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The Elimination of Magneto Disturbance in the Reception of Wireless Signals on Aircraft.*

By CAPT. JAMES ROBINSON, R.A.F., M.Sc., Ph.D.

ON aircraft, and more especially on aeroplanes, the problem of the reception of wireless signals is complicated by two factors :—

(1) The external noise due to the engines and the rush of wind, and

(2) The disturbance produced in the receiver due to the magneto of the engines.

To deal with the external noises, the only possible thing is to use helmets and earpieces which fit as closely as possible to the head and ear. It is possible by taking such precautions to cut down the noise of the engines very appreciably. In any case, there is always so much noise that signals must be of much greater intensity than at ground stations in order to be of any use. It is thus essential to use the best of amplifiers in aeroplanes.

To deal with magneto disturbance a very different procedure is required, as the disturbance is electromagnetic, produced by the spark discharge of the magneto. Unless this disturbance is cut out, no gain is obtained by increasing the amplification of signals, for the amplifier usually also increases the magneto disturbance in the same proportion as it increases the strength of signals. This disturbance is especially bad in directional work, because the wireless energy picked up by loops is small.

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* Paper received August, 1919.

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Some laboratory experiments were undertaken to find out the cause of this magneto disturbance and to try to find effective methods for cutting it out. A magneto with six sparking plugs was fitted on a bench in the laboratory, the magneto being driven by a belt from shafting. A D.F.* single coil with a valve amplifier was used for reception, the amplifier having high and low frequency parts.

The effect of distance was first investigated. Moving the D.F. coil and amplifier together, it was found that the disturbance is large when within eight to ten feet of the magneto system and diminishes rapidly as the distance is increased above this.

The D.F. coil and amplifier were then moved separately, long leads being employed between them. It was found that with the D.F. coil near the magneto and the amplifier far away, the disturbance was just as bad as in the converse case of the amplifier near the magneto. However, when the D.F. coil was near the magneto, it was discovered that the disturbance was not cut down by breaking the circuit to the amplifier. One lead was broken at the coil end and then the other, and the disturbance was still bad. Hence it appeared that the leads were of importance. When the leads were taken away from the neighbourhood of the magneto, the disturbance diminished.

The leads were then removed from the amplifier altogether, and it was found that the disturbance vanished, unless of course the amplifier was close to the magneto. If the amplifier was used alone and was at such a distance from the magneto that there was no disturbance it was found that the disturbance appeared if a lead was stretched between the magneto and amplifier without touching either of them and in fact being at a distance of a foot from both the magneto and the amplifier. This showed that the leads were responsible to a large extent for producing the disturbance.

Attempts were made to shield the leads by putting them in an earthed tube, and this again inside another earthed tube, but without effect.

However, these experiments led to the inference that the cause of the disturbance was probably the emission of very short waves by the magneto system. This inference was strengthened by the following simple experiments. With the amplifier disconnected from the D.F. system and at a distance such that no disturbance

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* **D.F. = "Direction Finding."**

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was observed, the disturbance appeared when a wire of a few inches length was joined to one terminal of the amplifier the free end of this short wire being insulated. This seemed to show that this short wire acted as an aerial for very short waves. The short wire now had its free end joined to the other terminal of the amplifier. It was found that the amount of the disturbance depended on the shape given to this wire. When the wire was bent into a shape nearly circular, the disturbance was larger than when it was drawn out into an elongated form. This seemed to put beyond doubt the inference that the disturbance was due to short waves, for giving various shapes to this short wire was equivalent to giving different frequencies to this short wave aerial circuit.

In order to verify this conclusion finally, a short wave stopper was made, consisting of a variable condenser of a few centimetres capacity and of a very small inductance consisting of two or three turns of wire on a former of about two inches diameter. The D.F. coil was now joined up to the amplifier and placed in a position where magneto disturbance was obtained. The small condenser F and the small inductance H were joined up to form an oscillating circuit with a frequency corresponding to wave lengths which could be varied from two to ten metres. This oscillating circuit was placed in the lead from the coils to the amplifier close up to the grid terminal of the amplifier, and it is known that such a tuned circuit offers very large resistance to waves of the same frequency. It was found by this circuit that it was possible to cut down the magneto disturbance very considerably by varying the condenser F, thus proving that a large part, if not all of the disturbance, is due to waves of wave length between two and ten metres.

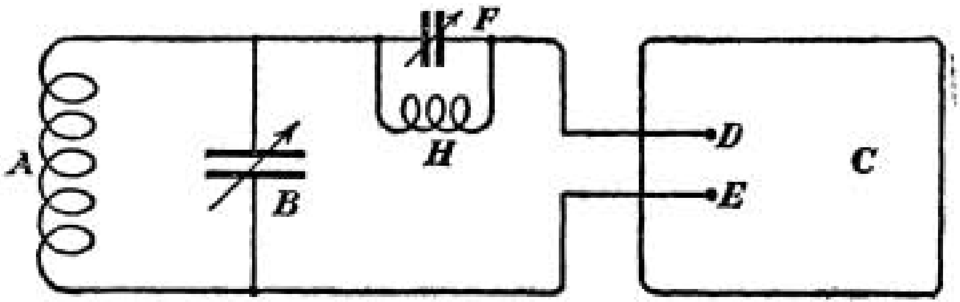

FIG. 1.

A. D.F. Coil.
B. Tuning condenser.
C. Amplifier.
D. Grid terminal of amplifier.
E. Filament terminal of amplifier.
F. Small variable condenser.
H. Small inductance.

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It is easy to see how such waves are produced. The magneto system consists of means for producing a high potential and a spark gap for discharging it. Leads are necessary to connect the magneto to the spark gaps and these leads have small capacity and small inductance, thus acting as oscillators and radiators of short wave lengths. The spark gaps have leads of various length so that various short waves are radiated from the magneto system of an aeroplane.

To get efficient cutting out of the disturbance by this means, it would be necessary to have a number of tuned stoppers. It was however suggested that all wave lengths would be cut out by using an inductance which would act as a choke for short waves. An inductance of 1,000 to 2,000 microhenries was found to be very efficient and to be without appreciable effect on received signals. Such a choke has increased the range of reception on aeroplanes very considerably.

However on certain aeroplanes, especially of large type, these short wave stoppers are not efficient enough for D.F. work. This is probably because the radiated waves from the magneto system of such aeroplanes are longer than those obtained in the laboratory experiments. It is easy to understand this for there are sometimes very long leads connected with the magneto system.

Various other devices were tried in the laboratory to try to cut out the disturbance completely. Stoppers for very long waves were tried without the smallest success.

It was thought that possibly a D.F. coil with a large number of turns might not be increased in efficiency by increasing the number of turns indefinitely. A device was tried of shorting a number of turns at each end of the frame. It was considered that these shorted turns might absorb all the magneto disturbance, but it was found to be of no benefit.

Balancing methods were tried on the assumption that it ought to be possible to pick up extra disturbances from the magneto of equal magnitude and opposite phase by the use of a search coil. Search coils were tried in the high-frequency circuit of the D.F. coil, and again in the low-frequency circuit of the telephones, in various forms. Some slight amount of cutting down of the disturbance was obtained by some of these balancing methods, but they were abandoned as being too complicated.

The most efficient magneto cutting-out device is to shield the magneto system completely. The magnetos themselves should

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be encased in metal shields. The high-tension leads from the magneto to the sparking plugs should be run in earthed tubes. The same applies to the low-tension leads. When this is done properly there is no trace of magneto disturbance in the most sensitive receiving system. It is not always necessary to put the magnetos in special metal cases. This applies in the cases where the engines are completely cowled. The earthing of the metal shields of the high-tension and low-tension systems is most important. It is not sufficient to bind earthing wires round the metal shield and the earth system if these metal parts are covered in grease. Good earths should be made to the common potential of the metal framework of the aeroplane, consisting of the engines, tanks, and bracing wires. The metal casing of the H.T. leads must be earthed every 18 inches or 24 inches by as short leads as possible. This applies also to the low-tension leads. This earthing at various places provides closed circuits which form oscillating circuits for very high frequencies, and thus help to absorb the short waves radiated from the magneto system.

This shielding of the magneto system is invariably efficient if care is taken. It is purely a matter of paying attention to detail, and in a large number of cases it has always been successful. At times the disturbance appears so bad as to make it seem hopeless to try to cut it down. Stray leads going past exposed magneto parts and then past the receivers are responsible for conveying the magneto disturbance.

In this connection, it is worth noting that disturbances appear which are often called magneto disturbance, but which are really nothing of the sort. There is so much vibration on aeroplanes that if there is anything loose about the receiver or the D.F. system, a vibration is set up which produces noises similar in character to magneto disturbance. Such cases have arisen as the following :—

(1) Loose connection in the receiver.
(2) Loose connection inside a valve.

An effect has been observed in certain types of amplifier which has so far not received satisfactory explanation. It is possible to choose valves and conditions such that without any other aid, the magneto disturbances are entirely cut out. This is of such importance that with such amplifiers it is worth while spending some time in interchanging valves and trying various adjustments.

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When the correct conditions are obtained, it is found that as the filament current of the amplifier is increased, the signals increase continuously in strength but the magneto disturbance increases to a point and then suddenly vanishes only to reappear if the filament current further increases (Fig. 2).

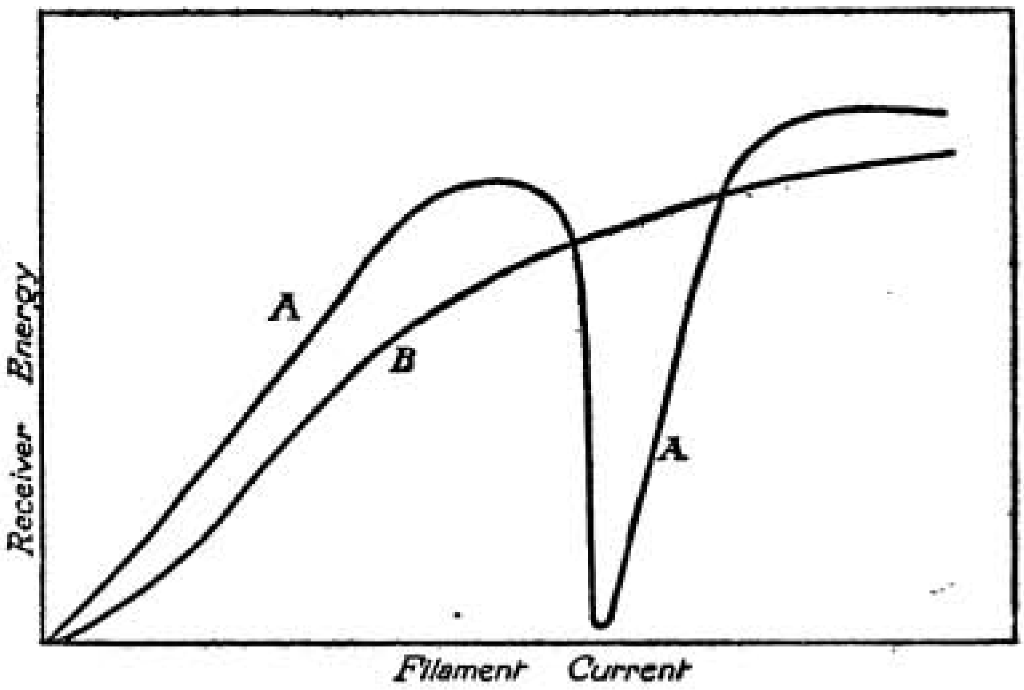

FIG. 2.

A. Magneto energy. B. Signal energy.

It is hoped that this effect will soon be understood so that it can be reproduced at will.

My thanks are due to Major J. Erskine Murray, D.Sc., for his interest and advice in the course of these experiments.

On the Goniometric Functions Applicable to Directive Aerials.

By A. BLONDEL.

(Continued from page 66.)

THE resultant electromotive force for the case of a Type D loop will be the integral of the elementary electromotive forces $2e_0 \sin\phi$ as defined above, calculated for each element of height *dz*.

In short the simple goniometric functions $\sin\phi$ and $\cos\phi$ previously used are replaced by more complicated integral functions:

$$\left.\begin{aligned} \text{gon}\,\theta_D &= \int_{z_0}^{z_1} \sin\left[\frac{2\pi f(z)\sin\theta}{\lambda}\right] dz \\ \text{gon}\,\theta_S &= \int_{z_0}^{z_1} \cos\left[\frac{2\pi f(z)\sin\theta}{\lambda}\right] dz \end{aligned}\right\} \quad . \quad . \quad . \quad (23)$$

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In the case where the antennæ are simply sloping straight wires for which the distance from the centre of the loop is x at the base of the aerial and x_1 at the top, and putting $z_0 = 0$ at the base, the function $f(z)$ has the simple form

$$x = x_0 + \frac{x_1 - x_0}{z_1} z.$$

If the aerial has a polygonal shape, each rectilinear section has an equation of the same form.

Generally it will be seen that the expression gon θ, instead of having the simple value given above, takes the form of the ratio of two integrals

$$\frac{\text{gon}\,\theta}{\text{gon}\left(\frac{\pi}{2} - \theta\right)} = \frac{\int_{z_0}^{z_1} \sin\left[\frac{2\pi f(z) \sin\theta}{\lambda}\right] dz}{\int_{z_0}^{z_1} \sin\left[\frac{2\pi f(z) \cos\theta}{\lambda}\right] dz} \quad . \quad . \quad . \quad . \quad (24)$$

For each value of θ, these integrals may be calculated, in any case by means of graphical integration by plotting the curve of the sines as a function of z.

It is possible therefore for any value of θ to determine the value of the function gon θ and to draw up a double-entry table or else a standardising curve, similar to those described in the above simpler case, from which θ can be determined by the general formula as soon as $\frac{\psi + \psi'}{2}$ has been measured by the radiogoniometer.

The accuracy observed in calculating gon θ must increase as the wave length decreases. The same must apply to the precision with which the aerials are constructed, so that for small wave lengths of 100 to 150 metres it is advisable that the aerials be constructed each of a single wire, rather than of a number of wires more or less separated from each other.

We see that the use of short wave lengths as prescribed by the International Convention introduces certain complications which do not exist with larger wave lengths.

S type frames may be connected to a fixed earth wire at an equal distance from the two aerials, so that the vectorial electromotive force of this earth wire is simply proportional to e_0 and is in phase

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with the resultant electromotive force of the two aerials, so that its effect is added in the circuit acting on the detector (represented by mutual inductance L).

The two equations (17) are therefore replaced by two others, of the following form:

$$\left.\begin{aligned} L + M \operatorname{gon}\theta - N \operatorname{gon}\left(\frac{\pi}{2} - \theta\right) &= \frac{H(\epsilon')}{2e_0} \\ L + N' \operatorname{gon}\left(\frac{\pi}{2} - \theta\right) - M' \operatorname{gon}\theta &= \frac{H(\epsilon')}{2e_0} \end{aligned}\right\} \quad . \quad . \quad . \quad (25)$$

The second term may be eliminated by subtracting these two equations term by term. It will then be seen that the term L is eliminated so that the solution is the same as for equations (17). This implies, of course, that the two earth wires are arranged in an exactly identical manner, and run from the same point in each loop, a condition which can easily be realised. It should be noticed also that L is eliminated in the case of the simple loops.

On the other hand, in the alternate measurement method (equation 19) the term $2e_0L$ must be added to each bracket under the sign F except when the function F is simply one of direct proportionality. When this is not the case the earth wire introduces a fresh complication into the comparison method.

II. THE EFFECT OF WAVE DECREMENT.

The logarithmic decrement does not give rise to any appreciable disturbance when using a single loop "zero-method" arrangement, since the two positions where the sound in the telephones disappears are always symmetrical with respect to the direction of the waves.

On the contrary in the case of direction-finding systems using two frame aerials, when the direction of the waves approximates to the plane of one of the loops, the magnitude and phase of the two induced currents may become unequally modified, and it is no longer correct to compare them in the same manner as in the case of undamped waves. The conditions under which the comparison methods may be legitimately applied must therefore be examined and the errors estimated.

Two types of wave damping must be considered :—

(*a*) Waves of simple decrement, produced by the sudden excitation of the sending aerial which is then left to oscillate freely (neglecting the transient period at the moment of shock excitation).

(*b*) Waves of complex decrement which occur (1) in the case of a quenched spark transmitter; and (2) in the ordinary waves resulting from the coupling of the aerial with a local oscillating circuit. In this latter case there is an alternating exchange of energy between the aerial and the oscillating circuit, the state of affairs in the aerial being represented algebraically by the sum of two oscillations of unequal wave length, of more or less unequal damping and for each of which a starting period should be considered.

(*a*) WAVES OF SIMPLE DECREMENT.

Neglecting the transients at the commencement of the oscillations, the received waves have simple decrement and constant frequency. The effect of damping is two-fold; firstly it modifies the time period, but this makes no radical change and it is merely necessary to substitute the new frequency; secondly, it weakens the wave as it is propagated, thus giving rise to a difference between the amplitudes of the electromotive forces induced in the two aerials, which increases with their distance apart. An important modification of the goniometrical functions results therefrom.

Goniometrical Functions.—For simplicity, let $\omega = 2\pi/T$, where $T =$ the time period; $\delta = \Delta/T$, be the damping coefficient, Δ being the logarithmic decrement *; $\pm t'$ be the time representing the phase difference between each antenna (assumed to be vertical) and the axis mentioned above; $2\pi\xi$ be the corresponding phase angle $[\xi = t'/T = x \sin \theta/\lambda]$; $j = \sqrt{-1}$. The other symbols are the same as used in Section I. above. The expression for the electromotive force, e_0, induced in a simple antenna placed on the vertical medial axis of the loop, takes the form:

$$e_0 = E\epsilon^{(-\delta + j\omega)t} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (26)$$

Since the phase of the waves reaching antenna 2, nearest to the transmitting station, is $-t'$ in advance, while, when they reach

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* The damping, as is well known, may be very small (0·05 to 0·01) with transmitters of long wave lengths using umbrella aerials, or aerials with low radiating power; it becomes very important (0·2 to 0·5) with simple aerials with large radiating power, excited either directly or indirectly. The latter are imperative with short waves to obtain the necessary range.

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antenna 1, furthest from the transmitter, the phase lag is $+t'$, the expressions for the electromotive forces e_1 and e_2 become:

$$e_1 = e_0\epsilon^{+(\delta+j\omega)t'} = e_0\epsilon^{+(\Delta+2\pi j)\xi}$$

$$e_2 = e_0\epsilon^{-(\delta+j\omega)t'} = e_0\epsilon^{-(\Delta+2\pi j)\xi}$$

By addition and subtraction, we obtain respectively:

(Type D):

$$\begin{aligned} e_1 - e_2 &= 2e_0 \sinh(\Delta + 2\pi j)\,\xi \\ &= 2e_0(\sinh\Delta\xi\cos 2\pi\xi + j\cosh\Delta\xi\sin 2\pi\xi) \quad . \quad (27) \end{aligned}$$

(Type S):

$$\begin{aligned} e_1 + e_2 &= 2e_0 \cosh(\Delta + 2\pi j)\xi \\ &= 2e_0(\cosh\Delta\xi\cos 2\pi\xi + j\sinh\Delta\xi\sin 2\pi\xi) \quad . \quad (28) \end{aligned}$$

The real part of these expressions represents the component in phase with the electromotive force e_0 in the imaginary aerial, and the imaginary part, the component at right angles. The amplitudes of the resultant vectors are respectively $2e_0G_D$ and $2e_0G_S'$, writing G_D and G_S' for the radiogoniometric functions:

(Type D):

$$\begin{aligned} G_D &= \sqrt{(\sinh\Delta\xi\cos 2\pi\xi)^2 + (\cosh\Delta\xi\sin 2\pi\xi)^2} \\ &= \sqrt{\sinh^2\Delta\xi + \sin^2 2\pi\xi} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (29) \end{aligned}$$

(Type S):

$$\begin{aligned} G_S' &= \sqrt{(\cosh\Delta\xi\cos 2\pi\xi)^2 + (\sinh\Delta\xi\sin 2\pi\xi)^2} \\ &= \sqrt{\sinh^2\Delta\xi + \cos^2 2\pi\xi} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (30) \end{aligned}$$

The corresponding phase angles are respectively:

$$\tan\gamma_D = \frac{\tan 2\pi\xi}{\tanh\Delta\xi} \quad . \; . \; . \; . \; . \; . \; . \quad (31)$$

$$\tan\gamma_S = \tan 2\pi\xi \,.\, \tanh\Delta\xi \quad . \; . \; . \; . \quad (32)$$

The goniometrical functions obtained by dividing (27) and (28) by $2e_0$ are no longer scalar functions but are vectorial, since there is a phase difference between them caused entirely by the damping.

It is easy to explain this more clearly by a geometrical interpretation. On page 58 the electromotive forces in the two aerials were represented simply by two equal vectors E_1 and E_2 making angles $+\phi$ and $-\phi$ respectively with the axis of reference corresponding to the phase of the central imaginary aerial. The damping does not change the values of the angles ϕ, but alters the values of the vectors E_1 and E_2 by multiplying them by the exponential

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$\epsilon^{-\delta t}$, δ being the damping coefficient defined above. As shown in Fig. 10, the extremities a_1 and a_2 of these vectors (having origin at the fixed point O) no longer trace out a circle as ϕ varies, but a logarithmic spiral.

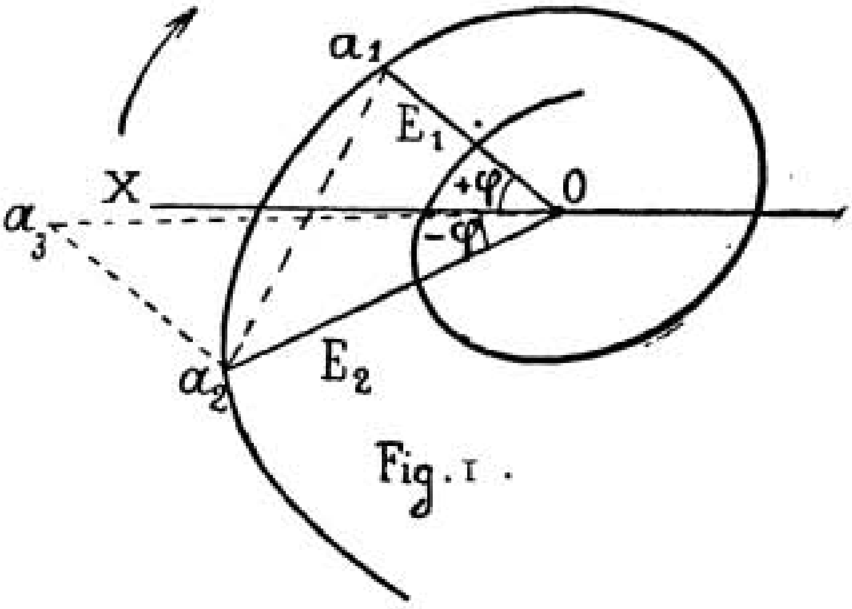

Fig. 1 .

Set off $a_2\,a_3 = Oa_1$, and join Oa_3 and $a_1\,a_2$, then the vector Oa_3 which is the resultant of $E_1 + E_2$, represents what we have called G_S' above, and makes an angle of lead γ_S with the line OX (angles of lag are measured in the direction of the arrow).

In the same way, the vector $a_2\;a_1$ representing the geometric difference of E_1 and E_2 corresponds in magnitude and phase with G_D, and the angle between $a_2\;a_1$ and OX is what we have called γ_D above.

By the help of Fig. 10 we can easily obtain expressions for these vectors and angles, by making use of the projections of E_1 and E_2 upon OX and upon an axis perpendicular to OX, thus:

Projection of $a_2\,a_1$ on $OX = e_0\,(\epsilon^{\delta t'} - \epsilon^{-\delta t'})\cos\phi$
$= 2e_0 \sinh \delta t' \,.\, \cos\phi.$

Projection of $a_2\,a_1$ on perpendicular to $OX = e_0\,(\epsilon^{\delta t'} + \epsilon^{-\delta t'})\sin\phi$
$= 2e_0 \cosh \delta t' \,.\, \sin\phi.$

Projection of Oa_3 on $OX = e_0\,(\epsilon^{\delta t'} + \epsilon^{-\delta t'})\cos\phi$
$= 2e_0 \cosh \delta t' \,.\, \cos\phi$

Projection of Oa_3 on perpendicular to $OX = e_0\,(\epsilon^{\delta t'} - \epsilon^{-\delta t'}) \,.\, \sin\phi$
$= 2e_0 \sinh \delta t' \,.\, \sin\phi$

which may be easily transformed by replacing $\delta t'$ by its value $\Delta\phi/2\pi = \Delta\xi$. In this manner the expressions (29), (30), (31), and (32) may easily be obtained.

In discussing the phase of the differential resultant $e_1 - e_2$, it is easier to consider the complementary angle $\psi = \frac{\pi}{2} - \gamma_D$, which may be calculated by the expression

$$\tan\psi = \frac{\tanh \Delta\xi}{\tan 2\pi\xi}.$$

As a matter of fact ψ becomes zero with undamped waves, and differs little from it with damped waves (Fig. 11).

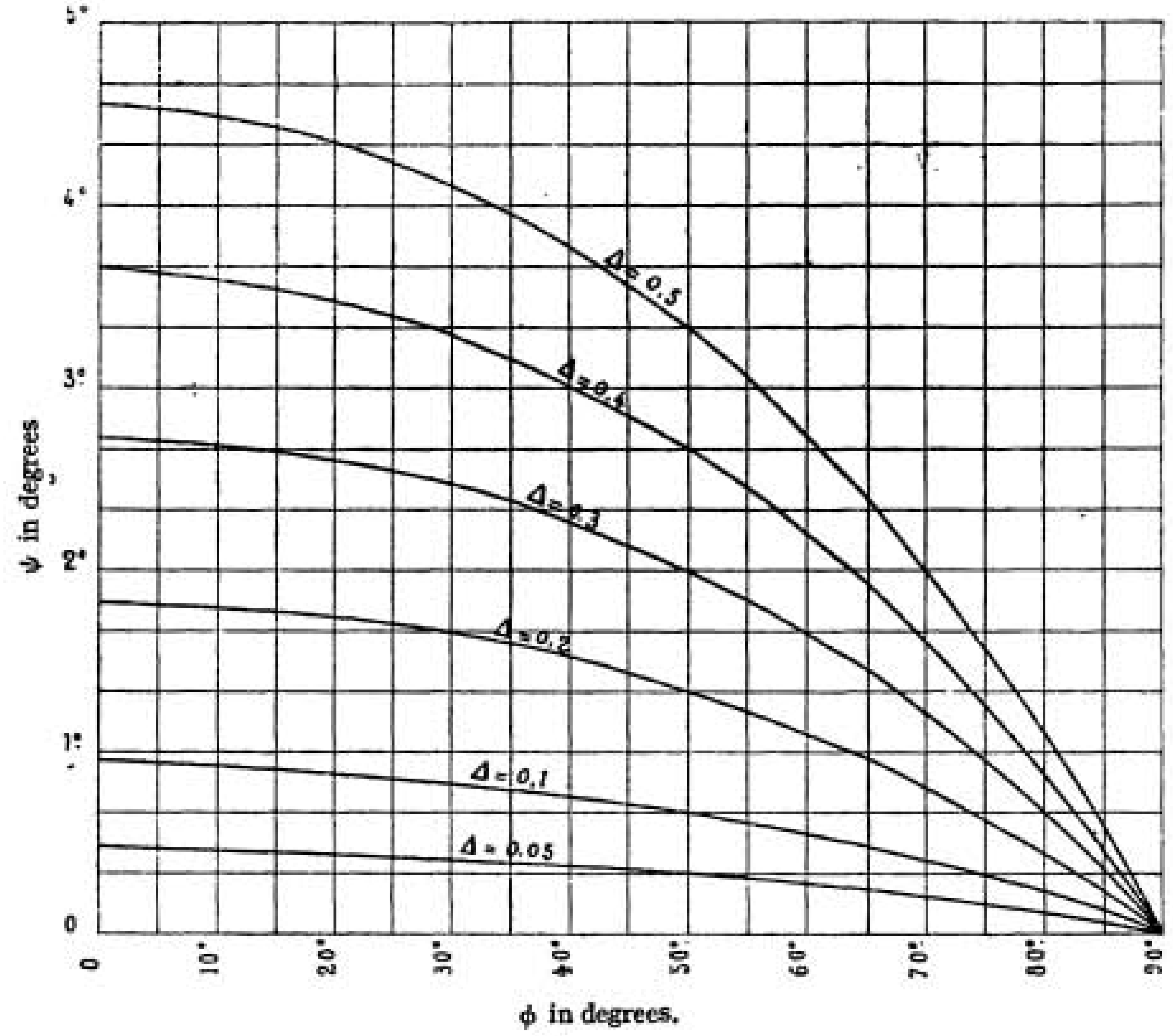

FIG. 11.

In the more general case of slanting aerials, it is necessary, as we have seen above, to integrate the components of the electromotive force at each point, making use of a knowledge of the equation of the shape of the loop, $\pm x = f(z)$—assuming for simplicity that the loop is symmetrical with respect to the vertical medial axis :

Type (D) :

$$\text{gon}\,\theta = \int_{z_0}^{z_1} \sinh \varDelta\,\xi\,.\,\cos 2\pi\xi\,.\,dz + j\int_{z_0}^{z_1} \cosh \varDelta\,\xi\,.\,\sin 2\pi\xi\,.\,dz \quad . \quad . \quad . \quad (33)$$

(Type S) :

$$\text{gon}\,\theta = \int_{z_0}^{z_1} \cosh \varDelta\,\xi\,.\,\cos 2\pi\xi\,.\,dz + j\int_{z_0}^{z_1} \sinh \varDelta\,\xi\,.\,\sin 2\pi\xi\,.\,dz \quad . \quad . \quad . \quad (34)$$

where

$$\xi = \frac{f(z)\sin\theta}{\lambda}$$

The calculation is therefore difficult.

Once in possession of the goniometrical functions for simple damped waves, it is easy to deal with the reception of these waves by frame aerial arrangements, using the same methods as employed above for undamped waves.

But the unknown function F representing the response of the detector with continuous waves, would here become considerably more complicated, if it were necessary to express it in greater detail, since it is known that the damping of the receiving circuits and their coupling, have a direct effect upon the strength of the damped current which passes through the detector.*

In any case—and this is the most important point to remember—because of the very fact that the waves are damped, the current to which they give rise is dissymmetrical and it is therefore no longer possible to neglect the direction in which the current commences with respect to the detector, when the latter is unsymmetrical, as is the case with crystal detectors.

If, for example, in the first instance the antenna a_1 receives the waves before the antenna a_2, and adjustments are made for the sound which is just audible in the telephones, the connections to the detector should be reversed in order to retain the same conditions when the loop is subsequently rotated so that antenna a_2 receives the waves before antenna a_1 in determining the second position of just audible sound. This complication can be avoided by the use of symmetrical detectors for integrating the energy. The effect of the wave damping can then be neglected as shown in Section III. below.

(*b*) Waves with Complex Decrement.

When the signals are formed of very highly damped wave trains, some account must be taken of the growth of each wave train. The calculation is therefore much more complicated even when it is assumed, as is done here, that both the loop (or system of two adjacent aerials) and the receiving circuit energised therefrom, are tuned sufficiently exactly to one of the two wave lengths set up by all indirectly coupled transmitters, that the effect of the other wave can be neglected.

It can merely be stated † that the electromotive force e_0 set up

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* See, especially, M. Wien, *Annalen der Physik*, 8, p. 696, 1902; and Drude, *Annalen der Physik*, 13, p. 528, 1904.

† See, Bjerknes, *Wiedemann's Annalen*, 44, p. 74, 1891; 55, p. 121, 1895; M. Wien, *Jahrbuch der Drahtlosen Telegraphie*, 1, p. 462, 1908; Zenneck, "Handbook of Wireless Telegraphy," pp. 79—81, 1909.

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in the imaginary central aerial by the wave length utilised, is the difference between two imaginary exponentials representing the two different decrements $\varDelta$ and $\varDelta'$. We may therefore write :—

$$e_0 = \eta E + \eta' E \quad . \quad . \quad . \quad . \quad . \quad . \quad (35)$$

where E is the maximum amplitude, $\eta = \epsilon^{(-\Delta + 2\pi j)\,t/T}$, and $\eta' = -\epsilon^{(-\Delta' + 2\pi j)\,t/T}$.

If, as above, $\pm\xi$ is the phase difference between the imaginary aerial and each of the two real antennæ, it is easily shown that the magnitude and phase of the resultant electromotive force in the loop is given by *

(Type D loops) :

$$e_1 - e_2 = 2E\eta \sinh(\varDelta + 2\pi j)\,\xi + 2E\eta' \sinh(\varDelta' + 2\pi j)\,\xi \quad . \quad (36)$$

(Type S loops) :

$$e_1 + e_2 = 2E\eta \cosh(\varDelta + 2\pi j)\,\xi + 2E\eta' \cosh(\varDelta' + 2\pi j)\,\xi \quad . \quad (37)$$

The response produced by the crystal detector being as stated above, a function F (depending upon the detector) of the electromotive force, of the [circuit] constants and of the dampings, it becomes necessary to separate out the terms involving $\varDelta$ and $\varDelta'$ and to consider the corresponding function F and F'. Each loop will therefore have a double goniometric function :—

(D loops) :

$$\left.\begin{aligned} \text{gon}\,\theta &= \eta \sinh(\varDelta + 2\pi j)\,\xi \\ \text{gon}'\,\theta &= \eta' \sinh(\varDelta' + 2\pi j)\,\xi \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (38)$$

(S loops) :

$$\left.\begin{aligned} \text{gon}\,\theta &= \eta \cosh(\varDelta + 2\pi j)\,\xi \\ \text{gon}'\,\theta &= \eta' \cosh(\varDelta' + 2\pi j)\,\xi \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (39)$$

and will give rise, at the detector, to a complex effect of the form

$$F\,(2E \bmod \text{gon}\,\theta) + F'\,(2E \bmod \text{gon}'\,\theta) \quad . \quad . \quad . \quad (40)$$

As an example, let us apply the preceding to the case of the compensation method with two loop aerials, of the same type and perpendicular to one another :

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* If the aerials are not vertical, but have a shape expressed by the equation $\pm x = f(z)$ as a function of the height z, these expressions should be replaced by integrals of the form

$$\int_{z_0}^{z_1} 2E\eta \sinh(\Delta + 2\pi j)\,\frac{f(z)\sin\theta}{\lambda}\,.\,dz + \int_{z_0}^{z_1} 2E\eta \sinh(\Delta' + 2\pi j)\,\frac{f(z)\sin\theta}{\lambda}\,.\,dz,$$

for Type D loops, as an example. The calculation thus becomes complicated.

Further let us neglect the commencement of the building-up period of the oscillation in the loop by assuming that the wave reaches the two aerials at the instant when e_0 rises from zero—which is not quite correct, but the error is sufficiently small to entitle us to neglect it.

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As above, let M and N be the mutual inductances between these two loops and the detector circuit when the detector current is reduced to the minimum perceptible value; ϵ' the electromotive force corresponding to this minimum; M' and N' the values of M and N for the second position of the movable loop to give the same minimum. Equations (11) are then evidently replaced by the following:

$$F\,[2E \bmod (M \operatorname{gon} \theta - N \operatorname{gon} \alpha)] + F'\,[2E \bmod (M \operatorname{gon}' \theta - N \operatorname{gon}' \alpha)] = \epsilon' \quad . \quad . \quad (41)$$

$$F\,[2E \bmod (M' \operatorname{gon} \theta - N' \operatorname{gon} \alpha)] + F'\,[2E \bmod (M' \operatorname{gon}' \theta - N' \operatorname{gon}' \alpha)] = \epsilon' \quad . \quad . \quad (42)$$

writing $\alpha = \frac{\pi}{2} - \theta$ to simplify the expression, and noting that F and F' are positive. In the case of an energy integrating detector, the symbols F and F' indicate that the expressions within the brackets should be squared; but the calculation, although then possible, remains difficult. In the case of crystal detectors F and F' cannot be determined either theoretically or even empirically in any useful manner, since E is unknown when making an observation, and varies with the distance from the transmitting station. The elimination of F, F', and E is therefore no longer possible, and θ cannot be calculated by a geometrical relation as in the previous cases.

The problem is only capable of approximate solution in the particular case when the decrements Δ and Δ' are very small and the width of the loop, $2x$, is sufficiently small compared with λ to enable the differences between the magnitudes and phases of the electromotive forces e_1 and e_2 to be neglected. It is then correct to express e_1 and e_2 as in the case of sustained waves, the only condition being that the function F takes complete account of the form and of the two decrements of the waves received by the loops. This solution is moreover only applicable to the Type D arrangement.

The whole of the above demonstration shows that direction-finding by means of short waves and with receiving aerials having a spacing which is a considerable fraction of the wave length, introduces complications which become more serious as the wave-form of the oscillations constituting these waves becomes more complex. The approximations allowable for taking account of

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the decrement of the waves in a simplified manner are indicated below.

III. THE ERRORS DUE TO NEGLECTING THE DAMPING.

In practice it is only necessary to consider a single decrement, particularly with impulse type transmitters which are the only ones which can be recommended.

Returning to the case of a simple decrement ($\Delta' = 0$) the expressions for G_D and G_S' can be studied more easily by putting them in the form :

$$G_D = \sqrt{\sin^2 \phi + \sinh^2 \frac{\Delta\phi}{2\pi}} \quad . \quad . \quad . \quad . \quad . \quad (29a)$$

$$G_S' = \sqrt{\cos^2 \phi + \sinh^2 \frac{\Delta\phi}{2\pi}} \quad . \quad . \quad . \quad . \quad . \quad (30a)$$

This form is suitable for estimating the error introduced by neglecting the damping—*i.e.*, by taking the values of $\sin \phi$ and $\cos \phi$ for G_D and G_S' respectively.

This error, which is zero when $\phi = 0$, increases with ϕ. Since $\phi = \frac{2\pi x}{\lambda} \sin \theta$, the value of ϕ increases with θ (which has a range of 0 to $\pi/2$) ; ϕ reaches its maximum of $2\pi x/\lambda$ when $\theta = \pi/2$. This maximum increases when x/λ is increased. In practical cases x/λ is not greater than 1/4, so that the maximum value of ϕ cannot exceed $\pi/2$. At this value the errors in G_D and G_S' will reach their greatest values. For the latter this error is $\sinh \Delta/4$, but for the former it is only $\sqrt{1 + \sinh^2(\Delta/4)} - 1$, *i.e.*, $\frac{1}{2} \sinh \Delta/4$ nearly. The effect of damping is therefore greater for G_S' than for G_D.

When $\sin \phi = \cos \phi$, that is when $\phi = 45°$ (corresponding to $\theta = \pi/2$, for $x/\lambda = 1/8$), the values of G_D and G_S' are equal, and the same error is made by taking them as both $= \sqrt{2}/2 = 0{\cdot}7$. Fig. 12 gives the values of G_D and G_S' as a function of θ; for the purposes of comparison, the corresponding values of G_D and G_S for $\Delta = 0$ (*i.e.*, for sustained waves) have also been plotted on the same diagram (dotted lines).

Even for the limiting case $x/\lambda = 1/4$ the error incurred by neglecting the damping hardly exceeds a few per cent., even for $\theta = \pi/2$. With a loop having a width of a quarter of a wave

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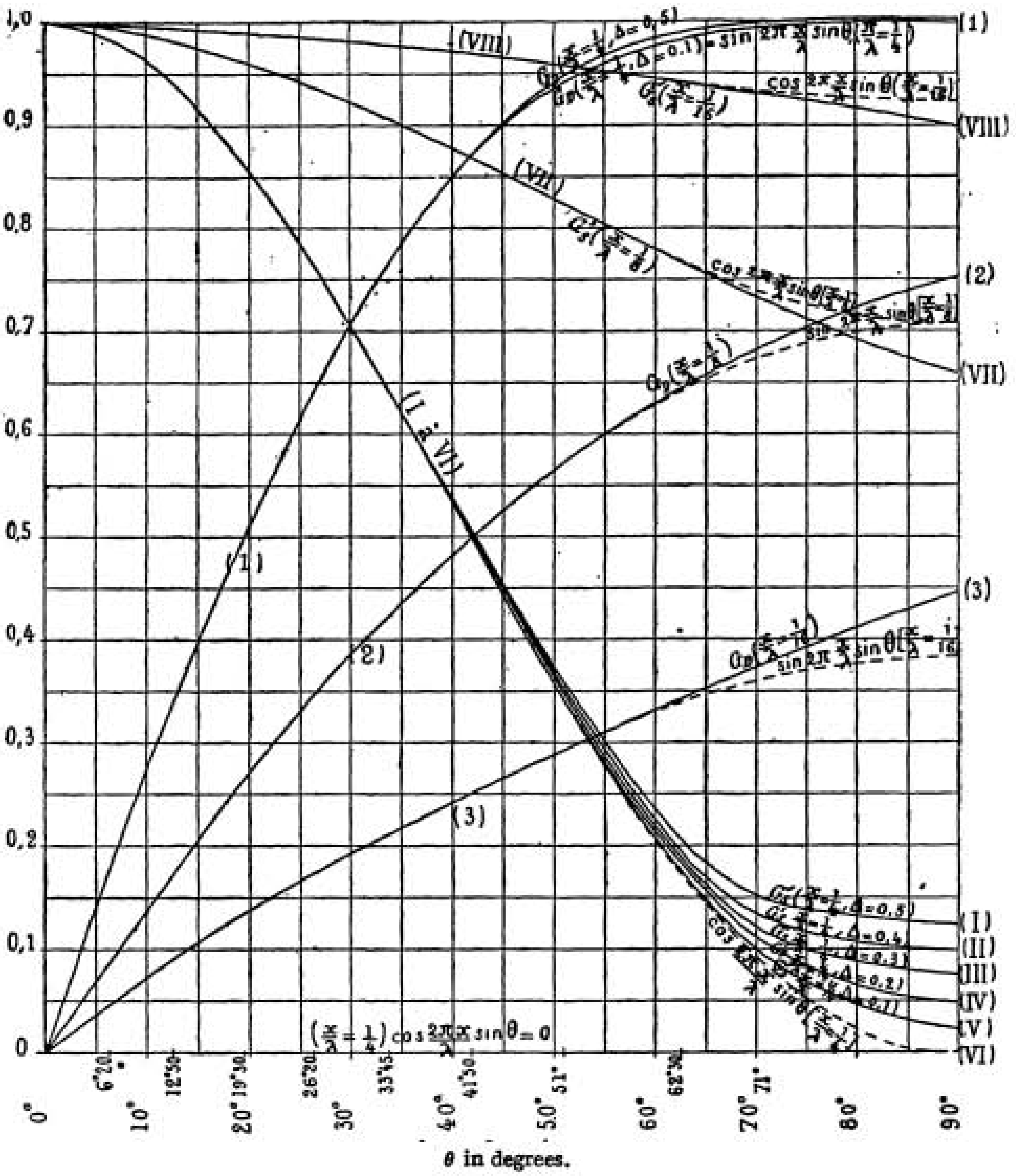
length ($x/\lambda = 1/8$), the greatest possible error will be less than 1 per cent. for G_D as well as for G_S'.

As to the errors in phase, they also may easily be considered by



$$G_D = \sqrt{\left[\sinh \frac{\Delta\phi}{2\pi} \cos \phi\right]^2 + \left[\cosh \frac{\Delta\phi}{2\pi} \sin \phi\right]^2}$$

$$G_S' = \sqrt{\left[\cosh \frac{\Delta\phi}{2\pi} \cos \phi\right]^2 + \left[\sinh \frac{\Delta\phi}{2\pi} \sin \phi\right]^2}$$

$$\phi = 2\pi \frac{x}{\lambda} \sin \theta$$

FIG. 12.

means of the expressions given above. It is easily seen that for Type D, the phase angle γ_D varies between the limits of $\pi/2$, for

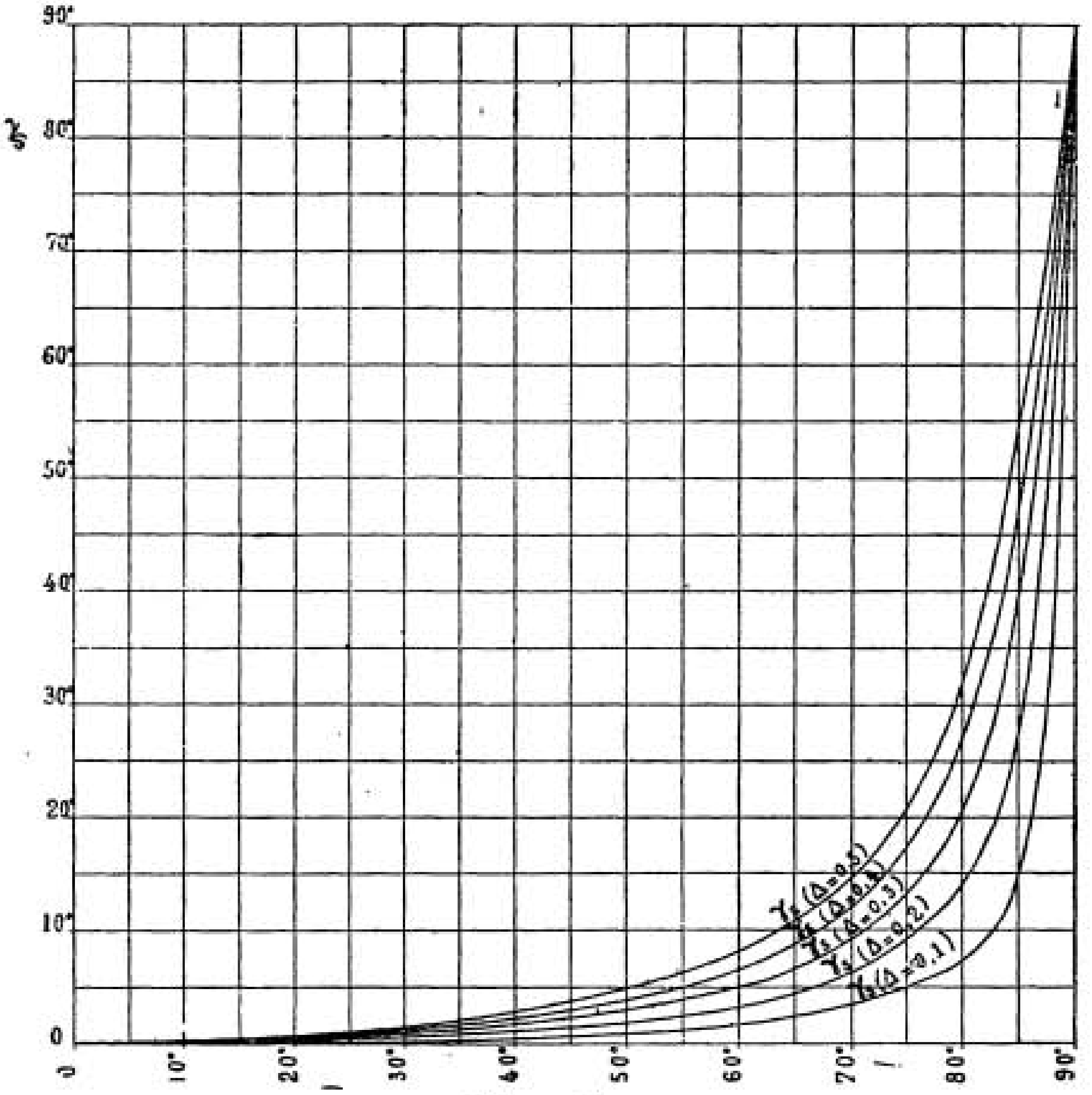
L

$\theta = \pi/2$ and any value of Δ, and $\tan^{-1} 2\pi/\Delta$ for $\theta = 0$, independently of the value of x/λ.

The phase error arising from neglecting the damping increases with the width of the loop but is always small for Type D—for example, when $\Delta = 0{\cdot}4$, it is at the most 3° 40′ (for $\theta = 0°$).

On the other hand, for Type S it may become very large, since γ_S, which is zero for $\theta = 0$ and any values of Δ and x/λ, becomes 90° when $\theta = 90°$ and $x/\lambda = 1/4$. For smaller values of x/λ, γ_S decreases very rapidly; for $x/\lambda = 1/8$ it is only 4°, for $x/\lambda = 1/16$, γ_S hardly reaches 1° when $\theta = \pi/2$.

Fig. 13 gives the values of γ_S as a function of ϕ.



Values of ϕ.

$$\gamma_S = \tan^{-1}\left[\tan\phi . \tanh\frac{\Delta\phi}{2\pi}\right]$$

Fig. 13.

The preceding investigation shows up the influence of damping on direction-finding. Primarily it must be noted that the action

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of the detector is sensibly modified but this need only be taken into consideration if the detector is of the rectifying crystal type. On the other hand, damping can give rise to considerable errors, but if care is taken to employ " Type D," which is now the only one used in practice and to adopt a wavelength longer than that at present fixed by the Convention of London, these errors become negligible. This is also the case if the size of the receiving aerials is reduced.

The object of the present paper has been especially to show the advantages of modifying the limit of 150 metres wavelength, which has been fixed for " radiophares," and to adopt a greater wavelength, such for example as 1,000 metres, but with the high sensitivity which can now be obtained with frame aerials of small dimensions by the use of amplifiers fairly practical and satisfactory results can be obtained with these frames. One difficulty only remains, resulting from the influence of wave reflections on the superstructure of the ships and of parasitic induced currents in all metallic parts of the ship such as stay wires, funnels, etc. In this connection it should be noted that larger wavelengths give rise to less trouble than small ones, for while the shrouds and metal masts are very liable to resonance with wavelengths of 100 to 150 metres, they are very much out of tune when wavelengths of 1,000 metres are used.

As to phenomena arising from reflections of the waves by metallic surfaces, the experiments of the lieutenant of the *Mesny* have shown up the remarkable fact that on an ordinary commercial vessel these reflections give rise to systematic *quadrantal* errors of the same type as the usual magnetic errors found with the compass, and in consequence the correction curve can be determined once and for all for each vessel.

In these favourable circumstances it is hoped that direction-finding on board ships will play a very important part in navigation in the future, provided that a sufficiently long wavelength can be employed.

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The Inductance of Single-Layer Rectangular Coils.

By THE EDITOR.

ONE of the results of the development of the cascade amplifier is the possibility of receiving relatively weak radio signals by means of a coil aerial without the use of an elevated antenna. Much of the transatlantic work is now received in this way. In addition to the saving of expense there is the advantage derived from the directional selective action of the coil with regard both to atmospheric disturbances and to interfering stations. The latter point is of great importance in duplex working where the interference comes from one's own transmitting station.

For constructional reasons the type of coil employed is usually rectangular; whether helical or plane spiral, the rectangular form is much more easily constructed than the circular.

The formulæ for the calculation of the inductance of rectangular coils are not so convenient as those for circular coils. In the August number of the *Jahrbuch der drahtlosen Telegraphie* a paper by A. Esau is published * in which a formula for rectangular coils is developed. The method adopted is that used by Strasser in 1905 for the inductance of cylindrical coils. It consists in adding up the self-inductances of all the turns and the mutual inductances between all the pairs of turns. The accurate formula for the mutual inductance involves benomials and logarithmic terms which are expanded in terms of the powers of the ratios g/a and g/b where g is the pitch and a and b the sides of the rectangle. Since these ratios are always small all powers above the square are neglected. The formula obtained, however, is very cumbersome, involving some twenty terms of various degrees of importance. It also necessitates reference to Strasser's constant $2 \log [(n-1)!\ (n-2)! \ldots 1]$ values of which are tabulated in Vol. 8, p. 195, of the *Bulletin of the Bureau of Standards*, U.S.A. When the two sides of the rectangle are equal, that is, when the coils are square the formula is greatly simplified and the inductance can be written $L = 8\,a\,n\,(S_1 + S_2)$ where a is the side of the square in centimetres, n the number of turns, S_1 a number depending on a/ρ (where ρ is the radius of the wire), and S_2 a number

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* RADIO REVIEW, Abstract No. 73.

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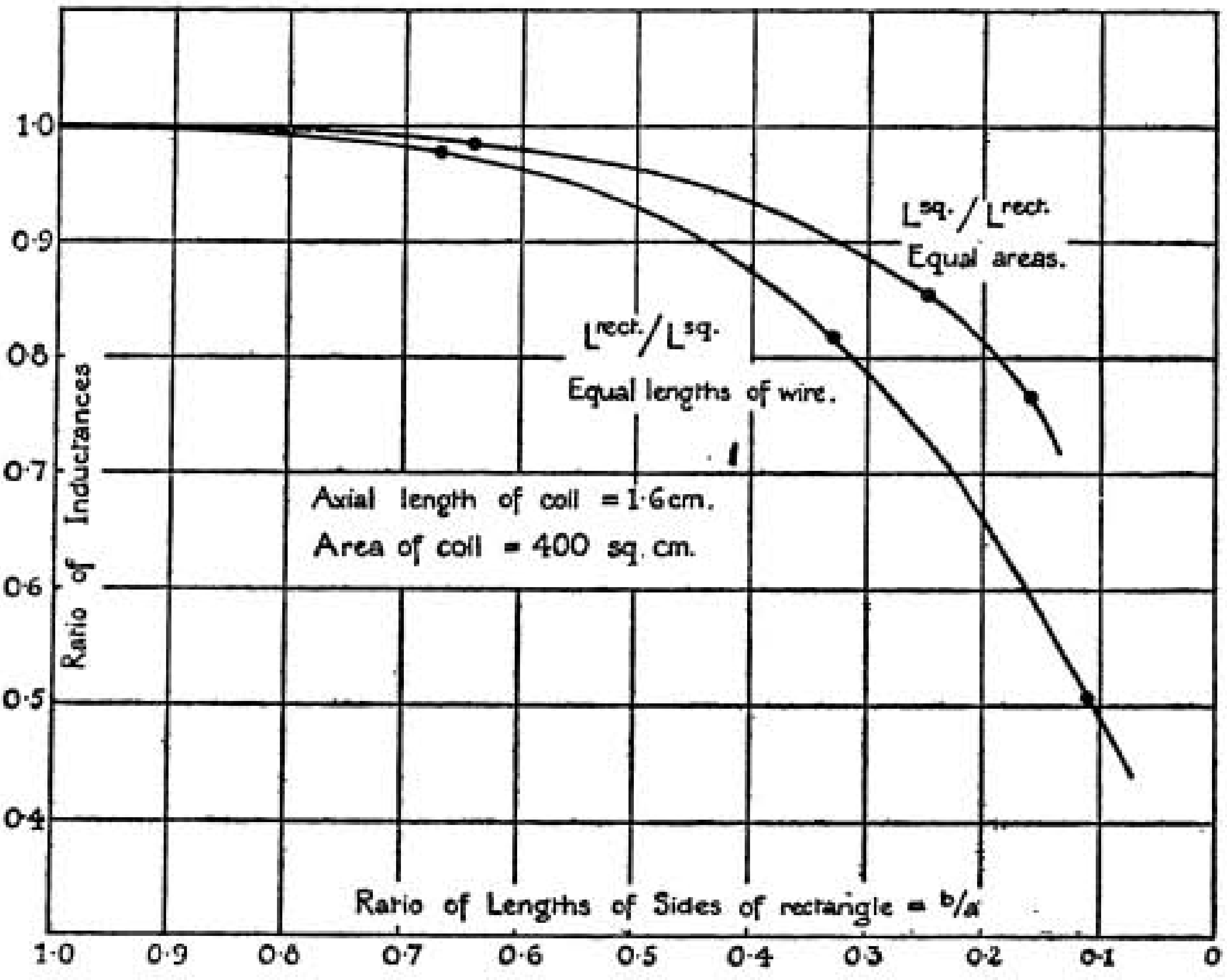
depending on n and g/a. Esau gives curves from which S_1 and S_2 can be read off if great accuracy is not required; he also gives tabulated values from which greater accuracy can be obtained.

By means of five examples the author shows that for a given length of wire the maximum inductance of a square coil is obtained when the axial length is about 0·45 of the side of the square. He also gives four examples of rectangular coils with different ratios of the sides a and b, but with a constant value of $a + b$, that is with a fixed length of wire. We have plotted his results and as the curve shows, the square has the largest inductance. Esau also compares the square coil with a cylindrical coil with the same length of wire and shows that the latter has about 15 per cent. higher inductance than the former.



In all his comparisons Esau assumes equal lengths of wire, but we wish here to draw attention to similar comparisons based on the assumption of equal areas of coils of different shapes. If a coil is very long compared with its diameter or diagonal the value of H within it for a given current is equal to $4\pi/10$ times the ampere-turns per centimetre whether the cross-section of the coil be circular, square, or rectangular. The total flux-linkages per ampere, and therefore also the self-induction, depend on the area of the cross-section and not on its shape. For coils in which the

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diameter is not very small compared with the length, this is not strictly true, but the area forms in all cases a much better basis of comparison than the length of the wire.

We have calculated the inductance of four rectangular coils each with twenty turns of wire of 0·067 cm. diameter with a pitch of 0·08 cm. and therefore an axial length of 1·6 cm. We have kept the area constant at 400 sq. cm. The results are as follows :—

Sides of Rectangle. $a \times b$	$\frac{b}{a}$	L	$\frac{L\ \text{square}}{L\ \text{rect.}}$
20 × 20	1·00	207,800	1·000
25 × 16	0·64	210,500	0·986
40 × 10	0·25	242,400	0·857
50 × 8	0·16	270,000	0·77

It will be seen that in this case, *the square has the lowest inductance,* and that even when the length of the coil is only 0·08 of the side of the square,—a very far departure from the infinitely long solenoid,—the equality of area gives much closer agreement between the inductances of squares and rectangles than does equality of length of wire. The values are plotted on the same diagram as the values given by Esau.

Square and cylindrical coils are used in practice much more than rectangular ones and it is therefore of greater interest to compare the inductances of square and round coils of equal area, more especially as radio-engineers are more familiar with the calculations for cylindrical coils and generally have the necessary formulæ or curves at hand. As we have already pointed out, the inductances for equal areas are identical if the coils are very long compared with the diameter ; if the coil is not so long, *the square coil has a greater inductance than the cylindrical one,* the ratio increasing as the coil is shortened and reaching its maximum with a single turn of wire.

Taking for example the square coil of 20 cm. side and twenty turns, a cylindrical coil of the same area would have a radius of 11·28 cm. and an inductance of 202,000 cm. ; hence even in this case the square coil has an inductance less than 3 per cent. greater than the cylindrical coil. A single square turn 20 × 20 cm. of 0·067 cm. wire has nearly 8 per cent. greater inductance than the circular turn of equal area.

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An Investigation of the Internal Action of a Triode Valve.

By W. H. ECCLES, D.Sc., M.I.E.E.

(*Continued from page* 77.)

EFFECT OF THE FALL OF POTENTIAL ALONG A FILAMENT.

When the cathode is a filament heated electrically there is a fall of potential along the filament amounting to four or six volts in small receiving triodes and to twenty or forty volts in large ones. It is necessary to examine the effect of this fall of potential upon the lumped characteristic. In Fig. 13, FF′ represents the length of a filament, F being the negative end, of a cylindrical triode. Let us suppose that, on being given a definite value of the anode and grid voltages relative to the negative end, a plane perpendicular to the filament is drawn at any point of it, and that the voltages of these electrodes above that of this point of the filament are represented by ordinates on the corresponding point of FF′. For instance, at the end F of the filament the end of the anode is e_a volts above the filament, and the end of the grid is e_g volts above; at the end F′ the anode is $e_a - e_f$ volts above the corresponding point of the filament, and the grid is $e_g - e_f$ above, where e_f is the voltage applied to the filament for maintaining its current. In order that the diagram may at once give the lumped voltage we

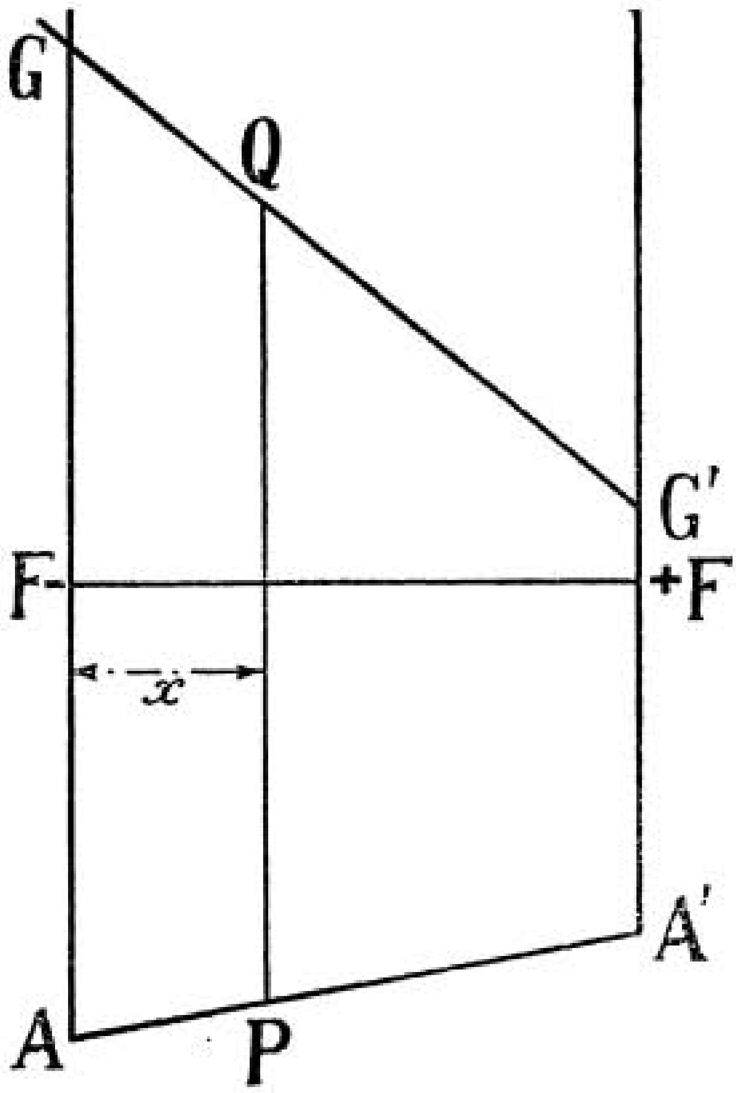

FIG. 13.

shall set g times the grid voltage to scale up the page, and the anode voltage to the same scale down the page. This is done at G and G′, at A and A′. It is evident immediately that the relative voltages in any plane, and the corresponding lumped voltage, are given by joining GG′ and AA′ by straight lines and then drawing an ordinate through the filament abscissæ concerned. At a point distant x from the end F the lumped voltage relative to the filament is given by the length PQ. Since the gradient of the anode line is e_f/l and that of the grid line ge_f/l, the anode is $e_a - xe_f/l$ volts and the grid $ge_g - xge_f/l$ "transferred" volts, above the filament in the plane distant x from the negative end, l being the length of the filament. The lumped voltage is, therefore,

$$PQ = e_a + ge_g - (1 + g)\, e_f x/l$$

in any plane, and the electron current in this plane is proportional to the three-halves power of this expression. The total current at any given adjustment is given by integrating the ordinate PQ throughout the area AA′G′G. The formula is easily obtained, but is not required here.

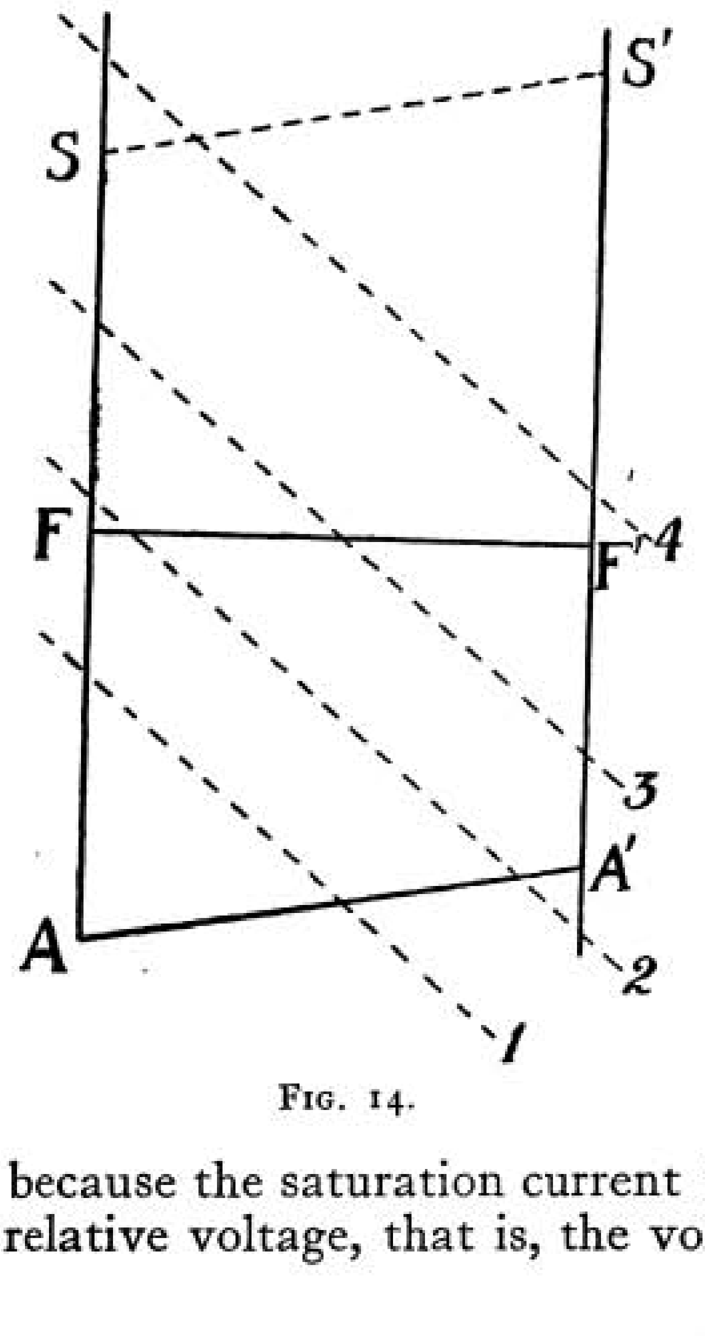

FIG. 14.

As the grid voltage rises the line GG′ moves up the page parallel to itself; as the anode voltage rises the line AA′ moves *down* the page parallel to itself. Keeping the anode voltage fixed, and varying the grid voltage from extreme negative values to extreme positive values of potential, we see that the grid lines take successive positions such as those numbered 1, 2, 3 in Fig. 14. The area swept over by the moving line is at first a rapidly growing triangle—then a rhomboid growing steadily, and then a slowly growing five-sided figure when the line SS′ is intersected. This line represents the saturation level. It is drawn parallel to AA′ because the saturation current is reached at each end at the same relative voltage, that is, the voltage AS equals the voltage A′S′.

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Inspection of the areas swept over by the moving line shows, without elaborate calculation, that the effect of the fall of potential along the filament is practically confined to the knees of the lumped characteristic—the middle portion is not affected. This conclusion is exhibited graphically in Fig. 15, where the actual curve that would be obtained by an experimenter using one end of the filament as his zero of potential is shown as a mean between two ideal curves that would be obtained from the same triode if, first, all the filament were at the potential actually possessed by one end, and, second, all at the actual potential of the other end.

THE STRAIGHT PART OF CHARACTERISTIC CURVES.

For many practical purposes the straight part of the triode characteristic is the most important part, and there are many types of tube in which it is longer than the curved parts. In some cases the three-halves power law holds over only about a sixth part of the characteristic. It is very desirable to have an explanation of this striking departure from the three-halves power law, for in the absence of an understanding of the causes the designer works in the dark. There are many factors to which the phenomenon might be attributed—factors omitted from the analysis of the preceding pages. Among these are the finiteness in the length of the electrodes and the consequent stray electric field, the magnetic effect of the filament current, the flow of the electron current to right and to left along the filament, the distribution of velocity of the electrons at emission, the production of secondary electrons, the space charge that accompanies the flow of the grid current, the cooling of the ends of the filament, and others. We have investigated already the effects of the fall of potential along the filament and have found that it cannot have

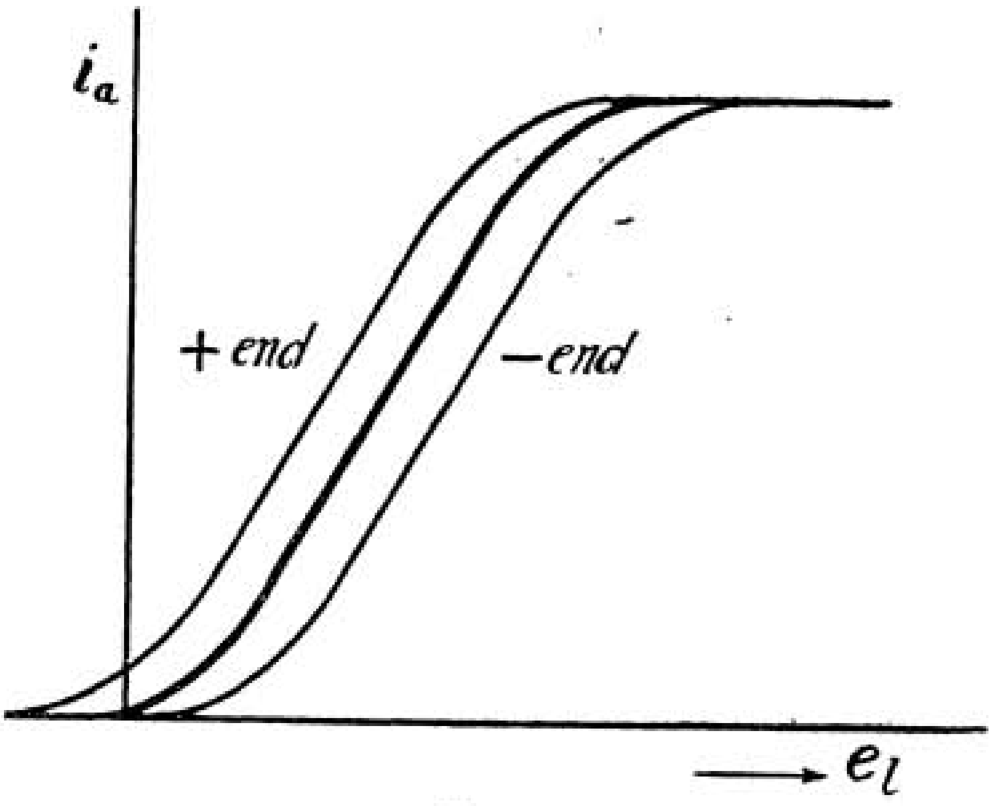

FIG. 15.

any appreciable influence in producing the straight part of the characteristics; and upon close examination it is found that only one of the factors enumerated above can account for the facts; this is the cooling of the ends of the filament, or, in other words, the rise of temperature from the ends to the centre of the filament.

The explanation to be offered applies to all forms of triode utilising heated filaments as cathodes, and does not depend on whether the filament is straight or folded; but for simplicity we shall assume that we are dealing with a cylindrical triode possessing a straight axial filament. The middle parts of the filament are surrounded by the anode, which serves incidentally as a good reflector of the heat radiated from the filament, and therefore tends to keep up the temperature of the centre portions. The ends of the filament are, on the other hand, rather strongly cooled by the leads that support it and also by the opportunity for radiation. Now, the electron current that can be drawn from a hot filament increases rapidly with rise of temperature—for example, the saturation current per unit length of a certain filament while at a uniform temperature of 2,200° K was 15 mA, and this was attained at 30 V, while the same filament at 2,400° K gave a saturation current of 110 mA at 115 V. A difference of 200° in temperature between the middle and ends of a filament in a triode is not at all unlikely, and therefore in such an instrument the ends yield their maximum current at a lumped voltage of 30 V and cannot contribute more though the voltage be raised. Up till that voltage every point of the filament would obey the three-halves power law, but after that the ends yield 15 mA while the centre portions continue to obey the law. But as the lumped voltage is raised further and further more and more of the filament attains saturation and ceases to contribute further increases of current. Evidently the law which the total current obeys will depend greatly upon the law according to which the temperature is distributed along the filament, and it is clear that the filament as a whole will not give its final saturation current till the

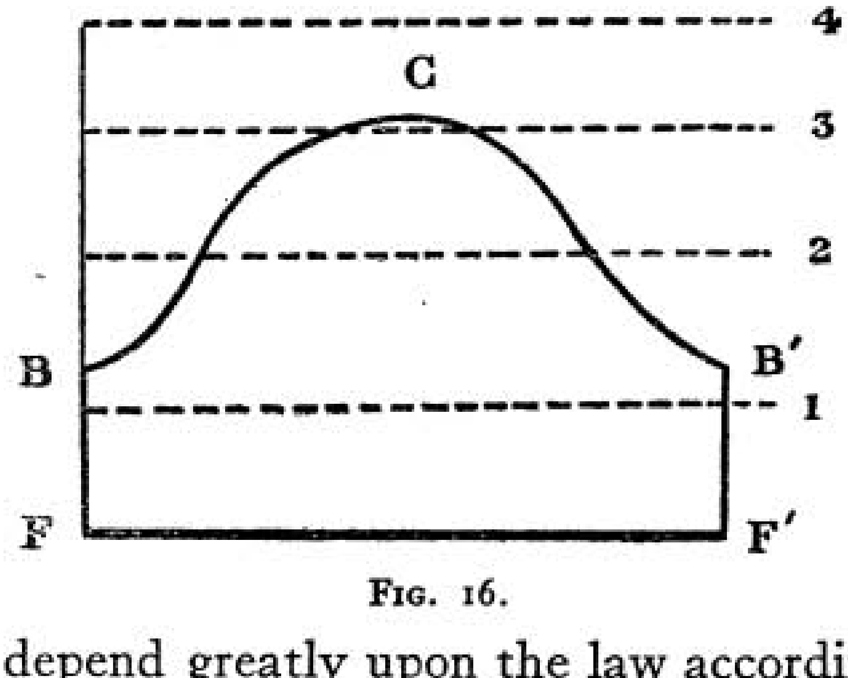

Fig. 16.

voltage is raised to the saturation value corresponding to the temperature of the hottest part of the filament. All this is represented graphically in Fig. 16. In this figure FF′ represents the length of the filament, and the ordinates of the curve BCB′ represent values of the saturation current per unit length at the corresponding points of the filament.

Since it has been shown that the fall of potential along the filament is not fundamentally concerned in the present problem we shall suppose the filament is at uniform potential throughout its length and shall therefore represent any lumped voltage between it and the other electrodes by a straight line parallel to FF′. Such lines are drawn and marked 1, 2, 3, 4 in the figure; they are placed at heights that represent to scale the electron current per unit length corresponding to the voltage, that is, their heights are proportional to the three-halves power of the lumped voltage. At the position marked 1 the voltage is such that even the ends of the filament are not giving their saturation current, which is equal to FB; and every portion of the filament is yielding current at equal rates per unit length and according to the three-halves power law. At the position 2 we have a state of affairs in which large portions near the ends of the filament are giving their various saturation currents while the middle portion still follows the three-halves power law in responding to rise of voltage. At the position 3 almost every part of the filament is giving its saturation current, and at position 4 the current has ceased to respond to changes of the lumped voltage. At any stage the whole current i_a is equal to the area under the line and within the curve.

Let l be the length of the filament, y the length of the centre unsaturated portion in any general position of a line such as that numbered 2, i_u the electron current being taken per unit length of the unsaturated portion, e_l the lumped voltage throughout the length of the triode, i_a the total current from anode to cathode. Since the filament is all at one potential we are free from anxiety about the zero of the lumped voltage and write, therefore,

$$i_u = A' e_l^{\frac{3}{2}}.$$

Imagine that the voltage undergoes the increment de_l; the line in the diagram will rise and add to the area underneath it an amount equal to the length of the unsaturated portion multiplied by the increase in the electron current throughout that portion. The total current increases by the amount di_a, and we have

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$$di_a = y\,di_u.$$

By aid of the preceding equation we obtain

$$\frac{di_a}{de_l} = \frac{3}{2}A'ye_l^{\frac{1}{2}}.$$

This differential equation is the expression of the law connecting i_a, e_l, and y.

In position 1, y is l, and we can then integrate the equation and obtain

$$i_a = lA'e_l^{\frac{3}{2}}.$$

In position 2 the length of y varies as the line rises and, therefore, the equation cannot be integrated till the law of variation is given for the particular filament in use. In position 3 the equation is about to be put out of action by the fact, not expressed in it, that the temperature has a limit. In position 4 the equation is completely out of action; obviously the area of the whole curve FBCB′F′ represents the total saturation current of the tube.

The determination of y, which implies the determination of the temperature at every point of the filament, if it had to be done from the fundamental physical laws of the conduction and radiation of heat, would demand a complete knowledge of the dimensions and properties of the filament substance and of the reflecting powers of its surroundings; consequently we leave the connection between i_a, e_l and y in the form of a differential equation. But it is interesting to reverse the process and to inquire how the electron current per unit length (and inferentially the temperature) would have to vary from point to point of the filament in order to give a specific shape to the characteristic. The designer is able to control the temperature distribution by, for example, using a filament of variable section and by altering the configuration of the reflecting surfaces. Therefore let us inquire into the variation of electron current needed to make a large portion of the characteristic curve a straight line. Let the equation of this straight part be

$$i_a = h_o + h_a e_l$$

where h_o and h_a are constants on this occasion.

Then
$$\frac{di_a}{de_a} = h_a,$$

and therefore
$$h_a = \tfrac{3}{2}A'ye_l^{\frac{1}{2}}$$

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gives the connection between y and e_l along the straight portion. In terms of the electron current per unit length this becomes

$$h_a = \tfrac{3}{2}A'y(i_u/A')^{\frac{1}{3}} = \tfrac{3}{2}A'^{\frac{2}{3}}yi_u^{\frac{1}{3}}.$$

By aid of this equation the curve of Fig. 17 is constructed to exhibit the highest electron current possible at each point of the filament. The parallel straight line boundaries marked F B, F′ B′ are drawn a distance l apart where the length l is the active part of the filament. The upper boundary line parallel to the base has yet to be determined. To do this we may return to the differential equation

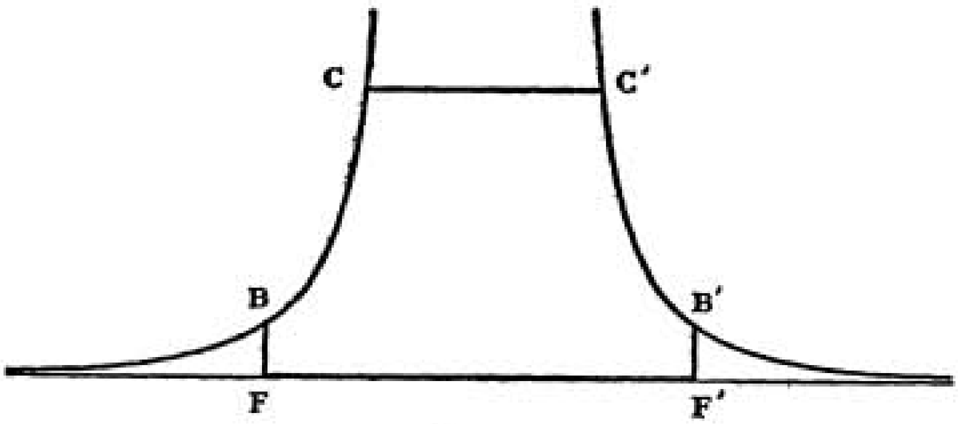

FIG. 17.

$$di_a = ydi_u$$

and eliminate i_u by aid of the last equation. First put this in the form

$$i_u = cy^{-3}$$

for brevity, and notice that if i_{a1} represent the total current across the vacuum at the instant when the ends of the filament reach saturation values, then at that instant

$$i_{a1}/l = cl^{-3}$$

in accordance with the above equation. Thus

$$i_{a1}l^2 = c.$$

Now write

$$\begin{aligned} di_a &= yd(cy^{-3}) \\ &= -3cy^{-3}dy. \end{aligned}$$

On integrating we get

$$i_a = \frac{3}{2}\,\frac{c}{y^2} + \text{constant.}$$

When $y = l$, $i_a = i_{a1}$, therefore,

$$i_{a1} = \frac{3}{2}\,\frac{c}{l^2} + \text{constant.}$$

Hence

$$i_a - i_{a1} = \frac{3}{2}c\left(\frac{1}{y^2} - \frac{1}{l^2}\right).$$

Upon eliminating c by aid of the previously found relation we have

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$$\frac{i_a}{i_{a1}} - 1 = \frac{3}{2}\left(\frac{l^2}{y^2} - 1\right),$$

or

$$\frac{y^2}{l^2} = \frac{3i_{a1}}{2i_a + i_{a1}}.$$

This equation gives the fraction of the length of filament still unsaturated when the total current is known by measurement. For example, if $i_a = 9i_{a1}$ at the extreme end of the straight portion of the characteristic, that is to say, if in a certain tube the length of the straight portion of the characteristic is such that the current at the upper end is nine times that at the lower end, we have

$$\frac{y^2}{l^2} = \frac{3}{18 + 1},$$

or

$$y = 0{\cdot}397l.$$

In words, the central four-tenths of the filament is at a practically uniform temperature which is higher than that of the portions of filament on each side of it.

The writer takes this opportunity of thanking Mr. H. Davies for making the measurements involved in this paper and in the drawing of the characteristics of Figs. 11 and 12.

The British Association Meeting at Bournemouth.

The Three-Electrode Thermionic Valve as Alternating Current Generator.

By Professor C. L. FORTESCUE.

(*Continued from page* 88.)

3. THEORY OF THE COMBINATION OF VALVE AND CAPACITY-INDUCTANCE CIRCUIT.

In designing the valve and circuit two things have to be kept in mind. In the first place the conditions must always be such that any incipient oscillation in the capacity-inductance circuit will cause sufficient power to be supplied from the valve for the oscillation to be built up from the indefinitely small initial values to relatively large amplitude. In the second place

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the circuit arrangements should be such that the maximum power is taken from the tube, so setting up oscillations of the greatest possible amplitude, in which connection it may be remarked that with bad proportioning of the circuit and the valve, the current generated may reach a stable maximum value long before the possible maximum power output from the tube is attained. Bad design of this kind is obviously wasteful, as it leads to the use of unnecessarily large and expensive valves.

Referring to the simple circuit arrangement of Fig. 3, it will be seen that in the course of one cycle of the oscillating current in the capacity-inductance circuit, the effective voltage both between the grid and the filament and between the positive electrode and the filament are varying. In Fig. 6 the variation of these two voltages is plotted for one cycle in the correct relative phases to the current in the inductance, the positive direction of the current in the inductance being from the point *a* to the point *O*, and on to the point *b* (Fig. 3). With regard to the tube, the positive direction for the voltages at both the positive electrode and the grid is when the filament is negative. In order to determine the nature of the current in the part *Ob* of the inductance *L* it is necessary to refer to the characteristics of the valves. These may be plotted as in Fig. 2, but are preferably drawn out, as in Fig. 7, a method adopted in H.M.S. *Vernon* in 1915. In this figure the voltage at the grid is plotted horizontally, the voltage at the positive electrode vertically, and the current at the positive electrode is drawn in as a series of contours of constant current.

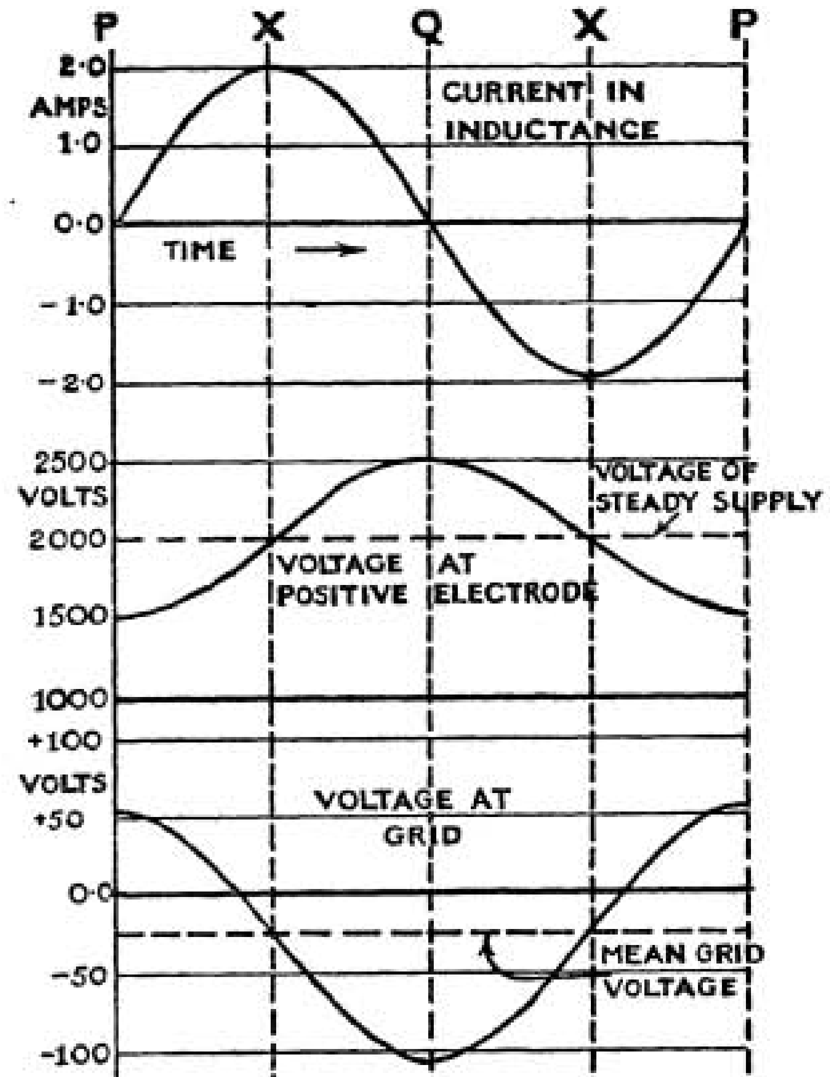

Fig. 6.

The first point of the cycle of Fig. 6 is a point where the voltage at the grid is a maximum and that at the positive electrode a minimum. This will correspond to a point *P* in Fig. 7. After one quarter of a cycle has been passed through the voltage at both the grid and the positive electrode will be at the normal values as maintained by the batteries. This state corresponds to the point *X* of Fig. 7 (which also corresponds to the point *X* of Fig. 2). After one-half cycle has been passed through, the point *Q* of Fig. 7 will have been reached. After three-quarters of a cycle, a return is made

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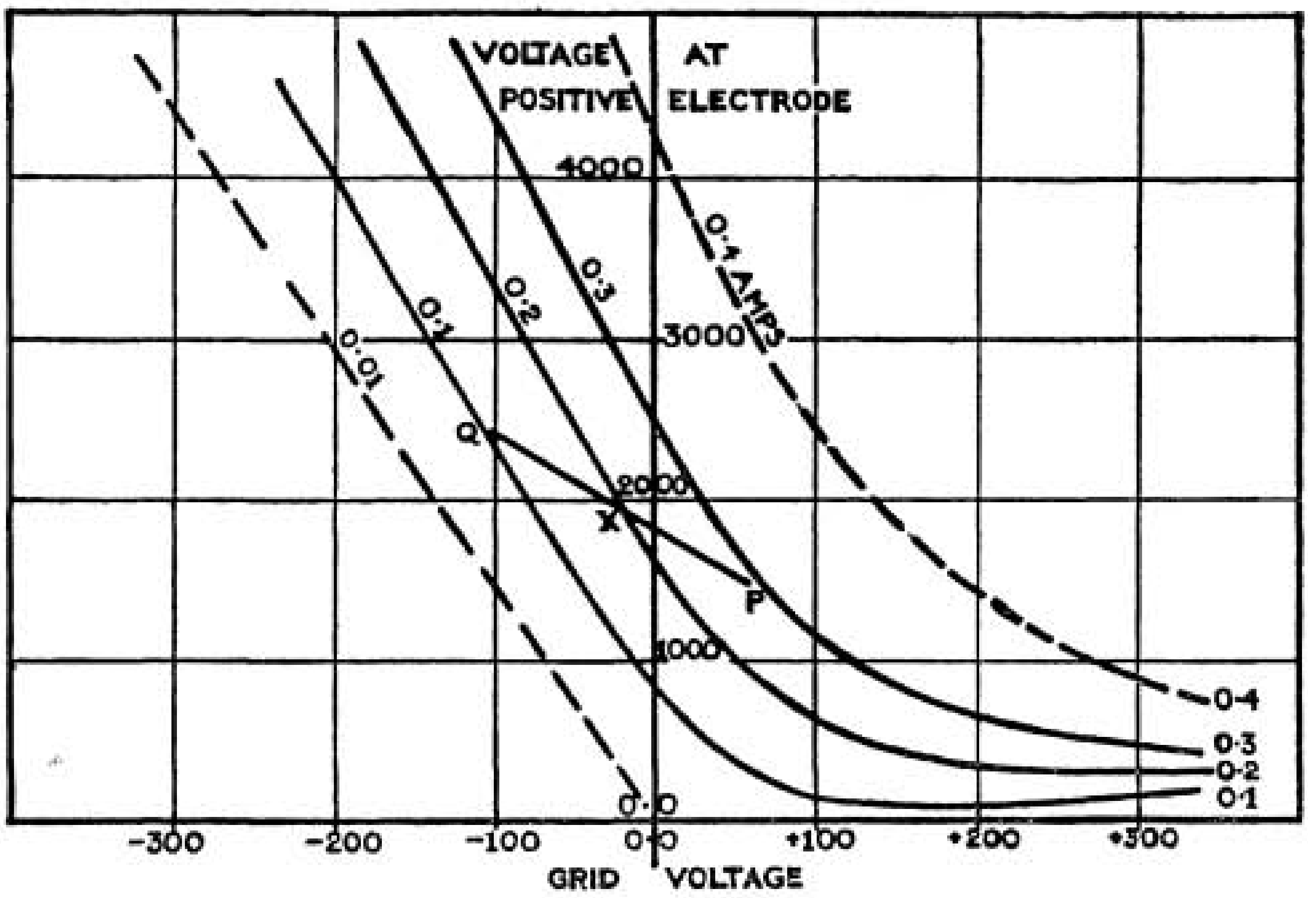

FIG. 7.

to the point X, and back again to the point P on completion of the whole cycle. Since the alternating components of the voltages in Fig. 6 differ in phase by 180°, the points P, X and Q of Fig. 7 will lie on a straight line, which has been called the "Oscillation Line." The way in which this line cuts the contours in Fig. 7 shows the variation of the current in the part Ob of the inductance L. This variation has been plotted in Fig. 8 in its correct phase relation to the current in the inductance. It will be seen from an inspection of the second curves of Figs. 6 and 8 that the alternating component of the current flowing in at O and out at b (Fig. 3) is opposite in phase to the alternating component of the voltage between these two points. The conditions chosen for the diagrams represent, therefore, a supply of alternating power to the inductance. Had the oscillation line been drawn as in Fig. 9, the phase of the current would have been reversed, and power would have been abstracted

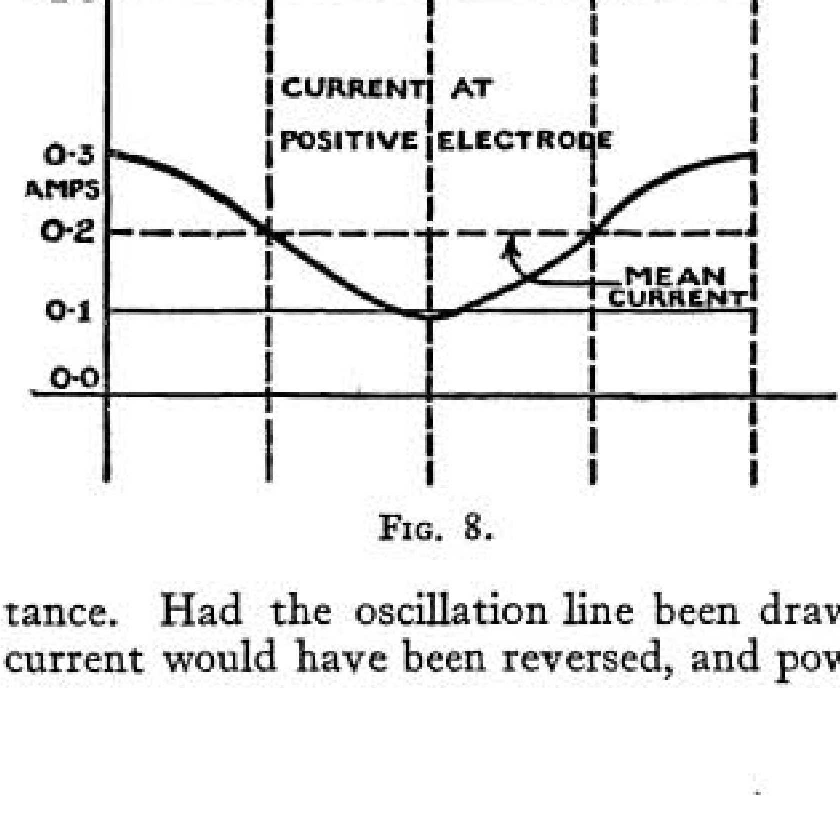

FIG. 8.

from the circuit. One condition necessary for the building up of a small incipient oscillation is, therefore, that the oscillation line should lie as in Fig. 7, and not as in Fig. 9. Another condition is that the alternating power supplied to the circuit should exceed the sum of the power expended in the circuit and the power abstracted from the circuit (by any means whatever). The power expended in the circuit is due to the main oscillating current in the inductance and the condenser, and to the exciting valve current in the part *Ob* of the inductance. With the simple circuit the power abstracted is only that required to vary the voltage of the grid, observing that the grid current is usually in phase with the alternating voltage across the part *aO* of the inductance.

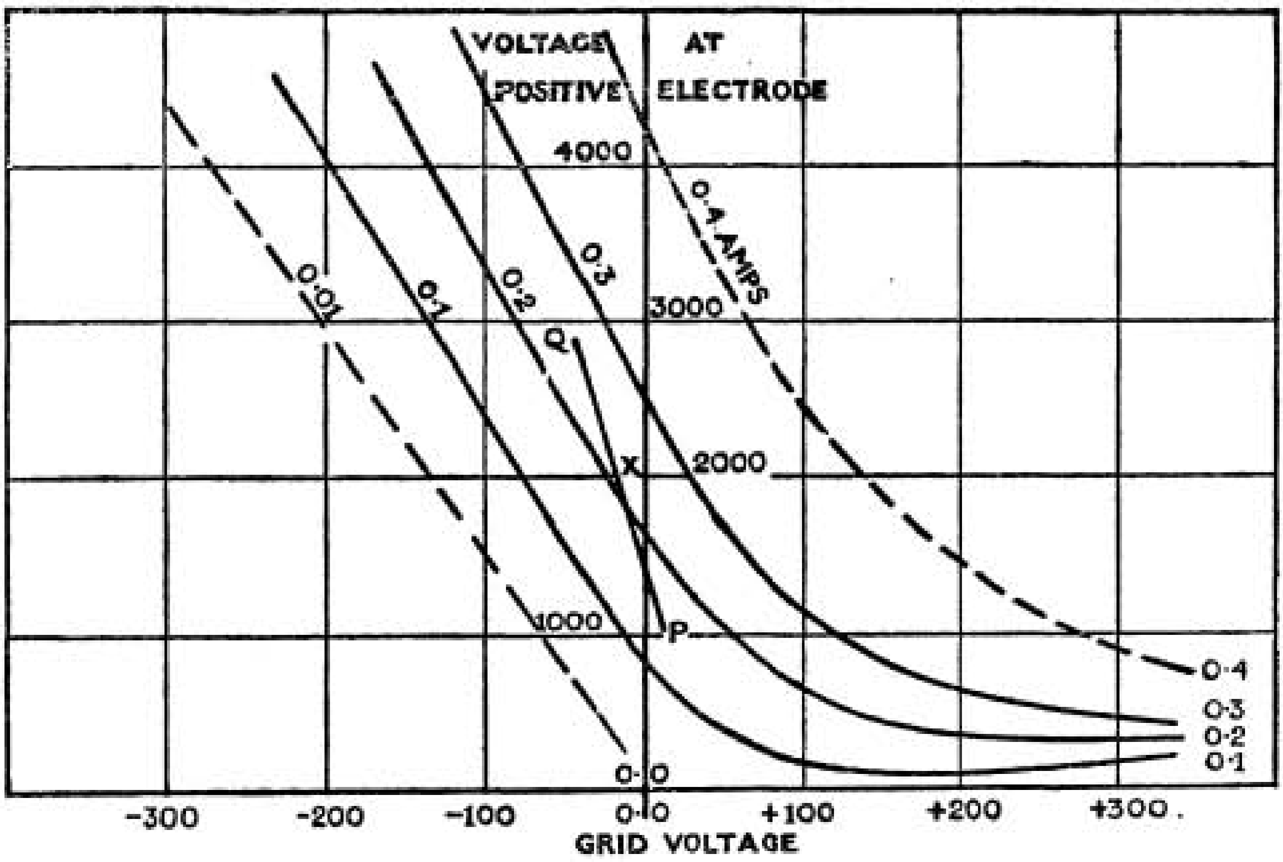

FIG. 9.

As a very good first approximation, which is good enough for most designing purposes, the following assumptions may be made:—

(*a*) The power expenditure arising from the passage of the exciting current from the valve through the part *Ob* of the inductance may be neglected in comparison with the whole loss due to the main oscillating current.

(*b*) The power abstracted from the circuit to operate the grid may be neglected in comparison with the loss due to the main oscillating current.

(*c*) The resistance component of the voltage across each part of the inductance may be neglected in comparison with the reactance component; *i.e.*, the relative phases of the voltage and current may be taken as differing negligibly from 90°

(*d*) The amplitude of the incipient oscillation may be assumed to be so

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small that the characteristic curves may be taken as straight lines over the whole range under consideration.

(*e*) The alternating component of the current to the positive electrode may be assumed small compared with the main oscillating current, and to cause only slight changes in the alternating voltages applied to the grid and positive electrode.

With these assumptions the conditions necessary for the maintenance of oscillations can be calculated easily. Let δI be the R.M.S. value of the incipient alternating current in the inductance. The corresponding R.M.S. voltage, δV, across the whole inductance is

$$\delta V = L\omega.\delta I \quad \ldots \ldots \ldots \quad (1)$$

where $\omega = 2\pi$ times the frequency.

Let the voltage across the part aO of the inductance be some fraction of δV, viz., $a\,\delta V$, and that across the part Ob some other fraction, viz., $b\,\delta V$; the only limitations to a and b being

$$a + b \not> 1 \quad \ldots \ldots \ldots \quad (2)$$

Let k_1 be the rate of increase of the current at the positive electrode with respect to the increase of the grid voltage, and k_2 the rate of increase with respect to the voltage at the positive electrode. The alternating component of the valve current through the part Ob of the inductance is then

$$k_1 a.\,\delta V - k_2 b.\,\delta V$$

If δW denotes the mean power supplied to the circuit, then

$$\delta W = b.\,\delta V\,(k_1 a.\,\delta V - k_2 b.\,\delta V)$$
$$= (k_1 ab - k_2\, b^2)\,\delta V^2 \quad \ldots \ldots \ldots \quad (3)$$

With the foregoing assumptions, the power expenditure in the circuit is $\delta I^2 R$, R being the effective resistance of the oscillatory circuit.

The conditions necessary for a small oscillation to build up to a large one are therefore

$$(k_1 ab - k_2\, b^2)\,\delta V^2 > \delta I^2 R \quad \ldots \ldots \ldots \quad (4)$$

But $\delta I = \delta V/L\omega$, and so the condition becomes

$$k_1 ab - k_2\, b^2 > R/L^2\omega^2 \quad \ldots \ldots \ldots \quad (5)$$

And putting $\omega^2 = 1/LC$, which is nearly true, the condition reduces to

$$k_1 ab - k_2\, b^2 > RC/L \quad \ldots \ldots \ldots \quad (6)$$

or

$$Labk_1 > RC + Lb^2\, k_2 \quad \ldots \ldots \quad (6a)$$

With power valves the term Lb^2k_2 is sometimes much greater than the term RC, and when this is the case the approximate conditions for the maintenance of oscillations become $a/b > k_2/k_1$, which is simply an expression of the requirement that the oscillation line must lie as shown in Fig. 7 and not as in Fig. 9.

Equation (3) is also of interest in that it gives a value for the "negative resistance" of the valve. Putting $\delta V = L\omega\,\delta I$, the power supplied to the circuit is

$$\delta W = (k_1ab - k_2b^2)\,L^2\omega^2\,\delta I^2$$
$$= \frac{L}{C}(k_1ab - k_2b^2)\,\delta I^2$$

from which it follows that the negative resistance is

$$(R-) = \frac{L}{C}(k_1ab - k_2b^2)\,. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

The required condition for the maintenance of oscillations is that this negative resistance shall exceed the actual resistance, R, *i.e.*, that

$$\frac{L}{C}(k_1ab - k_2b^2) > R \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6b)$$

which is identical with equation (6).

Assuming that the necessary conditions are complied with, any small oscillation that may be started by the closing of a switch or by any other means, will gradually increase in amplitude. The corresponding oscillation line will lengthen proportionally and in course of time will extend into regions where the values of k_1 and k_2 are no longer constant throughout the whole of the cycle and the alternating component of the current from the valve will be no longer a sine wave. The effect will be particularly marked when the oscillatory current reaches such a value that the voltage at the positive electrode is reduced almost, or quite, to zero at the beginning of the cycle. In consequence of this irregularity the power supplied to the circuit from the valve will increase less rapidly than the square of the current in the main oscillatory circuit. Stable conditions where the power supply is equal to the power expenditure will thus be reached quickly and no further increase of the current will take place unless the resistance of the circuit is reduced.

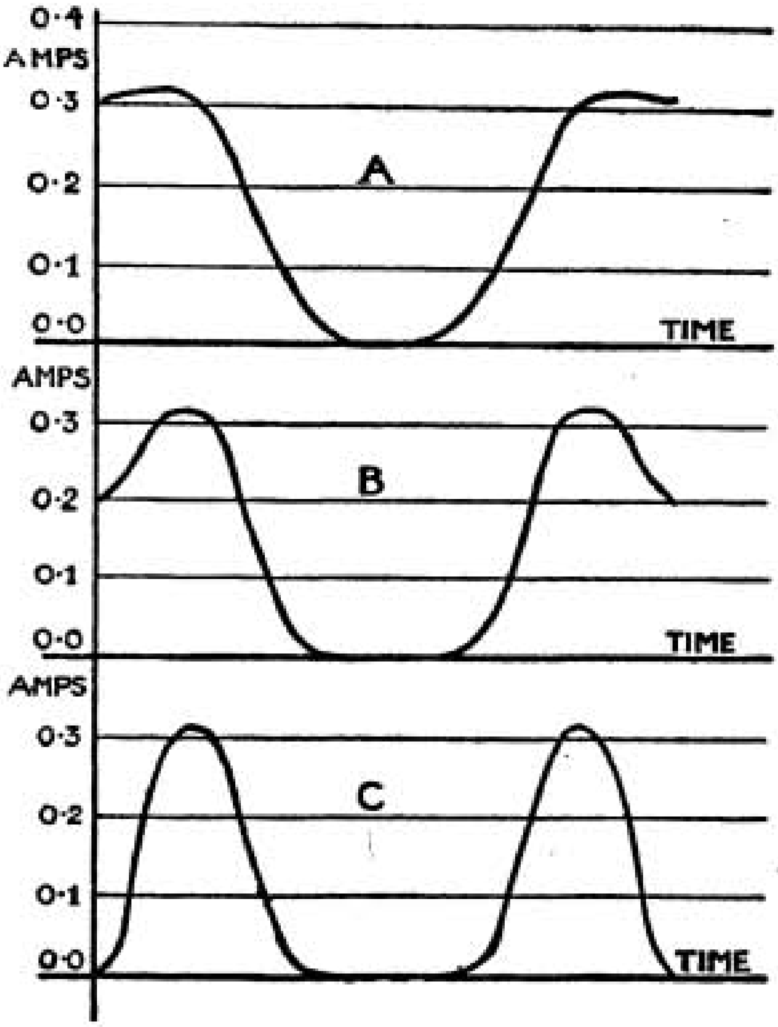

Fig. 10.

In Fig. 10 three cases have been taken. The circuit for which the curves are plotted consists of an inductance of 3,050 micro-henries and a capacity of 3,000 cm., so giving a wave length of about 6,000 metres. The connections to the valve are such that $b = 0{\cdot}26$, $a = 0{\cdot}04$, and the valve characteristics assumed are the same as those of Fig. 7. The curve A has been drawn for a

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current of 3·7 amperes, which will reduce the voltage at the positive electrode to 700 volts at the beginning of the cycle. The power supplied to the circuit will be about 116 watts and the current would be stable at this value if the resistance of the circuit was 11·8 ohms. In curve B a larger oscillatory current of 4·85 amperes is assumed, which would reduce the voltage at the positive electrode to 300 volts. A very marked kink is then appearing in the top of the wave of exciting current. The power supplied to the circuit will be about 137 watts and the current would be stable at this value if the resistance of the circuit was 5·8 ohms In curve C the oscillatory current has been taken as 5·7 amperes, which will just reduce the voltage at the postive electrode to zero. Compared with the curve B the irregularity of the wave will be much greater, and the power supplied to the circuit will be reduced both actually and relatively, with the result that this current could only be maintained if the resistance was reduced to about three ohms. These curves show quite clearly why it is that with a valve generator the current increases but little when the resistance of the circuit is reduced, unless some alteration is made to the adjustments. They also illustrate a self-protecting property of the valve. If the load is taken off there is a small increase in the current, accompanied by a reduction of the mean power taken from the supply. In curve A the mean current at the positive electrode is about 0·17 ampere, but in curve C it is only 0·12 ampere.

For the particular conditions in which the mid-point of the cycle of maximum amplitude is at the mid-point of the characteristics, the R.M.S. value of the exciting current from the valve is $\frac{I_e}{2\sqrt{2}}$, I_e being the saturation electron current; and the R.M.S. value of the voltage across the part Ob of the inductance is $\frac{V_0}{\sqrt{2}}$, V_0 being the steady voltage applied to the positive electrode.

The maximum power that can be obtained from the tube is then

$$\frac{I_e}{2\sqrt{2}} \cdot \frac{V_0}{\sqrt{2}} = \frac{1}{4} I_e V_0.$$

If I and V are the R.M.S. values of the alternating current and voltage in the oscillatory circuit, the stable maximum conditions are then approximately

$$I^2R = \frac{1}{4} I_e V_0.$$

But $I = \frac{V}{L\omega}$, and if the oscillation line just stops at the horizontal axis,

$$bV = \frac{V_0}{\sqrt{2}}.$$

Hence

$$b^2 = 2\frac{V_0}{I_e} \cdot \frac{RC}{L} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

This equation gives the suitable value for b, and the corresponding value of a for the maintenance of the oscillations follows from equation (6).

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The average current taken from the supply is $\frac{1}{2} I_e$ at the steady voltage V_0. Hence the efficiency of the valve, neglecting the power supply to the filament, is 50 per cent.

This, however, is by no means the highest possible efficiency. Any arrangement of the valve and circuit that leads to an irregular wave of current giving a considerable power to the circuit, but having at the same time a lower arithmetic mean will give a much higher efficiency than 50 per cent. If a steady negative voltage is applied to the grid so that the midpoint of the cycle is towards the bottom of the characteristics, efficiencies up to as high as 75 per cent. can be obtained. A battery may be used for this purpose, but the circuit shown in Fig. 5 is preferable. Here the small rectified current from the grid passes through the resistance R_3, and so automatically maintains the grid at a negative voltage depending upon the amplitude of the oscillations.

This theory of the action of the circuits is applicable to any form of circuit. If, for example, a mutual coupling to the grid is used, the grid voltage can still be expressed as a fraction of the voltage across the main inductance. If M is the mutual inductance, $a = \frac{M}{L}$ and the condition for the building up of the oscillations is

$$Mbk_1 > RC + Lb^2k_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

4. A Short Description of certain Valve Transmitting Sets used for W/T in the Naval Service.

Most of the valve transmitting sets in the Naval Service have been designed to work, as far as possible, from the power supply of existing spark telegraphy sets. This power supply is in the form of a high-voltage single-phase alternating current of frequency from about 100 cycles per second upwards. To use this supply it is, therefore, necessary to fit rectifiers which will convert the alternating supply into a direct current supply. The rectifiers used are two-electrode valves, differing from the three-electrode valves only in that the grid electrode is omitted. Fig. 11 shows a simple method of connecting up a two-electrode valve for this purpose. During the half cycles, when the positive electrode P is positive to the filament, negative electrons are drawn from the filament. During the other half cycles no reverse current can pass. Consequently there is a deficit of

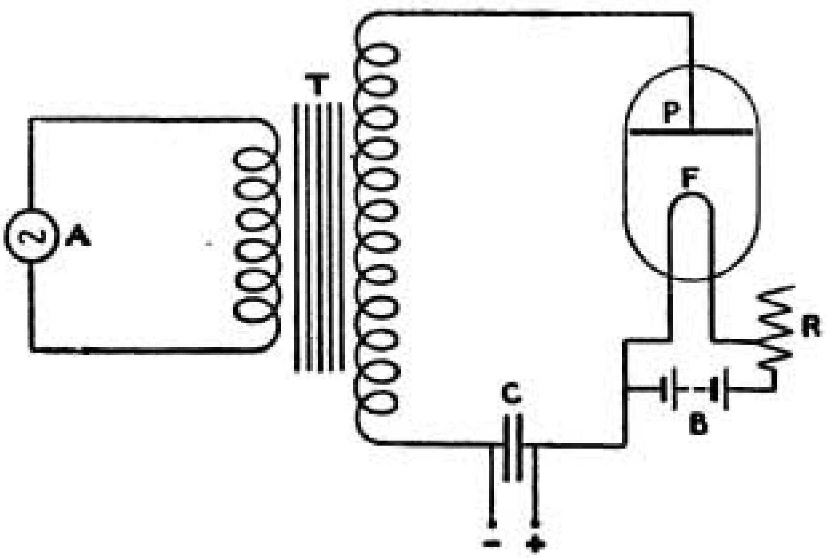

Fig. 11.

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negative electrons on the plates of the condenser connected to the filament of the valve. The terminals of the condenser C can then be used as a direct current supply. By increasing sufficiently the capacity of the condenser the uniformity of the D.C. supply can be increased to any desired extent. The numerical relationships of rectifiers of this type have been given recently by the author.*

An improvement on the simple circuit of Fig. 11, involving the use of two valves, has generally been used. Fig. 12 shows such a typical circuit arrangement. With this system one valve is operative during each half cycle, and for a given uniformity of the direct current supply, the capacity required in the condenser C is much less. The facts that the midpoints of the secondary windings of the spark set transformers were already connected to earth, and that the whole secondary voltage was usually in excess of that required for the valves, were additional reasons for the adoption of the two-valve system.

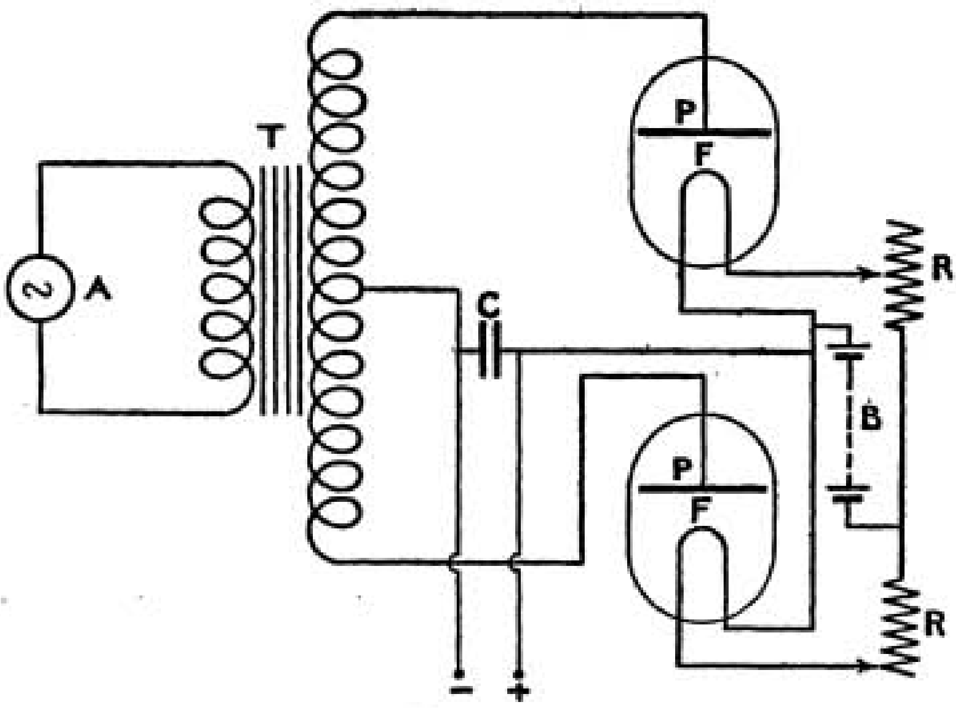

Fig. 12.

For the oscillating circuit two systems have been used: one in which the aerial has constituted the capacity in the circuit, and the other an arrangement of coupled circuits, in which the aerial circuit is separately tuned and is loosely coupled to an oscillating circuit connected to the valve.

When using the aerial as the capacity, the circuit arrangement is as shown in Fig. 5, with the addition of the necessary switch for the control of the oscillations in accordance with the Morse signals to be sent. This switch has to perform two functions, viz., to break the primary supply to the transformer, and to throw the earth connection of the aerial coil over to the receiving instruments. Magnetically operated switches have generally been used for this purpose, which are controlled by the operator in the receiving compartment by a single Morse key of the ordinary type.

Figs. 13 and 14 are photographs showing the general arrangement of one of the valve transmitting sets used in the Naval Service.

In the centre of Fig. 13 are the two rectifying valves with the controlling rheostat and instruments on the left, the whole unit being mounted on porcelain insulators. The alternating supply comes in on the extreme left;

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* Paper read before the Physical Society of London, June 27th, 1919. (See Radio Review, Abstract No. 12.)

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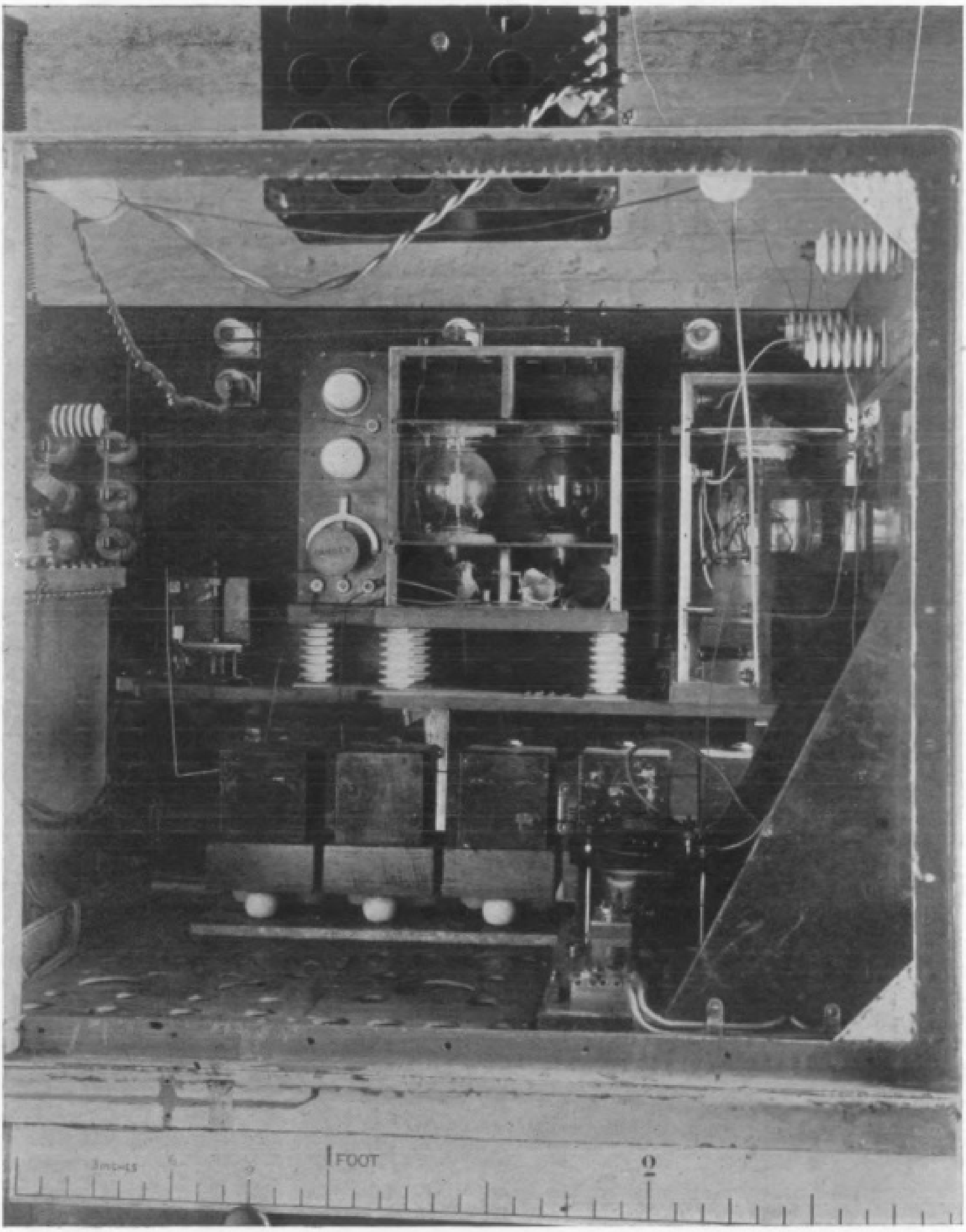

FIG. 13.

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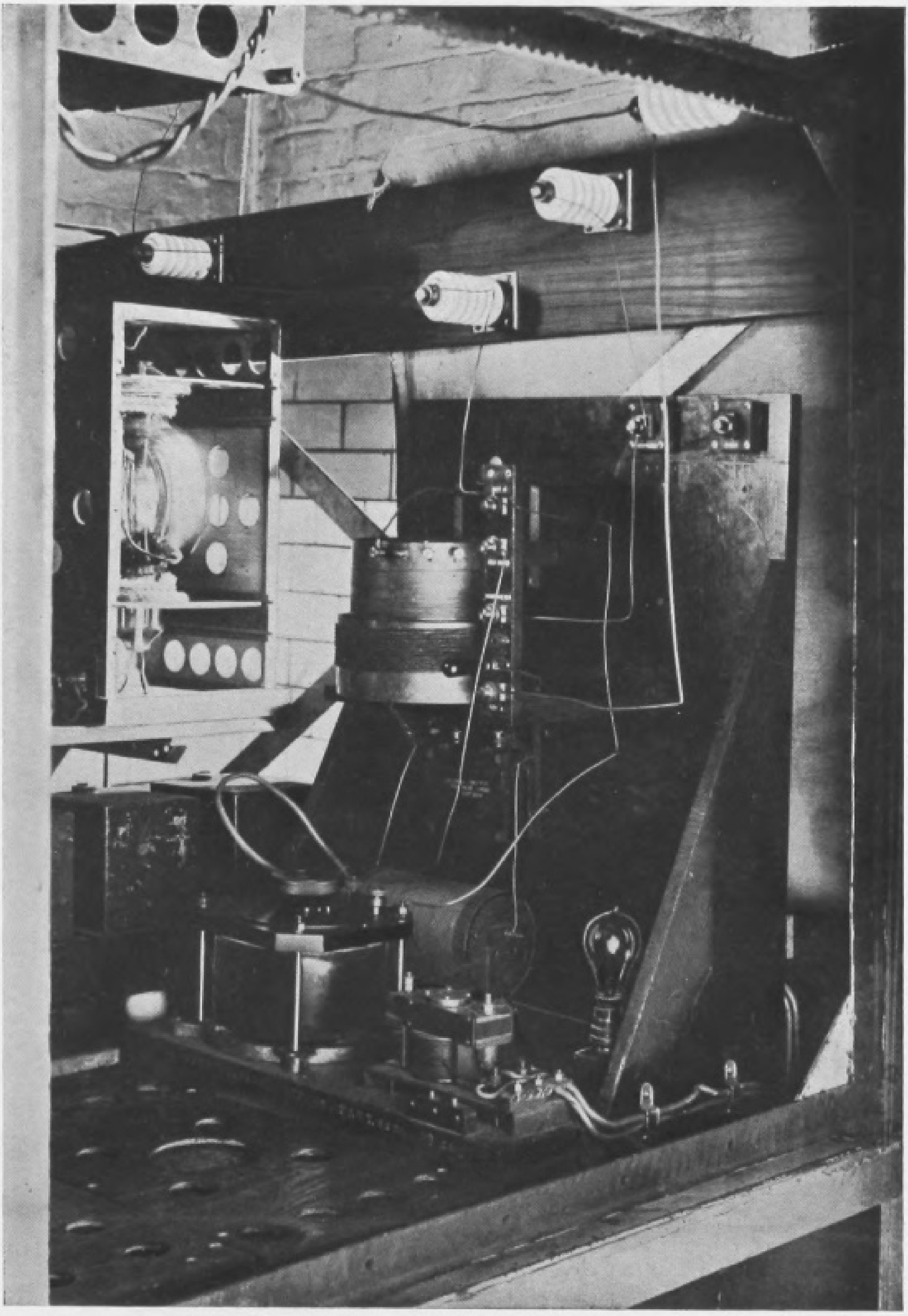

FIG. 14.

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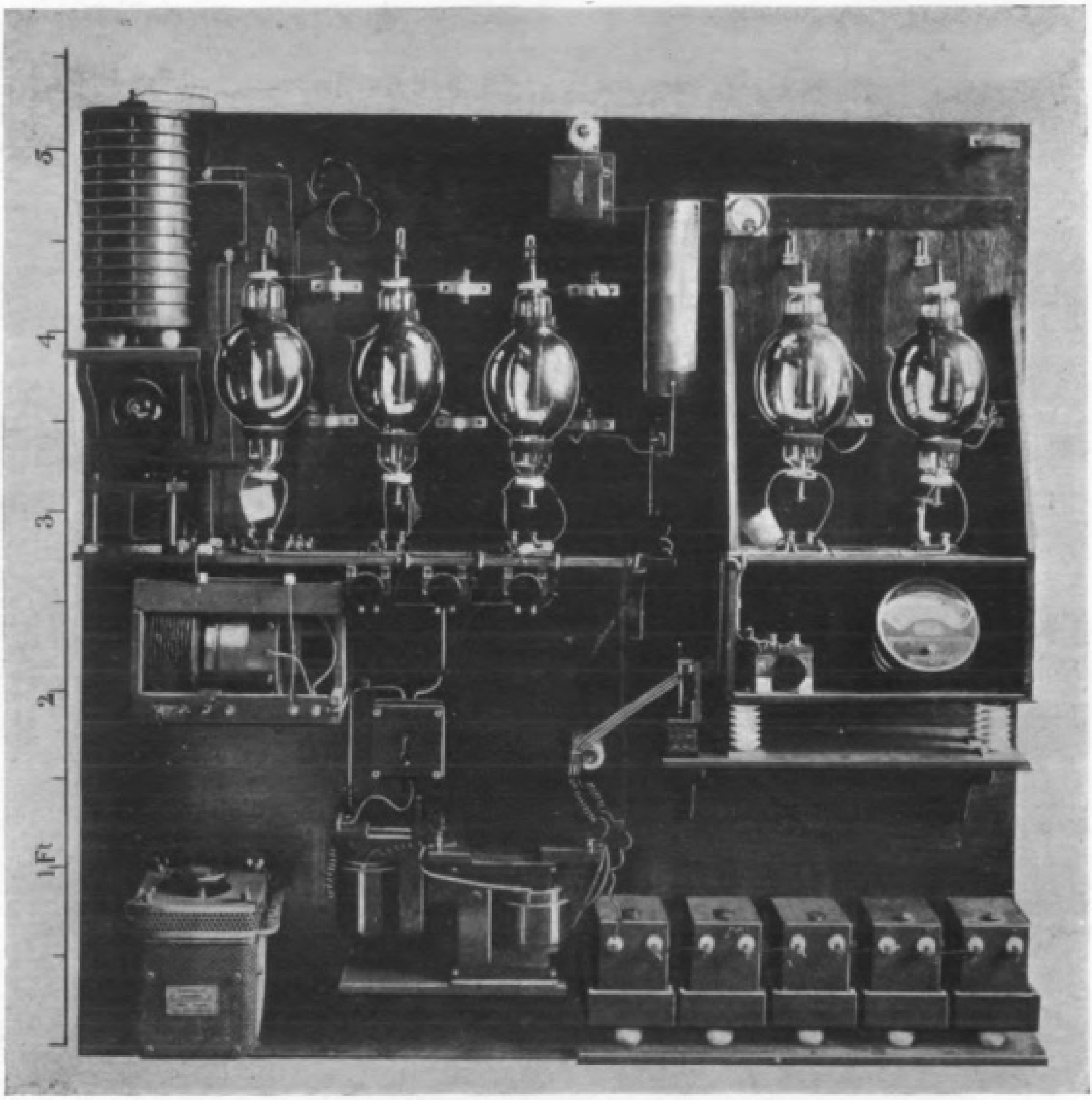

Fig. 15.

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below the rectifier unit are the four condensers used for smoothing out the current from the rectifiers. The single oscillating valve is placed to the right of the rectifiers and appears on the extreme right of Fig. 13. Fig. 14 shows the additional apparatus required to couple the valve to the existing aerial circuit, together with a further view of the oscillating valve on the left. In the centre of Fig. 14 is the grid coupling coil. One part of this is connected in series between the aerial tuning inductance and earth. The upper part is connected to the grid, and in this set a variable condenser is used in parallel with this inductance in order to tune the grid circuit. The cylindrical object at the back of this condenser is the resistance R_3 of Fig. 5. The small magnetic switch in the front of Fig. 14 is the switch changing over the aerial connections from the earth connection to the receiving instruments in the interval between the Morse signals.

Fig. 15 shows the complete set of additional apparatus required for use with a much more powerful installation.

The complete rectifier unit is on the right, with the smoothing condensers below.

Three oscillating valves are used in parallel, the three filament regulators being situated immediately beneath them.

The grid coupling coil and grid circuit tuning condenser are in the centre on the left, and the R_3 resistance is in the left-hand top corner. At the bottom, on the left, is the alternator field regulator, and between it and the smoothing condensers are two transformers supplying the filament current for the valves.

In conclusion, the author would like to add a word of thanks to the staff of the W/T Department of H.M. Signal School, Portsmouth, for the assistance given in the preparation of this paper.

A Trigger Relay Utilising Three-Electrode Thermionic Vacuum Tubes.

By W. H. ECCLES, D.Sc., and F. W. JORDAN, B.Sc.

Paper read before Section G (Engineering) of the British Association.

In a well-known method of using a triode for the amplification of wireless signals an inductive coil is placed in the filament-to-anode circuit, and another coil magnetically coupled with this is introduced into the filament-to-grid circuit. This "back-coupling," as it is sometimes conveniently called, if it is arranged in the right sense, greatly exalts the magnification produced by the tube in any alternating E.M.F. applied to the grid; for the

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induced E.M.F. passed back to the grid is in correct phase relation to add directly to the original alternating E.M.F. applied there. If, instead of using inductive retroaction of this kind, we attempt to use resistance back-coupling, then the retroactive E.M.F. applied to the grid is exactly opposite in phase to the original alternating E.M.F., and the amplifying action of the triode is reduced. Since, however, one triode can produce opposition in phase in the manner indicated, it is clear that two or any even number of similar triode-circuits arranged in cascade can produce agreement in phase. Hence we conclude that retroactive amplification can be obtained by effecting a back-coupling to the first grid from the second, fourth, and so on, anode circuit of a set of triodes arranged in an ohmically-coupled cascade.

It is possible to take advantage of the fact above stated for obtaining various types of continuously-acting relay, but the purpose of the present communication is to describe what may be called a one-stroke relay which, when operated by a small triggering electrical impulse, undergoes great changes in regard to its electrical equilibrium, and then remains in the new condition until re-set.

In what follows, the circuit comprising the space in the tube between anode and filament, the external conductors and the source of E.M.F., will be called the anode circuit, and the current flowing in it the anode current. The circuit comprising the space in the tube between the grid and the filament, external conductors and a source of E.M.F., will be called the grid circuit, and the current flowing in it the grid current.

The operation of the relay is most easily explained when two tubes, each with resistances and battery in its plate circuit, and with a resistance and battery in its grid circuit, are used and interconnected in the manner shown in Fig. 1.

The electrical stimulus from outside which it is desired to detect and magnify is applied in the grid circuit in the first tube so as to make the grid transiently more positive in potential relative to the filament. This causes an increase of current in the plate circuit of the first tube, and consequently an increase of the P.D. between the terminals of the plate circuit resistance. This increased P.D. is transferred to the grid circuit of the second tube in such a manner that the grid becomes more negative than before relative to its filament. Consequently the plate current of the second tube decreases, and the P.D. between the terminals

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of its plate circuit resistance decreases also. This decrease of P.D. is now transferred to the grid circuit of the first tube in such a manner that it tends to make the grid more positive relative to the filament. The result of these processes is that a positive stimulus from outside given to the grid of the first tube initiates a chain of changes which results finally in the plate current of the first tube attaining the highest value possible under the E.M.F. of its battery, and the plate current of the second tube falling to its lowest possible value. This condition, therefore, persists after the disappearance of the initial stimulus. In the initial condition, with the two-tube arrangement just described, the plate current of the first tube is made very small, and that of the second tube large; after the reception of the outside stimulus on the grid of the first tube the final condition is a large plate current in the first tube and a small plate current in the second tube. Either the decreases or the increases of plate current can be used for indicating. In order to restore the initial conditions it is easy to interrupt for an instant the linkage between the tubes, or to stop the operation of one or both of the tubes, as, for instance, by dimming its filament.

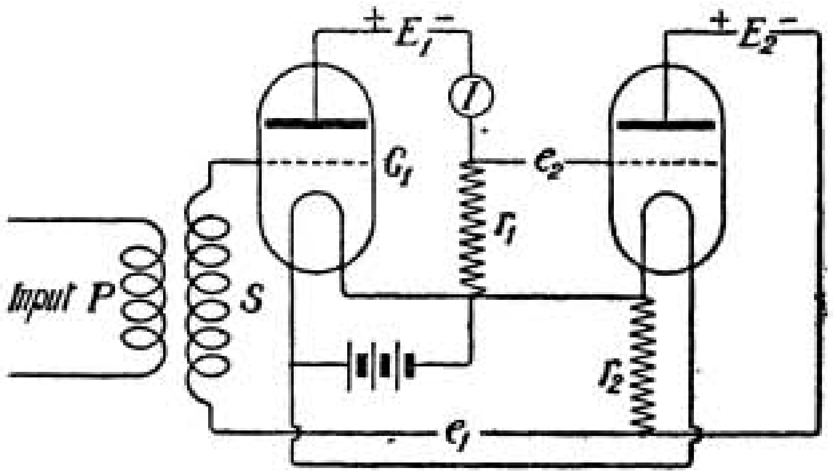

Fig. 1.

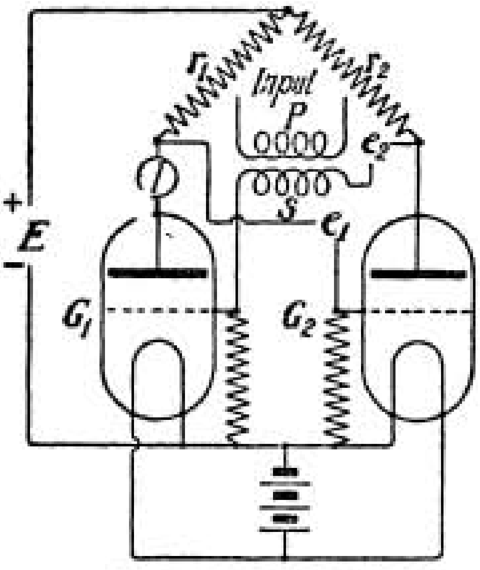

Fig. 2.

The external stimulus is led into the primary P of transformer PS, of which the secondary is connected to grid G_1. The plate circuit of this first tube contains the indicating instrument I, such as an ammeter or a moving tongue relay. The resistance r_1 in the plate circuit of the first tube has its terminals connected to the filament and grid of the second tube. Similarly, the resistance r_2 in the plate circuit of the second tube has its terminals connected

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to the filament and the grid of the first tube. The plate circuits contain batteries E_1, E_2, and the grid circuits batteries e_1, e_2. The following values are typical, and show the performance of the relay :—

E_1=78 volts. E_2=74 volts.
r_1=22,000 ohms. r_2=12,000 ohms.
e_1=31 volts. e_2=17·5 volts.

The change in the indication of an ammeter at I is from 0 — 2·5 micro-amperes.

The sensitiveness of the arrangement depends on the transformer *PS* to some extent. Using a telephone transformer of the kind made for Army C Mk. III. Amplifier with 20 ohms resistance in the primary, and with the primary connected to a Brown telephone of 60 ohms resistance, the relay is operated with certainty by snapping the thumb and finger at a distance of five feet from the telephone.

Fig. 2 shows another mode of inter-connection of two tubes. The stimulus from outside is introduced to the grid of the first tube through a transformer, as before, and the indicating instrument is again placed in the plate circuit of the first tube. The two plate circuits are in parallel with a common battery E, and the connections are such that the changes of P.D. between the anode and the filament of the first tube are imposed between the filament and grid of the second tube, and the changes of P.D. between the anode and filament of the second tube are imposed between the filament and grid of the first. In order to help to maintain the grids' advantageous potentials, grid leak resistances are connected as indicated.

The following numerical values are typical dimensions :—

E=80 volts
$r_1=r_2$=100,000 ohms.
$e_1=e_2$=40 volts.

The sensitiveness of this relay could be made greater than that of Fig. 1, when these large resistances are used.

The devices just described were the subject of a patent, numbered 10290/1918, taken out by the Admiralty, and the description is now published by permission.

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Review of Radio Literature

1. Abstracts of Articles.

72. A COMPARISON OF COILS AND AERIALS FOR RECEPTION. M. Abraham. (*Jahrbuch der Drahtlosen Telegraphie*, 14, pp. 259—269, August, 1919.)

The author investigates (1) the amount of energy which the coil or aerial can abstract from the electromagnetic wave, and (2) their relative susceptibility to atmospheric disturbance.

(1) It is known that the maximum amount of energy which an aerial can abstract from an undamped wave is independent of the constants of the aerial, *i.e.* it is the same for any aerial. To obtain this maximum it is necessary to adjust the ohmic resistance (aerial, detector, earth) to equality with the radiation resistance. The author shows that a coil or frame acts just like any other form of aerial and can abstract just as much energy if the ohmic resistance is correctly adjusted to the radiation resistance.

The radiation resistance R_r of a vertical coil is $\frac{4\omega^4 A^2}{3c^3}$, where $\omega = 2\pi f$, A = area × turns, and $c = 3 \times 10^{10}$, whereas the radiation resistance R_r' of an aerial is $\frac{4\omega^2 h^2}{3c}$, where h is the height. These values allow for the effect of the earth. Hence

$$\frac{R_r}{R_r'} = \frac{\omega^2 A^2}{c^2 h^2}.$$

This is usually a very small fraction; hence the total ohmic resistance should be made much smaller with the coil than with the aerial, and, of course, the resistance of the circuit apart from the detector should be made as small as possible. The author states that there is little prospect of the coil being made equivalent to the aerial in this respect.

(2) If an atmospheric disturbance produces a damped aperiodic electromagnetic field which can be represented at the receiving station by the formula

$$E = cH = a\varepsilon^{-rt}.$$

the equation for the coil is

$$\frac{d^2 i}{dt^2} + 2\rho \frac{di}{dt} + \omega^2 i = \frac{A}{L} \cdot \frac{ar^2}{c} . \varepsilon^{-rt},$$

and that for the aerial

$$\frac{d^2 i'}{dt^2} = 2\rho' \frac{di'}{dt} + \omega^2 i' = -\frac{h}{L'} . ar . \varepsilon^{-rt}.$$

The solution for the coil is

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$$i = B\left\{\varepsilon^{-rt} - \varepsilon^{-\rho t}\left(\cos mt + \frac{\rho - r}{m}\sin mt\right)\right\}$$

where

$$m = \sqrt{\omega^2 + \rho^2} \text{ and } B = \frac{aA}{cL}\cdot\frac{r^2}{m^2 + (r-\rho)^2}.$$

If the disturbance is much more damped than the receiver, $(r >> \rho)$, the first term may be neglected. If, moreover, $\rho << \omega$, $m = \omega$, and

$$B = \frac{aA}{cL}\cdot\frac{r^2}{\omega^2 + r^2}.$$

and the energy supplied to the detector of resistance R_d is

$$Q = R_d\int_0^\infty i^2 dt = \frac{R_d}{4\rho}\cdot\frac{a^2A^2}{c^2L^2}\cdot\frac{r^4}{\omega^2(\omega^2 + r^2)}$$

Similarly, for the aerial,

$$Q' = \frac{R_d'}{4\rho'}\cdot\frac{a^2h^2}{L'^2}\cdot\frac{r^2}{\omega^2(\omega^2 + r^2)}.$$

The author adopts as a measure of the freedom from disturbance, the ratio q of the energy supplied to the detector in a given time T, by an undamped wave to which it is tuned, to that supplied by an aperiodic disturbance.

For the coil

$$q = \frac{T}{2\rho}\cdot\frac{\omega^4(\omega^2 + r^2)}{r^4}$$

and for the aerial

$$q' = \frac{T}{2\rho'}\cdot\frac{\omega^2(\omega^2 + r^2)}{r^2}.$$

These formulæ assume that the initial amplitude of the disturbing field is equal to the amplitude of the undamped field.

$$\frac{q}{q'} = \frac{\rho'}{\rho}\cdot\frac{\omega^2}{r^2}.$$

Hence the freedom from disturbance in either case is inversely proportional to the damping constant $(\rho = R/2L)$ of the coil or aerial. Usually $\rho < \rho'$ and the aerial should therefore be superior to the coil in this respect. The coil is superior to the aerial if r is small compared with ω, that is if the aperiodic disturbance dies away slowly. This is generally the case.

[No reference is made to the directive action of the coil in excluding disturbances originating in directions normal to its plane.]

73. CALCULATION OF SELF-INDUCTANCE OF RECTANGULAR COILS.

A. Esau. (*Jahrbuch der Drahtlosen Telegraphie*, 14, pp. 271—281, August, 1919.)

The present paper deals only with box-type coils, plane coils are reserved for a subsequent paper. Neumann's formula is used to calculate the mutual inductance between two parallel rectangles; the logarithmic terms are

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expanded and all terms beyond the squares neglected. The formula is then integrated over the whole n turns. This is an application of Strasser's method to rectangular coils.

The formula obtained for rectangular coils is very cumbersome and involves constants which must be obtained from Strasser's paper or from Rosa and Grover's paper in the *Bulletin of the Bureau of Standards.*

For square coils the formula is simplified and written $L = 8\,a\,n\,(S_1 + S_2)$, where a is the side of the square, n the number of turns, S_1 a function of a/ρ only, where ρ is the radius of the wire, and S_2 a function of a/g and of n, where g is the pitch of the turns. Tables and curves are given of these functions.

For maximum inductance with a given length of wire, the length l of the coil should be between 0·4a and 0·45a.

For a given length of wire, the square coil has a greater inductance than a rectangle with unequal sides, but a round coil has 1·17 times the inductance of the square. Confirmatory experimental results are given.*

74. On the Multi-Section Quenched Gap. M. Schuleikin and I. Freiman. (*Proceedings Institute Radio Engineers*, 7, pp. 417—425, August, 1919.)

The authors consider mathematically the relation between the breakdown voltage of a series of quenched gap section of the flat plate or "Telefunken" type, and that of a single section. Because of electric flux leakage from each plate to near-by plates and neighbouring conductors, the relation of direct proportionality does not hold. The breakdown voltage of a number of gaps of given length cannot be made to exceed a limiting value. Fig. 1 shows the results obtained plotted against the number of gaps in series for various "leakage" factors k. The factor $k = c/C$, where $C =$ the capacity between adjacent gap plates, and $c =$ the capacity of a plate to earth and to other neighbouring conductors, other than the next plate. The curve applies when one end of the series of gaps is earthed. If the mid-point of the transformer supplying the gaps is earthed, the maximum limiting voltages are double those given by the curves.

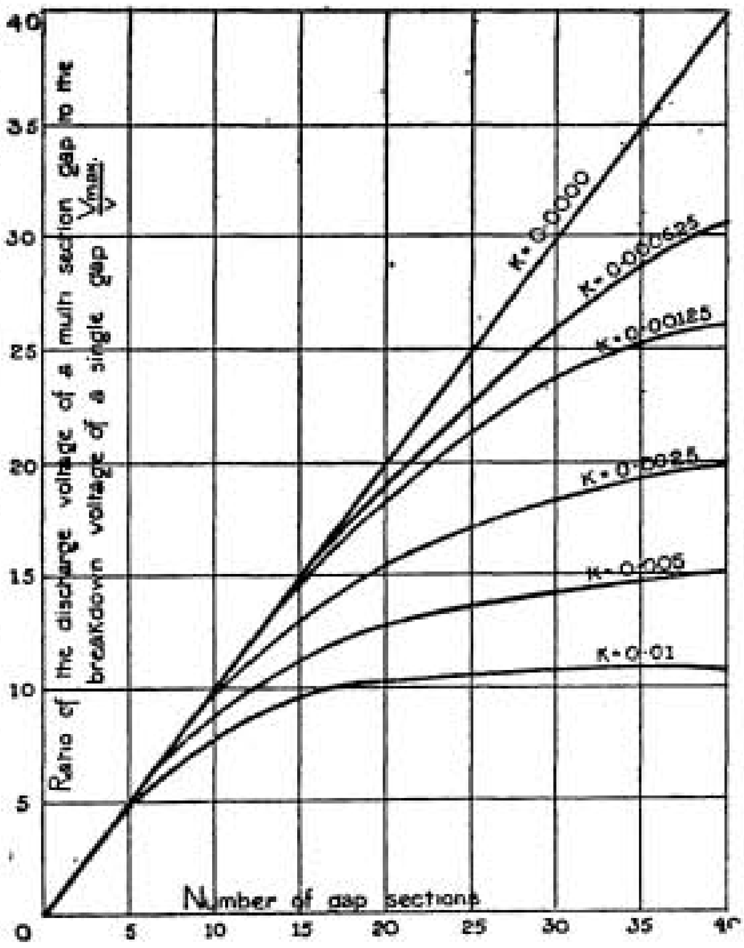

FIG. 1.

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* See RADIO REVIEW, 1, pp. 124–126, where this paper is commented upon in the Editorial Article.

75. Simultaneous Sending and Receiving. E. F. W. Alexanderson. (*Proceedings Institute Radio Engineers*, 7, pp. 363—390, August, 1919.)

Solutions for two distinct but similar problems are discussed in this paper, (1) the "Bridge" receiver, to provide a means for neutralising the overwhelming intensity of the transmitted signal so as to make the receiving set sensitive to the distant signal; and (2) the "Barrage" receiver, to enable reception of a distant faint signal to be made, through heavy interference, not from the adjacent transmitter of the same station, but from other stations which are intentionally or accidentally jamming the receiver.

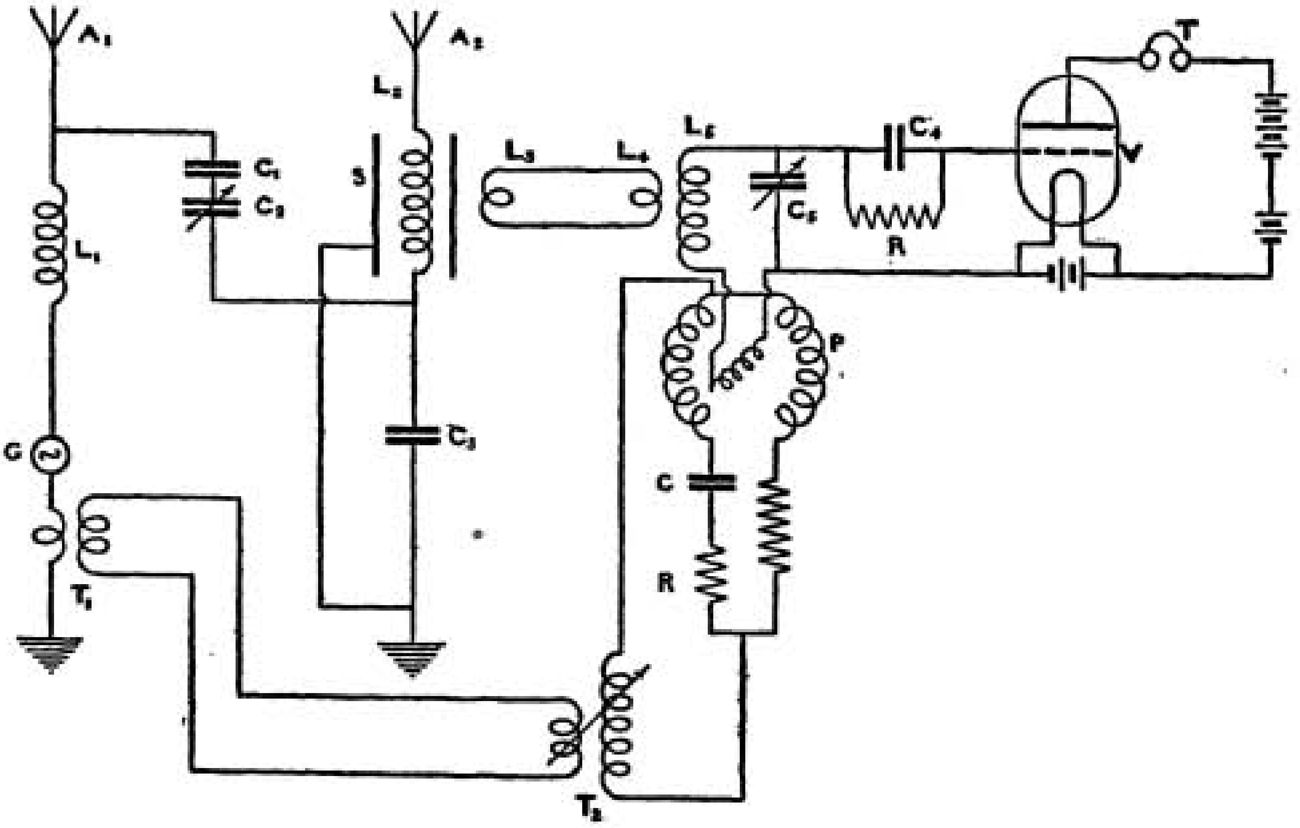

Fig. 2.

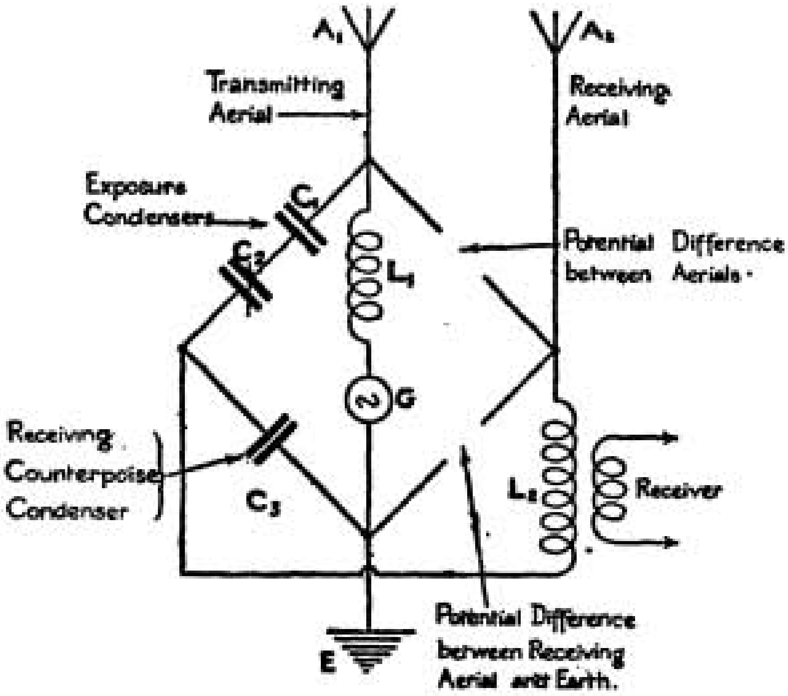

Fig. 3.

As an introduction to the Bridge receiver various other arrangements are considered for Duplex radiotelephony, *i.e.*, for radiotelephony in both directions without the necessity of repeatedly changing over the instruments from speaking to receiving during a conversation. In the first arrangement described, separate transmitting and receiving stations are employed,

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working on different wave lengths. The land line instrument is connected directly to the control amplifiers of the sending station; while the leads from the receiving station amplifiers are coupled (inductively) in series with this connection. Speech coming over the land line thus controls the transmitter; while incoming speech from the receiving station also operates the same control as well as the subscriber's land line telephone. Both halves of the conversation are thus repeated by both transmitters.

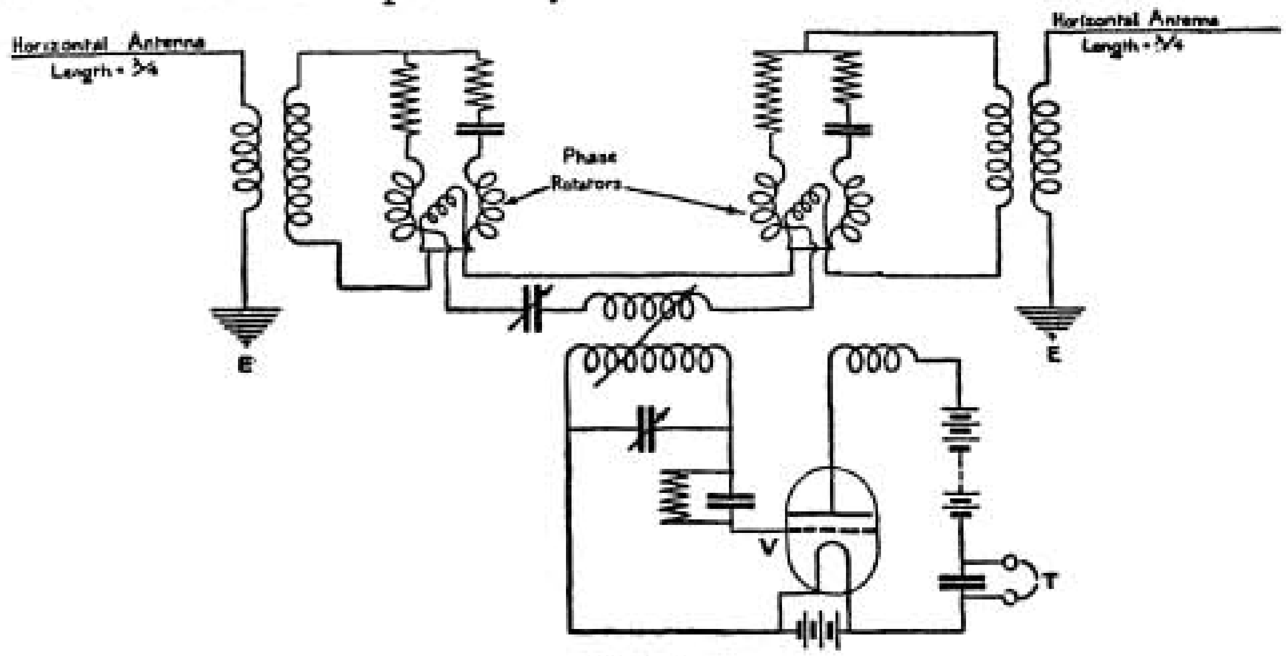

FIG. 4.

An analogous arrangement of two aerials at one station, with a system of inductive neutralisation of the interference between them, can also be used.

In the Bridge receiver proper an arrangement of capacitive neutralisation is adopted to eliminate the influence of the local transmitter upon the receiving instruments (Fig. 2). A_1 is the transmitting aerial; A_2 the receiving aerial, and G the source of oscillations. The coupling between the two aerials is effected through the "exposure" condensers $C_1 C_2$. The inductance in the receiving aerial circuit is screened electrostatically by the earthed sheath S, and is coupled through the untuned intermediate circuit $L_3 L_4$ to an ordinary type of receiver $L_5 C_5 V$. The coupling coil L_3 is external to the earthed screen S. The "phase rotator" P, coupled to the transmitting aerial is used to

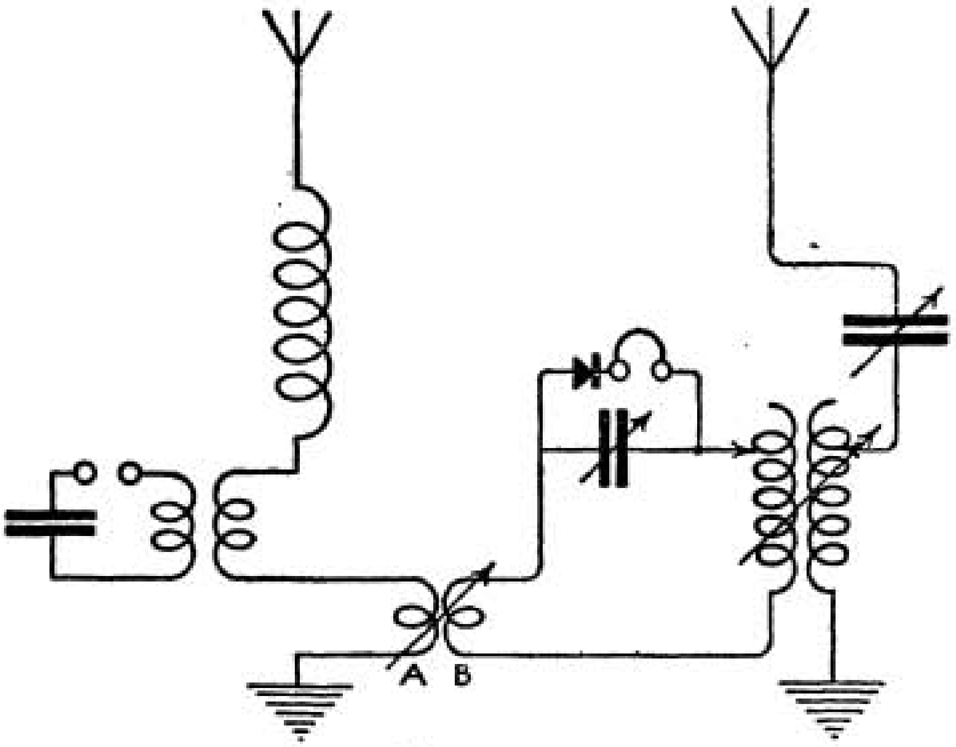

FIG. 5.

balance out the direct interference occurring inside the station. Fig. 3 indicates the " bridge " nature of this arrangement.

The Barrage receiver is fundamentally a uni-directional receiver. Leading features of the design :—

(1) The antennæ should be aperiodic ;
(2) the balancing should be effected between the E.M.F.'s in the aperiodic aerials, *i.e.*, the phase shifting device should be aperiodic ;
(3) The two or more antennæ should be of the same character.

The barrage receiver takes advantage of the geographic phase displacement in the wave as it travels over the surface of the earth. One arrangement is indicated in Fig. 4.

	Bridge Receiver.	Detector Balance Method.
Local transmitter antenna current	7·0 amps.	18·5 amps.
Local transmitter transformer input . . .	0·8 kw.	5 kw.
Distant transmitter antenna current	10 amps.	4 amps.
Primary receiver current at balance	150 milliamps.	0·78 amps.
Primary receiver potential .	Approx. 10,000 volts	Approx. 1,000 volts.
Residual noise in phones .	Great	Small.
Quality of received signal .	Barely readable through interference.	Very good.

In the discussion on the paper W. H. PRIESS summarised the researches on similar lines carried out by the U.S. Navy Department during the war. Of these the most successful is the Detector Balance arrangement indicated in Fig. 5. The above table gives typical test results comparing this Detector Balance with the Bridge receiver.

The arrangement of Fig. 6 was stated to be a good means of balancing out atmospherics since the ratio of signal to static is different in the pure loop circuit to what it is in the circuit using the loop as an ordinary elevated aerial structure. Circuit B couples the loop circuit to the detector circuit F, and circuit C couples the aerial circuit D to the same etector circuit F.

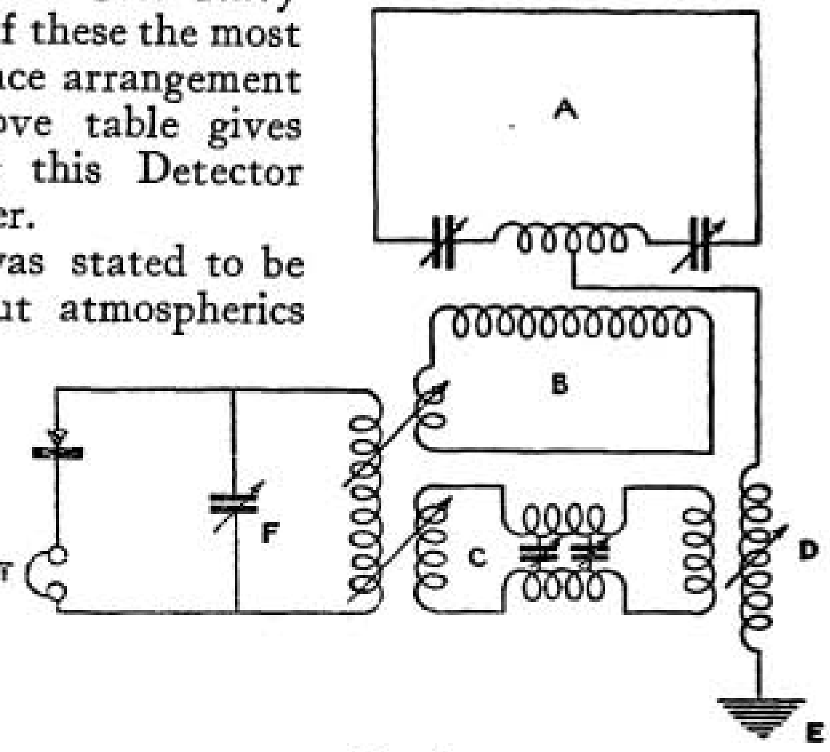

FIG. 6.

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76. A RADIOTELEPHONE TRANSMITTER. L. de Forest. (*French Patent* 492193. July 1st, 1919.)

The arrangement proposed is indicated in Fig. 7. The oscillating circuit C_1L_1 is joined between plate and grid of the valve. The transmitting microphone *M* is joined in series with a resistance R_3 of 25 to 100 ohms between the grid and filament. C_2 is merely a stopping condenser to keep the H.T. from B_2 away from the grid.

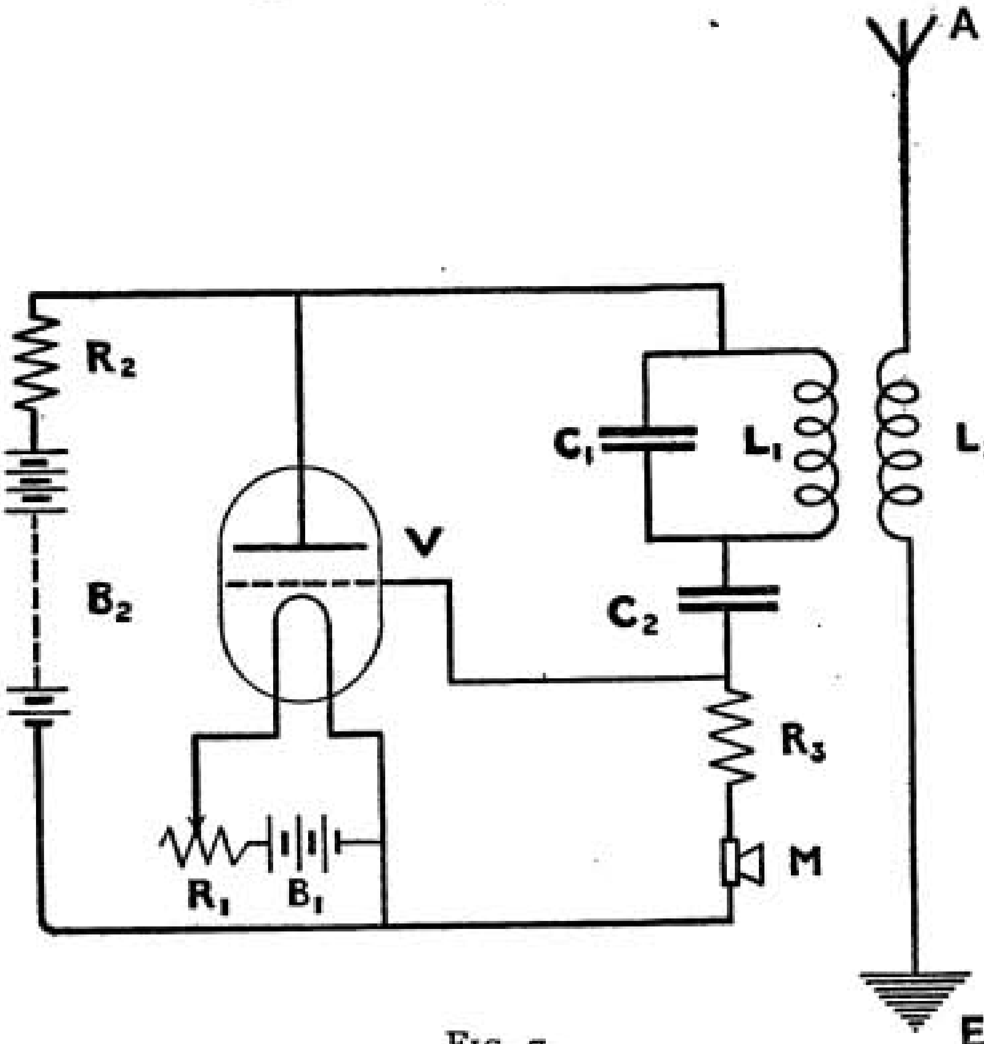

FIG. 7.

77. THE INTERNAL ACTION OF AMPLIFYING VALVES. M. v. Laue. (*Annalen der Physik*, 59, pp. 465—492, August, 1919. *Jahrbuch der Drahtlosen Telegraphie*, 14, pp. 243—259, Abstract.)

A mathematical investigation of the equipotential surfaces within three-electrode valves. Three types of valves are considered, (1) in which the anode and the control electrode are plane, the latter close to the filament but on the side remote from the anode; (2) in which the control electrode is a single wire parallel to the filament; (3) in which the anode is cylindrical and the control electrode consists of a number of wires parallel to and arranged uniformly around the filament. The problem is reduced to a two-dimensional one by assuming the filament, anode and grid to be infinitely long and the problem is further idealised by assuming:

1. that there is no space charge; and
2. that there is no potential drop along the filament.

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8. VACUUM TUBES IN THE ARMY. (*Wireless Age*, 6, p. 41, September, 1919.)

Details of various types of valves used by the U.S. Signal Corps during the war.

79. VACUUM TUBES. H. P. Donle. (*British Patent* 130965, August 8th, 1918. Not yet accepted, but open to inspection.)

Covers the arrangement described in RADIO REVIEW Abstract No. 17.

80. MEANS FOR DETERMINING THE DIRECTION OF A DISTANT SOURCE OF ELECTROMAGNETIC RADIATION. F. Adcock. (*British Patent* 130490, August, 1918. Patent accepted, August 7th, 1919.)

In D.F. stations the aerials are arranged with a vertical component to receive the radiation, and the horizontal connections arranged so that the effect of the radiation upon them is reduced to a minimum. Proposed connection arrangements for four vertical receiving aerials are shown in Fig. 8. In each case the earth lead for any aerial is taken across to the earth connection of the diametrically opposite aerial. L_{12} and L_{24} are the radiogoniometer coils.

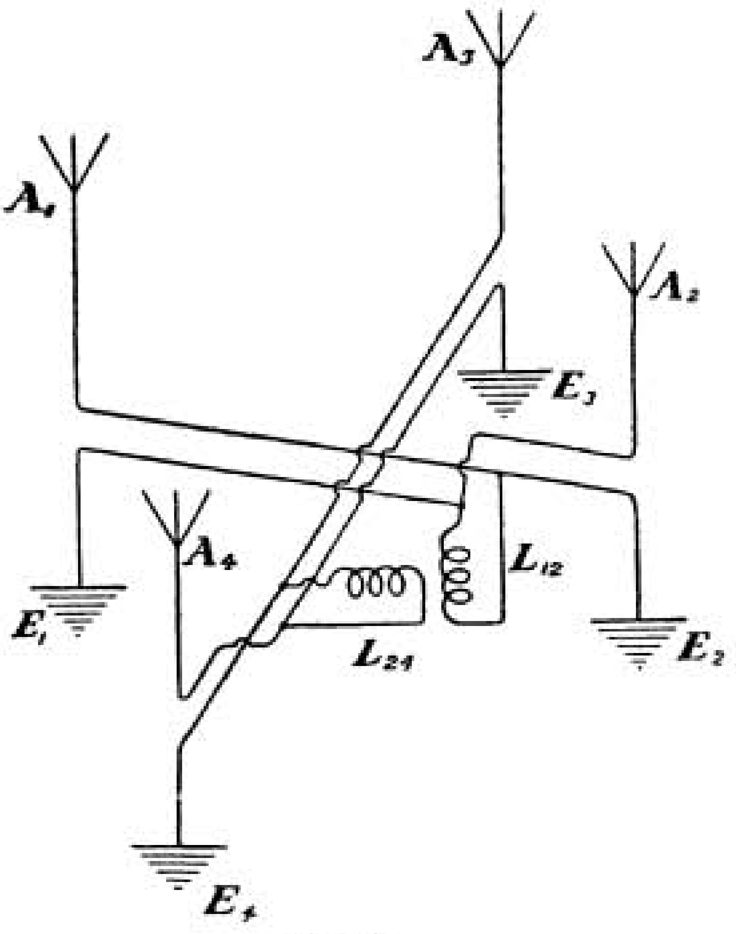

FIG. 8.

81. ÆTHER AND THE ABSOLUTE MECHANICS OF WAVE MOTION. G. Sagnac. (*Comptes Rendus*, 169, pp. 469—471, 529—531, September, 1919.)

82. THERMOPHONES OR HOT-WIRE RECEIVERS. (*Electrician*, 83, p. 242, September, 1919.)

Some further particulars are given *re* heater wires for thermophones. In support of the need for the use of very thin wires it is stated that $\frac{\text{watts expended in wire}}{\text{surface area of wire}} \propto d^3$ where d is the diameter of the wire; and that

$\frac{\text{surface area}}{\text{cross section}} \propto \frac{1}{d}$. Curves of these relations are also given. The weight of these receivers is given as 0·25 to 0·5 oz.; and their resistance may be given any figure between 20 and 3,000 ohms according to the use for which the instrument is required.

83. ELECTRIC RELAYS. By M. Latour. (*British Patent* 127318, April, 1916.)

The amplification of high-frequency currents by vacuum valves is dealt with in this patent, and, in particular, the design of the iron-cored inter-valve transformers to secure the maximum amplification. A novel feature is the arrangements made for securing any desired static potential on the iron cores, metallic casing, and other parts of these transformers by making suitable connections between these parts and various points of the common anode battery.

84. IMPROVEMENTS RELATING TO AUDIONS, LAMP RELAYS, OR AMPLIFYING APPARATUS. M. Latour. (*British Patent* 129659, September, 1916. Patent accepted July 24th, 1919.)

An addition to Patent No. 127318. The static potential of the telephone headpiece is determined in addition to that of the core of the inter-valve transformers, by connecting one terminal of the telephone transformer to the telephone headpiece frame and to one of the terminals of the anode circuit battery.

85. DEVELOPMENT OF LOOP AERIAL FOR SUBMARINE RADIO COMMUNICATION. J. A. Willoughby and P. D. Lowell. (*Physical Review*, 14, pp. 193—194, August, 1919, Abstract of Paper read before the American Physical Society.)

In the close of 1917, in the course of experiments made with the object of developing apparatus for the detection of submarines, it was found that radio signals could be received by means of a loop, either in air or submerged in fresh water. The loop aerial arrangement, as finally perfected, consisted of two insulated wires earthed at the extreme ends of the hull of a submarine, carried over suitable supports to the bridge, and thence to the receiving and transmitting apparatus. Communication at sea can be carried on under all conditions more efficiently with such a loop than with ordinary elevated aerials. Also it does not interfere with submergence. With the submarine submerged any North American or European station could be received as distinctly as on the surface. To receive short waves it is necessary that the top of the loop should be near the surface of the water, whereas a wave of 10,000 metres length can be received with the top of the loop submerged 21 feet. Signals could be transmitted from the loop a distance of 10 or 12 miles with the submarine completely submerged. The range falls to two or three miles with the top of the loop 8 feet to 9 feet below the surface,

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using 952 metres wavelength. Submergence of the submarine during reception or transmission does not alter the wavelength. With the submarine on the surface a transmission range of at least 100 miles can be obtained with a 1-kw. spark set even under very stormy conditions. The loop can also be used as a direction finder.

86. IMPROVEMENTS IN ELECTRICAL RESISTANCES. S. R. Mullard. (*British Patent* 131057, April, 1918. Patent accepted, August 21st, 1919.)

A high resistance for use with valves consists of a thread of partially carbonised cellulose or the like embedded in insulating material such as paraffin wax, and enclosed in a fibre or ebonite tube.

87. THE EVOLUTION AND ABSORPTION OF GASES BY GLASS. D. Ullrey. (*Physical Review*, 14, p. 160, August, 1919, Abstract of Paper read before the American Physical Society.)

The absorption of various gases by glass and their subsequent evolution with vacuum heat treatment have been studied particularly with respect to the production and maintenance of high vacuum.

Conclusions: (1) The rates of evolution of the gases are in general different functions of the time at any temperature, and for a given baking period, are different functions of the temperature.

(2) There is a large variation in the quantity of gases evolved per $cm.^2$ from different samples of the same glass.

(3) Annealing in air at atmospheric pressure always lessens the quantity of gases evolved on subsequent vacuum heat treatment, although several months may elapse between the two processes.

(4) At a given temperature and pressure, glass is in equilibrium with a definite amount of water. Water vapour is evolved at high temperatures and re-absorbed when the temperature is lowered.

(5) Glass from which practically all absorbed gases have been removed by melting in vacuo subsequently re-absorbs gases from the atmosphere at room temperature.

(6) At temperatures up to the softening point, diffusion of gases of the atmosphere through glass does not take place.

2. Review of Books.

THE THERMIONIC VALVE AND ITS DEVELOPMENTS IN RADIOTELEGRAPHY AND TELEPHONY. By J. A. Fleming, M.A., D.Sc., F.R.S. (London: *The Wireless Press, Ltd.* Pp. xv. + 280, Price, 15*s*. net.)

Any person concerned with matters technical who permits his fancy to wander over the arts which are his study and his occupation, finds himself at

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one time or another wondering what are the names of those to whom he is indebted for their first beginnings, and wanting to know something at least of how it all came about. These are idle thoughts, perhaps, for there is a quality about the work of the pioneer which never repeats itself as the subject becomes more widely exploited. Still, the processes of the application of scientific knowledge are not so obscure but that those who are in a position to break out into new fields of application in one art may expect to find practical utility in the study of the history of another. With original discovery, an obviously more delicate matter than application but not here in question, the deliberate study of method may, one must admit, end in defeating its own object.

The readers of this journal have to do with arts whose growth under the special stimulus of the last few years has been extensive and vigorous, and are therefore sure to feel in especial measure this interest in men and their methods, alike those entering upon their subject at some middle stage of its recent development, and those who find the full growth suddenly presented to their view.

Of the many who will take up Professor Fleming's book it will be those who are led by such stimulated historical curiosity who will be most likely to hold on to the end through all the distractions consequent on the utter thoroughness with which the author carries out his stated intention of vindicating his own personal case. They will also, after all is read, appreciate the full implications of the frank assignment to De Forest of the credit for introducing the third or grid electrode (p. 102).

This historical interest definitely predominates throughout the earlier chapters, and there are pages, for example p. 50 dealing with the bringing forth of the Fleming thermionic tube from its dusty cupboard, in which this interest will rise for some to a higher level, giving a sense of a really historic occasion.

But in this part of the book the technical exposition is continually interrupted or overlaid by the insertion of legal and similar extracts, to accommodate which an appendix is provided in addition. These extracts, however, embody numerous references, and may thus serve as an introduction to the " patent " aspect of the subject, and as some guide to such as expect to become involved therein, and even, it may be, to the Patent Office examiners to whom the author is so unkind on his opening page, always provided that their sense of duty leads them to read further. For some of these gentlemen, in this country at any rate, have been known to make a better success than Professor Fleming in combining a legal and technical exposition of this complex subject. They too will know better than the lay reader how to profit from the work of an author who is continually seen to be acting as expert witness in his own behalf.

In these first three historical chapters again, the technical reader must be content to repeat in his own person the errors and difficulties hitherto encountered by all who have entered unassisted on the study of valves. The latter will recognise certain familiar pitfalls, for instance, the overestimation of the importance of gas ionization, and the corresponding failure to appreciate the fundamental necessity of understanding what happens

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when the natural field between the electrodes is distorted by the appearance of free charges in space. Again on the electrodynamical side, it is of the first importance to see clearly how the energy set free in the anode circuit of a detector arrangement is actually made available, and such statements as that on p. 178, repeated from pp. 63 and 138, that "at each spark discharge at the transmitter a rectified train of oscillations, or a simple unidirectional *pulsating* flow of electricity passes *through the telephone*" are worrying in proportion to the thoughtfulness of the reader (the italics are the reviewer's). It is not until p. 181 in connection with Armstrong's work that any inkling is given of the functions of the shunting capacity, actual or virtual, in carrying the high-frequency pulsating component of the rectified train past the enormous impedance of the telephones. It is a pity that such recognised pitfalls, particularly in matters where to follow Professor Fleming's lead is but natural, should have been left so weakly guarded.

The division of aim from which the book suffers is far less pronounced in the later chapters, though by an unfortunate chance it is exemplified only too clearly in the closing paragraphs of the text. But from the technical aspect these later chapters improve progressively, and one is inclined to recommend those who seek up-to-date technical information clearly set out to begin by reading the last chapter of all. With the assistance of the excellent table of contents and the full index provided, they will readily pick up the earlier references to matters which this unconventional procedure may render obscure.

As regards the period of the war, here covered by a single additional chapter, the time for writing history has not yet come, and it is therefore not unexpected that few of the author's countrymen are specifically mentioned besides those responsible for the development of apparatus under the Marconi Company. For the same reason, perhaps, there is no mention of French work on valves and their circuits; nor among so many excellent photographic illustrations is there one of that instrument, the "French" valve, known later as the "R," which was used in hundreds of thousands by our troops, and which will in consequence be the one object called to the mind of the great majority of readers by the title of this book. To these the omission will appear inexcusable.

Official prohibition of the representation of so familiar an article is inconceivable, and indeed a sufficient description of it had in fact been approved for inclusion in Captain Turner's paper read to the Institution of Electrical Engineers in June of this year, a date prior to the latest appearing in this book, which is that of an American legal decision of July 7th, 1919.

It is a curious fact, and one that carries an unspoken commendation of De Forest's development work, that the characteristics of the "good" valve given on p. 167, which are those of the French valve alike with other valves of very different construction and appearance standardised and used in large numbers in this and other countries, are actually those usually found in the most reliable, though not the most sensitive of the audions. In the experimental development of the audion there must have been present either great skill or great luck. It was an instrument of notable possibilities,

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and its performances have provided a profitable occupation for many in unravelling the numerous problems they present. It seems in face of this that although the method of science may be more evident in Fleming, the spirit of discovery was more with De Forest.

On the question of nomenclature much might be said with little profit. The collected list of names for the "valve" given in the preface leaves one in truth breathless. To these the author proposes to add one more. As regards generality of application "thermion" is a slight improvement on "audion." It is euphonious, but, as is admitted, the fact that it is a coined word which has been used before in another sense is against it. However, in matters of taste the appeal to examples of proved merit is valid; the principles of such word-making have been imperishably enunciated by Faraday ("Experimental Researches," 397—403), on introducing what are now without exception established names in electro-chemistry and molecular physics. The study of "electrolytes" was well advanced when Faraday devised this and the allied words, but so well did he avoid names which might "at any time . . . lead to confusion or tend to support false views," that the "electrode," the "ion," and so forth are still without rivals.

Both the printing and illustration of the book are well carried out. Minor misprints have been observed on pp. 38, 105, 141. Something has gone badly wrong with the numbering of the paragraphs in Chapter I., where "7" occurs twice, on pp. 26 and 33, and "8" likewise on pp. 30 and 36.

In spite, however, of evidence of condensation, and of the large amount of information compressed into a comparatively small volume, the presentation of the subject in the later chapters is such, that one could wish that more of that sort had been written.

B. S. Gossling.

Correspondence.

THE OSCILLATING TRIODE.

To the Editor, the "Radio Review."

Sir,—On p. 37 of your first issue, Dr. Whiddington is reported as giving the expression $\frac{1}{k}\left(\frac{L}{\rho} + RC\right)$ for the minimum value of M necessary to start oscillation, where k is defined as the "amplification factor." If, however, this factor is defined as the ratio of change of anode E.M.F. to change of grid E.M.F. (which seems to the writer to be the correct definition) then the expression given appears to be of wrong dimensions, and should be multiplied by ρ, giving

$$\frac{1}{k}(L + \rho RC).$$

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If, on the other hand, k is the ratio of anode current to grid E.M.F. change, *i.e.* a quantity having the dimensions of a conductance, then the expression given is, of course, correct.

Is it not preferable, however, to express the amplification as a simple ratio of E.M.F.'s ?

R. C. CLINKER.

Rugby, *November 1st*, 1919.

HARDENING AND SOFTENING OF IONIC TUBES.

TO THE EDITOR, THE "RADIO REVIEW."

SIR,—With reference to Dr. Eccles' interesting letter in your last number, it would appear that his explanation is more of the nature of a detailed consideration of what happens when a positive ion falls into the filament than of an explanation of the hardening and softening phenomena.

Dr. Eccles' suggestion differs somewhat from the generally accepted view in that he attributes the whole hardening process to the occlusion of gas in the filament. It has previously been supposed that the "clean up" was due to gas being driven into parts of the valve at lower temperatures than the filament. The question asked in the discussion at Bournemouth may well be repeated "how are they (*i.e.*, the positive ions) retained in the filament at 2,000° C. ?" At that temperature the average velocities are high and the average time that would elapse before a particular ion acquired a velocity sufficiently high to enable it to break away from the surface of the filament would surely be very short.

The whole phenomena of hardening and softening has been frequently observed when the currents through the valve have been less than 20 per cent. of the saturation current. Moreover, if a valve is hardened at a high voltage and is then run at a low voltage it is never observed to return to its original soft state. It softens to a smaller extent than the original hardening.

It may be observed that the electrons and ions are by no means confined to the space between the electrodes. Some proportion of them are flying round in external orbits and in following these paths some will strike the containing walls. Several cases are known in which the bombardment from these side orbits has led to sufficient local heating of the glass to cause cracking and puncturing of the walls.

It is believed that the valve manufacturers have information available that would throw a good deal of light on this question if it were carefully analysed.

C. L. FORTESCUE.
G. B. BRYAN.

Royal Naval College,
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November 4th, 1919.

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