that the influence of the coupling can be brought out still more clearly by examining the ratio $\mathcal{E}_{g_2}/(E_{g_1}/D_1)$, instead of the ratio $\mathcal{E}_{g_2}/E_{g_1}$. As the frequency varies, the ends of the vector $\mathcal{E}_{g_2}/(E_{g_1}/D_1)$ describe a circle passing through the origin with its centre on the negative effective axis. The diameter of this circle, the formula for which is given, determines the maximum value that the amplification ratio $\mathcal{E}_{g_2}/(E_{g_1}/D_1)$ can assume.

FILTRE THERMOIONIQUE POUR L'ALIMENTATION D'UN RÉCEPTEUR SUR SECTEUR ALTERNATIF (Thermionic filter for supplying a receiver from the mains). — E. Fromy. (*L'Onde Electrique*, 6, 64, pp. 161-167.)

A thermionic valve possesses the property of becoming saturated: when the anode tension



reaches a certain value the current emitted remains strictly constant whatever the tension of the plate. This property can be utilised to control the output of a source of undulating E.M.F. or limit the current to a given value, the only condition being that at no moment the anode tension falls below the value corresponding to saturation. Under these circumstances a valve can play the part of an infinite impedance and be utilised whenever choke coils are ordinarily employed or low-pass filters consisting of inductance and capacity, and in particular, it can be used as filter for supplying a receiver from the mains, the circuit-arrangement being shown in the diagram inset.

Such a thermionic filter can also be used to modulate a transmitter by the constant current method, the circuit-diagram for which is also given.

RESISTANCE-CAPACITY AMPLIFICATION.—W. James. (*Wireless World*, 6th, 13th and 20th July, 1927.)

An article in three parts dealing respectively with: anode circuit conditions and the calculation of voltage amplification, the calculation of coupling condensers and grid-leak values, and stray capacities and their effect on the performance of resistance amplifiers.

SCREENED VALVES.—P. Willans. (*Wireless World*, 27th July, 1927, pp. 107-110.)

Description of a receiving system employing valves which may render unnecessary external neutralisation in H.F. circuits.

PROCÉDÉ D'ELIMINATION DE L'INFLUENCE, À LA RÉCEPTION, DES VARIATIONS DE FRÉQUENCE D'UN POST D'EMISSION À ONDES COURTES (Method of eliminating the effect at the receiver of frequency variations in a short wave transmitting station). — M. Veaux (*L'Onde Electrique*, 6, 66, pp. 263-265, June, 1927.)

SPECTRE DE HAUTE FREQUENCE ET DEFORMATION (High frequency spectrum and distortion).—R. Henon. (*Q.S.T. Français et Radio Electricité Réunis*, 8, 37, pp. 8-16.)

SUR LE CONTACT MÉTAL-SULFURE CUIVREUX (On the metal-cuprous sulphide contact).—J. Cayrel. (*Comptes Rendus*, 185, pp. 46-48, 4th July, 1927.)

The electric applications of imperfect contacts have led them to be considered under the triple aspect of coherers, rectifying detectors, and oscillation generators (Lossev effect). Results are given here establishing a connection between these different aspects and confirming the view of M. Blanc (*thèse*, 1905) as to the relationship between coherers and detectors. They show that:

1. The inversion of the rectification in the case of the contact metal-Cu_2S is due to a unilateral coherence of the contact.

2. This coherence is nothing but the fall of resistance utilised in the case of generating contacts to make d_v/dI negative.

3. The anti-coherence of the contact resistance in the sense metal-Cu_2S differs from the anti-coherences observed by M. Blanc with the aluminium-steel contact only by its discontinuous character and enormous magnitude.

F. SEIDEL'S "SELBSTTÖNENDER KRISTALL" (F. Seidel's "spontaneously oscillating crystal").—K. Lichtenecker. (*Zeits. f. techn. Physik*, 8, 4, pp. 161-163.)

According to F. Seidel (*Phys. Zeitschr.*, 27, 64 and 816) a metal-crystal contact in the circuit of the singing arc is able to give a continuous characteristic note.

The present article shows that the phenomenon is not due to the electro-magnetic oscillations but to the steep temperature gradient occurring at the metal point.

VALVES AND THERMIONICS.

ÜBER RÖHRENVERZERRUNGEN BEI VERSTÄRKERN (Distortion in amplifiers due to the valve).—M. von Ardenne. (*Zeits. f. Techn. Physik*, 8, 6, pp. 235-239.)

Investigation of distortion of the amplitude arising from the curvature of the working characteristic of a valve. Attempt is made to comprehend quantitatively the relation between distortion and input tension and between the curvature of the working characteristic and the resistance in the anode circuit.

DER CHARAKTEROGRAPH UND DIE DYNAMISCHEN CHARAKTERISTIKEN EINER ELEKTRONENRÖHRE (The characterograph and the dynamic characteristics of a valve).—B. Ostroumoff. (*Zeits. f. Techn. Physik*, 8, 4, pp. 163-164.)

Description of apparatus for obtaining automatically electrical characteristics and a method of recording the dynamic characteristics of a valve. Specimen results are shown.

LA LAMPE À DEUX GRILLES (The four-electrode valve).—M. Chauvierre. (*Q.S.T. Français et Radio Electricité Réunis*, 8; 37, 38 and 39; pp. 17, 38 and 68 respectively.)

THE K.L.1 VALVE.—F. E. Henderson. (*Wireless World*, 20th July, 1927, pp. 83-85.)

Constructional details and photographs are given and the advantages of indirectly heated cathode valves explained.

ELECTRON EMISSION FROM THORIATED TUNGSTEN—S. Dushman and J. Ewald. (*Physical Review*, 29, 6, pp. 857-870, June, 1927.)

The following abstract is given :—

Constants of the electron emission from a monatomic layer of thorium on tungsten at temperatures from 1,000 *degrees to* 2,000 *degrees K.*—The electron emission for a monatomic layer of thorium on tungsten is best represented for zero field strength by the relation $I = 3T^2\varepsilon^{-30{,}500/T}$, where I is expressed in amps./cm². The emission was measured for different states of activation of the filament. If we let θ be the fraction of surface covered with thorium, then for $\theta < 0.95$ (approx.) log A_θ varies linearly with b_θ when the emission for the given surface is represented by

$$I = A_\theta T^2 \varepsilon^{-b_\theta/T}$$

It is also pointed out that the emission for a monatomic film of thorium on tungsten is greater than that observed for metallic thorium.

THE CHARACTERISTICS OF TUNGSTEN FILAMENTS AS FUNCTIONS OF TEMPERATURE.—Part II.—H. A. Jones and I. Langmuir. (*General Electric Review*, 30, 7, pp. 354-361, July, 1927.)

Continuation of an article begun in the previous number of the Review, giving the most recent data on the characteristics of tungsten filaments in vacuo at various temperatures.

MEASUREMENTS AND STANDARDS

THE HIGH FREQUENCY RESISTANCE OF A BUREAU OF STANDARDS TYPE VARIABLE AIR CONDENSER.—S. Brown, C. Wiebusch and M. Colby. (*Physical Review*, 29, 6, pp. 887-891, June, 1927.)

A method is described whereby the high frequency resistance of variable air condensers is measured with an accuracy of 1 per cent. Data are given showing the resistance of a Bureau of Standards type 0.0035$\mu\mu$F condenser at wavelengths from 40 to 175 metres and at different positions on the scale. The values obtained range from 0.0283 ohms at 119 metres and 174 degrees scale setting (range 0 degree to 180 degrees), to 0.150 ohms at 63 metres and 20 degrees condenser setting. The resistance increases rapidly towards the lower positions on the scale, and also increases with wavelength. The calculated values of the high frequency resistance of large conductors were checked experimentally.

THE "LAW CORRECTION" OF VARIABLE AIR CONDENSERS.—W. Griffiths. (*E.W. & W.E.*, August, 1927, pp. 479-488.)

DETERMINING THE EXTREMUM SCALAR VALUE OF A COMPLEX QUANTITY.—H. Boyland. (*Electrician*, 24th June, 1927, p. 703.)

In a paper published in the *Proc. Inst. Radio Engineers*, for October, 1926, Mr. Roberts describes a method of determining an extremum of a complex quantity when the variable is either a pure real or pure imaginary quantity. The present article extends the method to the case in which the variable occurs both in the real and imaginary parts of the expression.

ÜBER MESSUNGEN AN PIEZO-ELEKTRISCHEN KRISTALLEN (Measurements on piezo-electric crystals).—K. Heegner. (*Zeitschr. f. Hochfrequenz.*, 29, 6, pp. 177-180.)

A method of recording the resonance curves of piezo-electric crystals is described and the dependence of the damping of an oscillating crystal upon mechanical and electrical influences investigated. A method of finding the coupling of a crystal is given together with observations on the "Ziehen" phenomenon.

DÉFORMATIONS ELECTRIQUES DU QUARTZ (Electric deformations of quartz).—M. Ny Tsi Ze. (*Comptes Rendus*, 184, 27th June, 1927, pp. 1645-1647.)

Description of an attempt to measure directly the small deformations of quartz under the influence of an electric field by the method of light interference. The experimental arrangement is analogous to that of Fizeau in which the relative displacement is observed between a fixed surface and one subject to the displacement under investigation.

Formulæ are given for the deformations in the three directions (normal to optic and electric axes, in direction of electric axis and in that of optic axis) and some idea of the magnitude of the phenomena. It is probably to the purely dielectric deformation in the direction of the optic axis that one must ascribe the third natural frequency of resonant quartz (Hund, *Proc. Inst. Radio Eng.*, 14, p. 447, Aug., 1926).

The deformations of quartz appear to be instantaneous and devoid of hypteresis and are very regular.

CIRCUIT ÉLECTRIQUE ÉQUIVALANT À UN QUARTZ PIEZO-ÉLECTRIQUE (Electrical circuit equivalent of piezo-electric quartz).—F. Bedeau. (*Q.S.T. Français et Radio Electricité Réunis*, 8, 37, pp. 22-24.)

It is shown how by simplifying the elemental circuit (leaving out the resistance) very simple calculation makes it possible to recover the two chief peculiarities observed by Cady, namely the existence of a negative capacity and a crevasse in the resonance curve.

A SIMPLE INDIRECT METHOD OF MEASURING GRID CURRENT.—(*E.W. & W.E.*, August, 1927, pp. 457-458.)

Explanation of von Ardenne's method of measuring very small grid currents described in the March number of the *Zeitschr. für Hochfrequenz.*

DAS EMPFANGS — ÜBERWACHUNGSGERÄT DER REICHS—RUNDFUNK—GESELLSCHAFT (The imperial broadcast society's instrument for checking reception).—W. Reisser. (*Elektrische Nachrichten-Technik*, 4, 5, May, 1927, pp. 225-227.)

A brief description of the apparatus is given with circuit diagrams.

EINE SCHALLREGISTRIERVORRICHTUNG ZUR AUFNAHME DER FREQUENZKURVEN VON TELEPHONEN UND LAUTSPRECHERN (A sound-registering apparatus for recording the frequency curves of telephones and loud-speakers.)—M. Grützmacher and E. Meyer. (*Elektrische Nachrichten-Technik*, 4, 5, May, 1927, pp. 203-211.)

Description of an instrument for recording the frequency curves of telephones and loud-speakers having the necessary requirement of a rectilinear frequency curve. The apparatus consists essentially of a condenser-microphone in a high frequency arrangement that can be calibrated acoustically in absolute measure by entirely electric means after a new method. A high frequency heterodyne buzzer is used as current generator with the continual change of frequency necessary for registration. Photographically recorded frequency curves of telephones and loud-speakers serve as examples. For investigating the frequency relation of the condenser microphone itself, experiments are arranged in vacuo; thereto the frequency curves of the condenser microphone with different pressures are recorded and the corresponding vibration figures of the membrane obtained.

SOME RECENT ADVANCES IN ALTERNATING CURRENT MEASURING INSTRUMENTS.—K. Edgcumbe and F. Ockenden. (*Journ. Inst. Elect. Engineers*, 65, pp. 553-599, June, 1927.)

The full text of the paper read before the Institution, 3rd February, 1927, with the discussion afterwards.

Abstracts of the paper appeared in the *Electrician* and *Electrical Review*, of 11th February.

MESSUNG DES WIDERSTANDES VON STROMZWEIGEN BEI DURCHGANG VON HOCHFREQUENTEM WECHSELSTROM (Measurement of the resistance of current branches when traversed by high frequency alternating current).—H. Bruun. (*Elektrische Nachrichten-Technik*, 4, 5, May, 1927, pp. 218-225.)

ABSORPTION WAVEMETER.—H. Dent. (*Wireless World*, 29th June, 1927, pp. 829-832.)

Description of an absorption wavemeter for use on all wavelengths between 14 and 200 metres.

SUBSIDIARY APPARATUS.

SUR UNE DISPOSITION DE CAGE DE FARADAY POUR RADIOTELEGRAPHIE (On a Faraday Cage Arrangement for W.T.).—MM. Beauvais and Mesny. (*Comptes Rendus*, 184, 20th June, 1927, pp. 1546-1547.)

With the usual type of Faraday cage it is often impossible to prevent the escape of electro-magnetic waves through the crack of the door closing the cage, also however well the door fits, the metal of the cage and that of the door mutually offer a certain contact resistance, which modifies the free passage of high frequency currents round the sides of the cage, and consequently the balance is disturbed. To remedy this the authors have designed a cage consisting of a box made of plates of metal carefully soldered, with the lid fitting into a groove in the upper part of the box: by making the sides of the groove and the lid with an amalgamated metal, and filling the groove with mercury, simply putting on the lid will secure a perfect joint through which no waves can pass.

NEUTRALISATION OF THE DEFLECTING FIELD IN A BRAUN TUBE WITH EXTERNAL ELECTRODES.—L. Jones and A. Cravath. (*Physical Review*, 29, 6, pp. 871-879.)

The field of the external electrodes is rapidly neutralised by the collection of ions and electrons on the tube walls so that the deflection is not simply proportional to the applied voltage. The neutralisation proceeds like the discharge of a condenser through a resistance for which the time constant is $RC=T$. This time constant T, which is a reciprocal measure of the rate of neutralisation, was both calculated and measured directly. The deflection of the beam is found as a function of T and the applied voltage, and the expressions for amplitude and phase of deflection for sinusoidal applied voltage are derived, the results being

$$D = V_0 S \cos \delta \sin (2 \pi f t + \delta)$$
$$\delta = \cot^{-1} 2 \pi f T$$

where D is beam deflection, V_0 the applied voltage, f the frequency, and S is a constant of the tube.

Battery Eliminators, or Appliances for the Operation of Radio Receiving Apparatus by Energy derived from Electric Supply Mains.—P. Coursey and H. Andrewes. (*Journ. Inst. Elect. Engineers*, 65, pp. 705-726, July, 1927.)

The full text of the paper, read before the Wireless Section, 6th April, abstracts of which have already appeared.

The Hot-Wire Microphone and Audio-Resonant Selection.—G. Blake. (*E.W. & W.E.*, August, 1927, pp. 493-501.)

Paper read before the R.S.G.B., 25th May, 1927.

H.T. from the Mains.—H. Kirke. (*Wireless World*, 22nd June, 1927, pp. 779-783.)

Some notes on mains units and their application to receivers.

Gramophone Pick-up Devices.—G. Sutton. (*Wireless World*, 20th June, 1927, pp. 66-68.)

Description of method of comparing loud-speakers with the aid of the gramophone.

Loud-Speaker Inefficiency. — N. McLachlan. (*Wireless World*, 6th July, 1927, pp. 11-14.)

An account of sources of energy loss which reduce efficiency to 1 per cent.

GENERAL PHYSICAL ARTICLES.

Über die Richtwirkung von Schallstrahlern (On the directivity of sound radiators).—H. Stenzel. (*Elekt. Nachr.-Technik*, 4, 6, pp. 239-253, June, 1927.)

Mathematical investigation of the directivity of the sound coming from a series of point sources, passing on to a calculation of the directivity of the radiation from a source of sound that can no longer be considered small compared with the wavelength, by regarding it as composed of an infinite number of point sources.

On the Propagation of Sound in the General Bessel Horn of Infinite Length.—(*Journal Franklin Institute*, June, 1927, pp. 849-853.)

Discussion by Mr. Hanna of Mr. Ballantine's paper published in this journal of January, 1927, p. 85, followed by a reply from Mr. Ballantine.

Die Lautstärke von zusammengesetzten Tönen und Geräuschen (The intensity of composite notes and noises).—H. Barkhausen and H. Tischner. (*Zeits. f. Techn. Physik*, 8, 6, pp. 215-221.)

Kathodenzerstäubung (Cathode sputtering).—A. Güntherschulze. (*Zeits. f. Techn. Physik*, 8, 5, pp. 169-178.)

Ionisation by Collisions of the Second Kind in Mixtures of Hydrogen and Nitrogen with the Rare Gases.—G. Harnwell. (*Physical Review*, 29, 6, pp. 830-842, June, 1927.)

Two main conclusions are drawn from the experiments: firstly, that at a certain number of collisions between an atomic or a molecular ion and an atom or ion of lower ionising potential an electron transfer will occur, and secondly, the probability that a given transfer will occur is an inverse function of the difference between the ionising potentials involved.

What is Electricity?—W. M. Thorton. (*Journ. Inst. Elect. Engineers*, 65, pp. 674-680.)

The full text of the third Faraday lecture, delivered before the Institution 17th March, abstracts of which have already appeared. The lecture is divided into the following three parts:—

Evidence that the two units of electricity have the nature of screws or twists.

Evidence of how such screws came into being.

How they combine to form matter and by their vibrations give rise to the electrical radiation we know as light and heat.

STATIONS: DESIGN AND OPERATION.

Another Beam Service Opened. (*Electrician*, 8th July, 1927, p. 62.)

A direct wireless telegraphic service between London and Cape Town was inaugurated on 4th July. This is the third group of beam stations to be completed for direct communication with the Dominions, the beam services with Canada and Australia being already in operation. The fourth and last group of the Imperial Wireless Beam Chain will be completed next month, when the service with India will be opened. The stations for South African communication are the first to have actually in operation the principle of using two wavelengths, one for daylight and the other for night communication, the exact wavelengths of the English transmitting station being 16.146 and 34.013 metres, and those of the South African station 16.077 and 33.708 metres. It is estimated by the Marconi Company that the stations are capable of handling about 160,000 words per day in each direction, and the service is able to deal expeditiously with all available traffic between South Africa and England.

The *Electrical Review* of 8th July also gives details of the service with illustrations of the equipment.

Daventry Junior.—H. Kirke. (*Wireless World*, 20th July, 1927, pp. 69-70.)

Technical details of this new high-power transmitter are given with illustrations.

Alterations to the Modulating Panel at 2LO.—E. Green, J. Hewitt and T. Petersen. (*E.W. & W.E.*, August, 1927, pp. 467-488.)

MISCELLANEOUS.

South Africa—Single Management—(*Electrical Review*, 24th June, 1927, p. 1021.)

The recently-formed South African Broadcasting Co., after having taken over and resuscitated the Johannesburg station, has since also purchased the Cape Town station and entered into an agreement with the Durban Town Council to take over its station. With all the South African broadcasting stations now under one management, it is intended to interconnect them all with land lines and take full advantage of relaying. The new company, being also interested in the African Theatres Trust, intends to transmit items from various theatres with greater variety of artistes than there is under present arrangements.

The Organisation and Problems of National Broadcasting.—A. N. Goldsmith. (*General Electric Review*, 30, 7, pp. 349-353, July, 1927.)

The Distribution of Broadcasting Stations.—P. P. Eckersley. (*Wireless World*, 13th July, 1927, pp. 32-35.)

Making Synthetic Galena.—G. Tatham. (*Wireless World*, 22nd June, 1927, pp. 774-778.)

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.

SENDADO.

Ŝanĝoj al la Modula Panelo ĉe 2LO.—E. Green, J. L. Hewitt, and T. G. Petersen.

La artikolo priskribas eksperimentojn faritajn je la sendilo ĉe la originala 2LO, kun celo atingi konstantecon de modulado je ĉiuj modulaj frekvencoj, la evoluoj efektivigitaj estante enkorpigitaj en la posta Londona Stacio.

La sendilajn cirkvitojn oni montras plene kaj konsideras skeletoforme, dum oni utiligas la anodvoltajn—anodkurentajn karakterizojn (jam antaŭe diskutitaj de unu el la aŭtoroj en *E.W.* & *W.E.*, Julio kaj Aŭgusto, 1926a), por montrila funkciajn kondiĉojn de la valvoj je diversaj modulaj frekvencoj. Oni desegnis novan tipon de modula valvo, kapablanta pligrandan dispeliĝon, kaj similaj kurvoj estas montritaj por ĉi tiu tipo, kun diskutado pri la plibonigoj efektivigotaj kaj pri ŝanĝoj al la sub-modulatora panelo.

Du aldonoj sekvas, la unua traktanta pri kalkulado de la Funkciaj Elipsoj por la diversaj okazoj, kaj la dua pri la Potencaj Interrilatoj en la Oscilatora kaj Modulatora cirkvitoj, kiam oni uzas ŝokbobenan kontroladon.

RICEVADO.

La Varmfadena Mikrofono kaj Aŭd-Resonanca Selektado.—Raporto de Prelego legita de S-ro. G. G. Blake, M.I.E.E., A.Inst.P., ĉe la Radio-Societo de Granda Britujo, je 25a Majo, 1927a.

La lekcianto prezentis la temon per priskribo pri fruaj aplikadoj de la varmfadena principo, aparte rilate al sono, kaj pri la *Tucker* varmfadena mikrofono kaj ĝia utiligado je milita sonkalkulado. Oni faris longan aludon al la artikolo de D-ro. H. E. Watson pri la temo en *E.W.* & *W.E.*, de Marto, 1927a.

La aŭtoro poste priskribis siajn proprajn eksperimentojn kiel daŭrigo pri la temo, inkluzive la priskribo de resonatoroj de diversaj konstantoj, kiuj estas cititaj. Oni demonstraciis pri la utiligo de la varmfadena mikrofono kiel malhelpilo de interfero. Eksteraj signaloj, influitaj de multa interfero produktita de la lekcianto, estis selektitaj pere de la resonanca mikrofono, kaj ilia ricevado, libera je ĝeno, montrita sur registrilo. La aŭtoro finis, sugestante pluajn aplikadojn de la varmfadena mikrofono je ricevado.

Raporto pri la diskutado, kiu sekvis la prelegon, estas ankaŭ presita.

Krad-signalaj Karakterizoj kaj aliaj Helpoj je la Numera Solvo de Krad-Rektifaj Problemoj.—W. A. Barclay.

Post mallonga konsiderado pri la principoj de krada rektifado, la aŭtoro skizas la ordinaran diagramon de kradkurenta karakterizo, kaj tiam disvolvas pluan kurvon montrantan, kiel krada kurento varias dum signala tensio E estas impresita sur la kradon de diversaj mezaj kradaj potencialoj. Ĉi tiun novan kurvon li priskribas kiel la kradan signalan karakterizon por signala amplitudo E.

Li poste disvolvas ĝeneralan esprimon por krada kurento en la ĉeesto de signalo, kaj ilustras kaj geometriajn kaj aritmetajn metodojn por deternini la kradsignalan karakterizan kurvon. La metodoj estas ilustritaj per aparta aplikado al serio de kradsignalaj karakterizoj por valvo de difinita tipo

La artikolo estas daŭrigota.

MEZOROJ KAJ NORMOJ.

Simpla Nerekta Metodo Mezuri Kradan Kurenton.

Redakcia noto pritraktanta metodon—ŝulditan al von Ardenne—per kio, kradkurentoj de 10^{-10} aŭ 10^{-9} amperoj estas mezureblaj. La metodo estas bazita sur la fakto ke, se krada rezistanco de konata valoro estas uzita, la kradkurento kaŭzas falon de potencialo laŭ la elflua rezisteco, kaj tiel ŝanĝos la kradan potencialon per kvanto determinebla per la ŝanĝo de anoda kurento produktita.

La principoj de la metodo estas diskutitaj kaj ekzempleroj donitaj, la metodo montrita donante mezurojn de proksimume 2×10^{-9} amperoj.

HELPA APARATO.

La "Leĝo-Korektado" de Varieblaj Aeraj Kondensatoroj.—W. H. F. Griffiths.

Ĉi tiu artikolo estas plua kontribuaĵo de la aŭtoro pri la temo de la leĝoj de varieblaj kondensatoroj. Ĝi traktas aparte pri la efekto ĉe la "leĝo de plata rotacio" de la minimuma aŭ restanta kapacito de la finita kondensatoro, kiel pliigita per la kapacito de la cirkvito, de kio ĝi estas parto. Komerca ekzemplo de la leĝo-korekteco estas ilustrita en la okazo de komerce produktita Rektlinia Frekvenca Kondensatoro, kun diskutado pri eraroj kaj foriroj for de la rektlinia leĝo. Metodoj por korekti la Rektlinian Leĝon (por la Rektlinia Frekvenca ekzemplo) estas poste pritraktitaj, inkluzive la limigo de skalo de alĝustigo enkondukita per la metodo de korektado. La diskutado estas bone ilustrita per kurvoj de eksperimentoj kaj kalkulitaj rezultoj.

La korektado de Rektliniaj Ondolongaj Kondensatoroj estas poste diskutitaj, kun pluaj kurvoj por leĝo-korektado.

La aŭtoro konkludas, ke estas plibone utiligi varieblajn kondensatorojn kun konstantaj kapacitaj skaloj, kie ekzakta konformeco al leĝo estas absolute necesa.

DIVERSAĴOJ.

Resumoj kaj Aludoj.

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

Matematiko por Senfadenaj Amatoroj.—F. M. Colebrook.

Daŭrigita el antaŭaj numeroj. La nuna parto komencas la konsideradon pri la Diferenciala kaj Integrala Kalkuluso, traktante pri la celo kaj amplekso de la diferenciala kalkuluso, proporcio de ŝanĝo, ĝenerala difino de diferenciala koeficiento, geometria interpretado de diferenciala koeficiento, la signo de la diferenciala koeficiento, kaj la diferencigo de pozitivaj potencoj de X.

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.

Television.

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

Sir,—Though Dr. von Mihaly's book* contains very full descriptions of the television apparatus which he has invented and named the "Telehor," one finds only a very few words as to results obtained with it. He tells us (p. 100 and p. 147) that with the first model he succeeded in transmitting some simple geometrical figures, white on a black ground, artificially illuminated, but the reception was not quite satisfactory, and he was "depressed (*missgestimmt*) by the bad results." With the later model (p. 157) "the transmissions were scarcely any better than the previous ones." He ascribes this lack of success to instrumental deficiencies which he hopes to improve.

With great diffidence, I venture to point out an extraordinary oversight which the inventor appears to me to have made in planning the optical part of the transmitter, and which would amply account for failure, even given perfection in all other respects.

The following is the plan adopted. By means of a powerful lens-system, a very small real image of the object is thrown upon the minute *plane* mirror of an oscillograph. This mirror (in its mean position) is at 45° to the optic axis, and therefore the beam of light, after forming the image, is deflected through a right angle. After travelling some distance it strikes a thin opaque screen, some 10 cm. wide, with a hole 1 mm. square at its centre, covering a selenium or photo-electric cell. The beam forms a luminous patch on the screen. The mirror oscillates, with two synchronised movements of rotation of very different frequencies, about two perpendicular axes, horizontal and vertical. Hence the reflected patch of light travels across the screen rapidly in zigzag fashion, so that every element of it in turn comes over the hole, and acts on the cell.

The oversight referred to consists in assuming that this out-of-focus patch of light on the screen is a true picture of the object, which, of course, is not the case. And, naturally, if the picture transmitted is faulty one cannot expect good reception. The error occurs three times over, both in text and diagrams, differently expressed each time (pp. 101-2, 106, 158; Figs. 66, 69, 96).

It may be remarked that there is no lens between mirror and screen, and the description of the mirror (p. 162) clearly implies that it is plane: "a thin glass plate, silvered, 3×3 mm., area 9 mm." A plane mirror has no effect on the convergence or divergence of rays, but merely deflects the beam as a whole.

* *Das elektrische Fernsehen und das Telehor*, by Dénes von Mihaly, M. Krayn, Berlin, 1926.

Only at the proper focus is there point for point correspondence between object and image (and not always there !). At any other distance a point in the object would be represented on a screen, not by a point, but by a blurred oval patch. Neighbouring points in the object would be represented by overlapping patches, so that not only outlines, but gradations of light and shade would be mixed and confused.

The trouble no doubt was that if the experimenter focused the image upon the screen over the cell, then the minute mirror could only intercept a very small portion of the wide beam necessary to give a fair-sized picture, and most of the light would pass straight on, instead of being reflected to the cell.

If the mirror was concave some sort of enlarged picture could be formed on the screen by focusing the previous image yielded by the lens-system, not *on* the mirror as the description states, but some distance in front of it, outside its focus. It may be remarked, however, that a concave mirror gives a very unsatisfactory picture of an extended object. In the case of a fixed mirror, compensatory errors might be introduced into the accompanying lens-system, but here the oscillation would upset the calculations.

Another practical difficulty presents itself. In the nature of the case the mirror must be very light, and we are told that it is made of skin-thin glass—microscope-slide cover glass. It is extremely doubtful whether such a fragile article could stand the manipulation necessary to produce an optically perfect surface, or even if so, could retain its form. Temperature changes, pressure of supports, etc., would affect it. The usual function of a galvanometer or oscillograph mirror is merely to reflect a small spot of light, a very different matter from yielding a detailed picture.

At the receiving station Dr. von Mihaly employs another oscillograph, similar to, and synchronised with, the one at the transmitting station, to reflect the concentrated light of a Pointolite (or similar) lamp upon a screen. The small illuminated patch on the screen traces very rapidly a zigzag (or, more strictly, sine curve) path, the intensity of illumination of the patch at any moment being regulated by the intensity of the current from the selenium cell.

Sunbury. ALICE EVERETT.

New Developments in Resistance Amplification.

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

SIR,—In reply to the letter from Mr. E. B. Moullin, published in the August issue of *E.W. & W.E.*,—I certainly do not plead guilty to any misinterpretation or misconception. The product

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

is perfectly symmetrical as far as R and R_1 are concerned and there is no more reason for saying that R_1 must be large compared with R than there is for saying the exact opposite. In order that the product shall be nearly unity it is equally important that R shall be large compared with R_a and that R_1 shall be large compared with R_a, and that's all there is about it. However, I am prepared to admit that the form in which I stated this conclusion in my article was calculated to arouse comment.

Mr. Moullin's further contention that the use of moderate anode resistances will result in equally high amplification per stage will not stand the test of practice unless he is prepared to use very inconveniently high anode voltages, *i.e.*, voltages up to 500 or so.

In my opinion the more serious criticism of the use of very high anode resistances relates to frequency distortion. The high input capacity of a valve with a high anode resistance, more particularly in the case of a valve with a high voltage factor, is the real limiting factor in the case of multi-valve arrangements. This matter is being investigated and it is hoped that more detailed information will shortly be available, but as far as my experience is concerned very satisfactory reproduction is obtained by the use of high anode resistances with ordinary high-frequency valves.

F. M. COLEBROOK.

The Audio-Transformer Problem.

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

SIR,—I observe that in your issue for August, Mr. E. Fowler Clark comments with some disfavour on my letter published in the June issue.

I feel this is unkind of him, for, on close reading of my letter, in conjunction with his own in the July issue, I think it appears that we are really in agreement on the principles of design.

We both emphasise that the valve A.C. resistance should equal the impedance of the transformer primary (neglecting any reaction of the secondary on it) at the lowest frequency to be effectively amplified.

Now I am mostly concerned with designing amplifiers giving really effective amplification down to 20 or 30 cycles when possible, and down to not less than 50 cycles anyway. I usually find that I want 80 to 100 henries of primary, and I find that to get it is not at all easy; in fact, it *is* the case, for me, that " L_1 will be as large as we can make it." This is, of course, subject to other limitations of design, such as self-capacity, D.C. ampere-turns, reasonable cost, and so on, some of them mentioned by him.

I find that with proper design the transformer (in spite of the statements of the resistance-coupling enthusiasts) has a very definite place, even in amplifiers with an effective frequency range of 20-8,000 cycles, and perhaps I was thinking too much of this kind of apparatus, and forgot that if one is content with a lower limit of 100 or 200 cycles, the best primary need not be " as large as we can make it."

But my statement still seems true to me for really first-class work.

I do not think it necessary for me to discuss in detail Mr. Fowler Clark's other comments on my letter, as the main principle is the important thing.

New Eltham. P. K. TURNER.

Some Recent Patents.

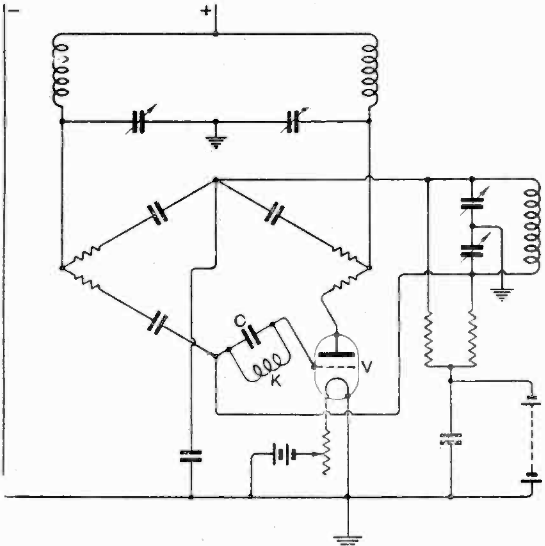
The following abstracts are prepared, with the permission of the Controller of H.M. Stationery Office, from Specifications obtainable at the Patent Office, 25, Southampton Buildings, London, W.C.2, price 1/- each

HIGH FREQUENCY BALANCERS.

(*Application date, 11th February, 1926. No. 270,800.*)

In a Wheatstone bridge system, such as that shown in the figure, for decoupling or disassociating the plate and grid circuits of an amplifier *V*, Mr. E. Green points out that the accuracy of balance, at frequencies of the order of ten thousand kilocycles per second, is liable to be upset owing to the inductive reactance of the external valve leads or connections.

In order to compensate for this effect, a vectorially negative reactance, such as the condenser *C*, is inserted in the grid lead of the valve *V* for the specific purpose of neutralising the positive inductive reactance, at the given working frequency, of the length of wire between the lower bridge junction and the grid terminal. A shunt choke-coil *K* allows the passage of direct grid current. Apart

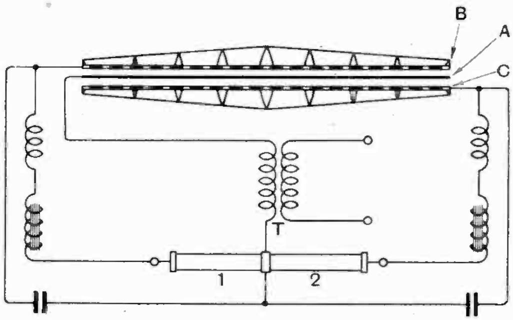


from this refinement, the general arrangement of the balanced bridge is identical with that described in a former patent No. 241,289 issued jointly to Mr. C. S. Franklin and the present inventor.

AN ELECTROSTATIC LOUD-SPEAKER.

(*Application dates, 23rd and 30th December, 1925. No. 271,125.*)

A movable diaphragm *A* is mounted for free vibration between fixed upper and lower electrodes *B*, *C*. A normally high potential difference is maintained between the fixed and movable members, but is so balanced that no effective force is applied to the movable diaphragm before the application of voice signalling currents. The fixed electrodes *B*, *C* may be in the form of metal-gauze



screens suitably supported, and are connected to the opposite poles of two dry piles 1, 2. The latter may be of the Zamboni type, formed of a number of adjacent paper discs coated on one side with black oxide of manganese and on the other with tin or silver foil.

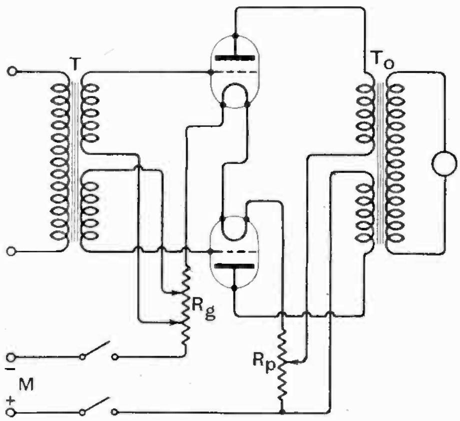
The movable diaphragm is a rigid structure, exceedingly light in character, and so mounted that whilst it is free to vibrate to and fro, it cannot be twisted or distorted as a whole with reference to the plane containing its outer periphery. It is connected through the secondary winding of a transformer *T* to the common junction of the two piles 1, 2. Speech frequency currents for reproduction are applied across the primary of the transformer *T*, and by upsetting the existing electrostatic balance throw the centre diaphragm *A* into vibration. The diaphragm and electrodes may be made conical instead of flat, and as many as five may be employed: namely, a fixed central plate, two parallel outer movable diaphragms, and an outside pair of fixed gauze electrodes similar to *B*, *C*. The patent is issued to M. and A. Graham and W. J. Rickets.

PUSH-PULL AMPLIFIERS.

(*Application dates, 14th and 30th April, 1926. No. 271,222.*)

In order to preserve strict symmetry between the plate, grid, and filament voltages of amplifying valves arranged in push-pull relation, special precautions must be taken where the filaments are supplied in series instead of in parallel. Series feed is advantageous when, for instance, the supply is taken from the domestic mains.

The British Thomson Houston Co. describe a method of feeding push-pull amplifiers from the mains, whilst at the same time preserving a strict symmetry between the operating potentials. The secondary winding of the input transformer T is divided, and tappings are taken to separate points on the grid bias resistance R_g. Similarly the primary of the output transformer T_0 is split, the



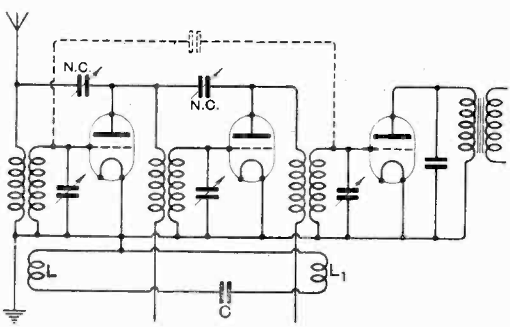
two tappings being taken to selected points on the resistance R_p, forming the source of the plate voltage. It will be seen that both resistances R_g and R_p, together with the two valve filaments, are all in series across the terminals of the supply mains M.

NEUTRALISING H.F. AMPLIFIERS.

(*Application date*, 8*th June*, 1926. *No*. 271,253.)

Magnetic coupling through a closed circuit L, L_1, C is utilised by the Igranic Co. and Mr. P. W. Willans, to compensate for the residual inherent capacity reaction that exists between H.F. amplifiers —even when "stabilised" by the ordinary neutralising condensers as shown at NC.

The coil L preferably consists of only two turns of stiff wire, and is coupled to the grid of the first valve. A similar coil L_1 is coupled to the third or



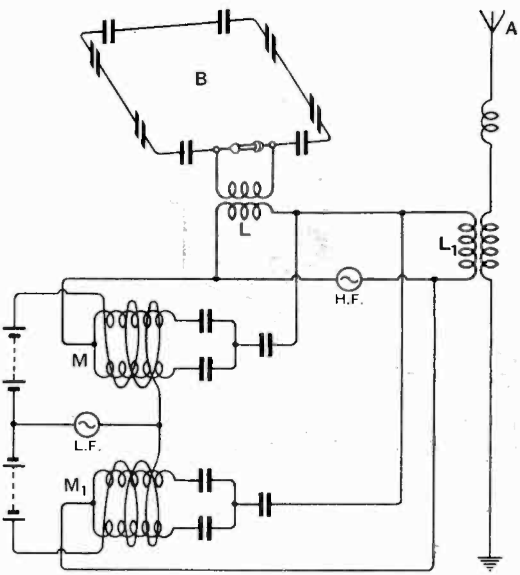
any other subsequent valve, so that at least two stages of valve amplification separates the two coils. The condenser C has a capacity of $0.006\mu F$. As shown the closed coupling-circuit is connected to the filament system.

PREVENTING FADING.

(*Convention date* (*U.S.A.*), 30*th November*, 1925. *No*. 262,152.)

In this patent issued to the British Thomson Houston Company, Limited, as assignees of E. F. W. Alexanderson, an attempt is made to overcome faulty reception due to fading. It is pointed out that the incidence of the distant fading effect is a function of the polarisation of the emitted wave. If the polarisation is kept constant, a receiver in any given location may therefore be subjected to considerable intervals of total fading. On the other hand, by continuously varying the plane of polarisation, the area of bad reception is constantly being shifted, so that any given receiver will pick up sufficient energy to give a continuous average response of reasonable strength.

As shown in the figure radiation takes place alternately from a vertical aerial A which emits a

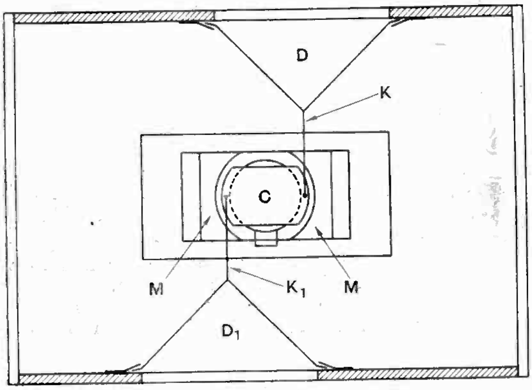


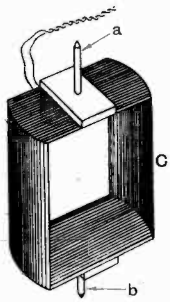
vertically polarised wave, and from a loop aerial B which produces a horizontally polarised wave. High frequency oscillations from the source HF are transferred alternately through a magnetic modulator M_1 and coupling L_1 to the aerial A, and through a second modulator M and coupling L to the loop B, the frequency of the change-over being controlled by a low frequency alternator LF.

LOUD-SPEAKERS.

(*Application date*, 9*th February*, 1926. *No*. 271,021.)

Dr. N. W. McLachlan's object is to produce a loud-speaker, or microphone, in which inherent resonance is reduced to a minimum, and is localised below the important audio frequency range, and from which objectional directional characteristics are absent. The coil C (shown separately) is freely mounted on axes a, b set between the poles of the magnet M. It is connected by means of members K, K_1 with two diaphragms D, D_1, which may be of conical or other form. The peripheries





of the diaphragms are loosely held between V-shaped strips of flexible material.

The restoring force is consequently very small, being provided by the peripheral mounting of the diaphragms. Instead of using only two diaphragms, any desired number may in fact be linked up with the vibrating coil, and may be of equal or different sizes. This arrangement ensures a more uniform distribution of sound than can be secured from a single diaphragm, owing to the focusing propensities of the latter at high frequencies.

A CONSTANT COUPLING ARRANGEMENT.

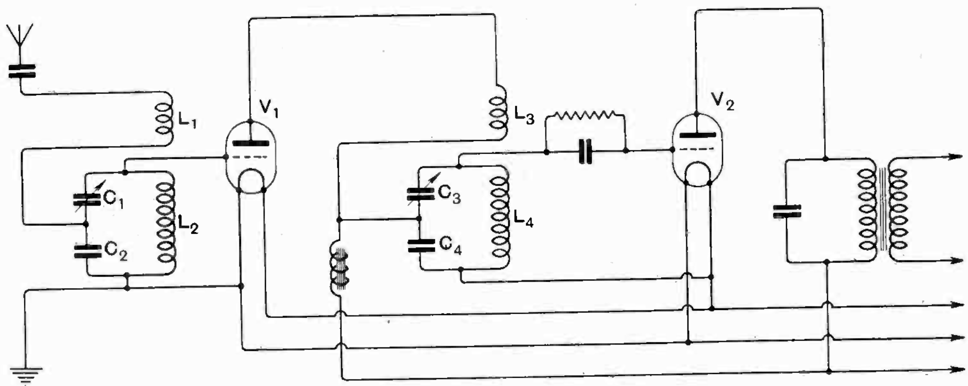
(*Convention date* (*U.S.A.*), *11th August*, 1925. *No.* 256,967.)

The names of Messrs. Loftin and White are already familiar to most experimenters in connection with the subject of constant coupling. In this British patent Mr. Sidney Young White covers a particular circuit arrangement designed for the purpose of (*a*) ensuring a constant rate of energy-transfer between two coupled valve amplifiers over a wide range of frequencies, and (*b*) preventing self-oscillation due to capacity reaction across the valve electrodes.

Taking the intervalve coupling first, it will be seen from the figure that energy will be transferred from valve V_1 to valve V_2 partly by the magnetic coupling between the coils L_3 and L_4, and partly by capacity coupling across the condenser C_4, which is common to the output of the first and the input of the second amplifier. The input circuit of the valve V_2 is tuned as a whole by the variable condenser C_3.

The energy transfer through the condenser C_4 will decrease as the received signals increase in frequency, whilst the transfer across the coils L_3, L_4 will increase under the same circumstances. If the direction of the coil L_3 is such that the induced magnetic and electric energy components are both in phase, the observed variations with frequency will mutually counterbalance, so as to ensure a constant over-all coupling throughout the entire tuning range.

A similar arrangement is used for coupling the aerial circuit to the input of the first amplifier, and the same considerations apply. By suitably adjusting the relative values of the coupling condenser C_2 and the tuning condenser C_1, the energy transfer from the aerial may be arranged either to increase or decrease with frequency variation, instead of remaining constant.



Reaction across the internal valve electrodes is reduced to negligible dimensions by limiting the value of the inductance L_3 and capacity C_4 to such dimensions that the plate circuit of the amplifier V_1 can never approach resonance with its input circuit.

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