# EXPERIMENTAL WIRELESS
## & The WIRELESS ENGINEER

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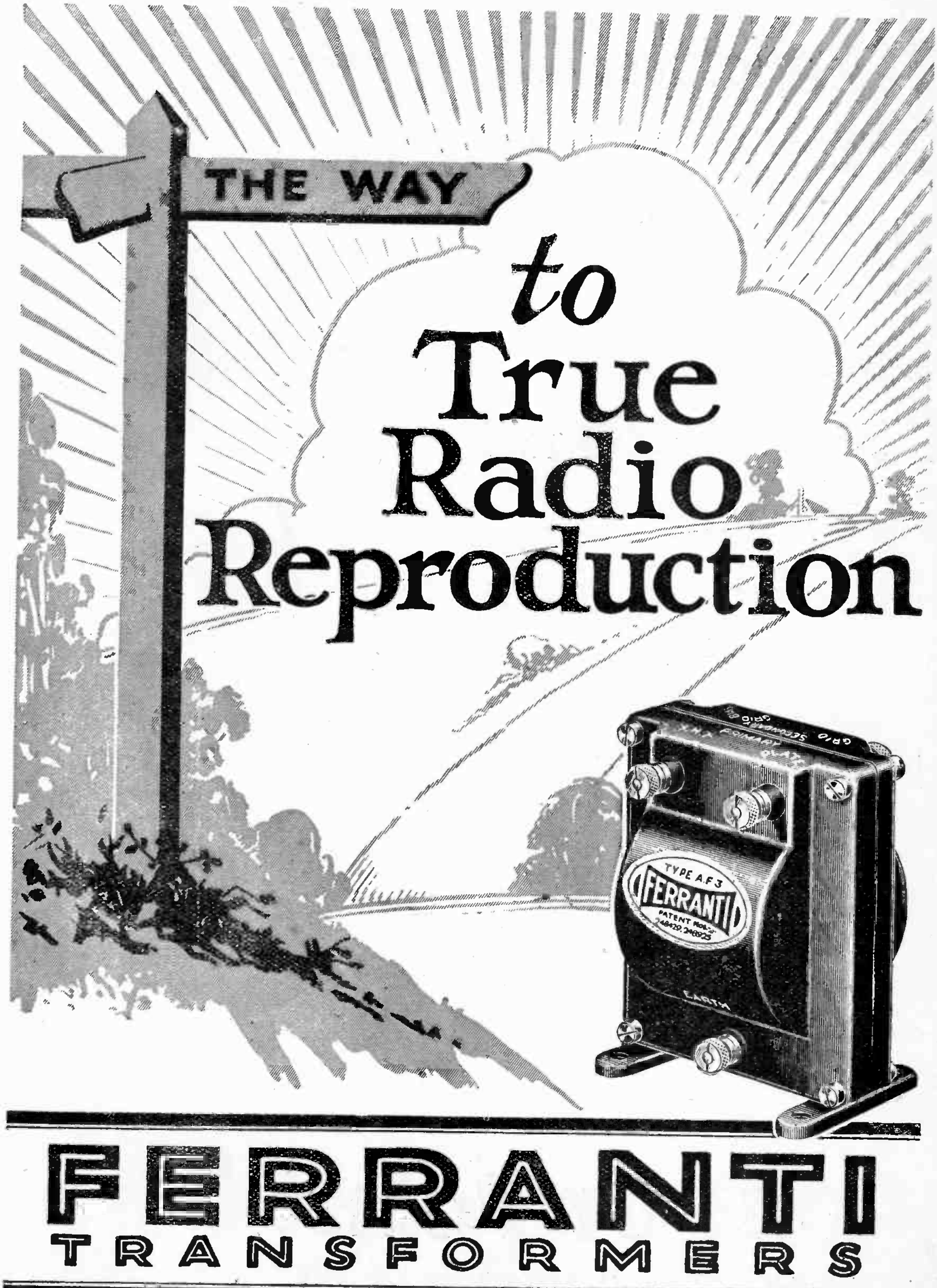
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# EXPERIMENTAL WIRELESS
## and The WIRELESS ENGINEER
*A Journal of Radio Research and Progress*

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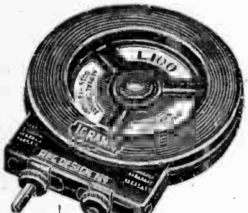

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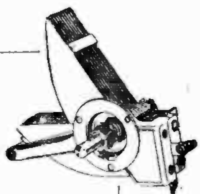

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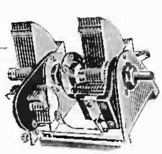

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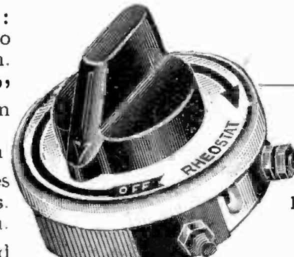


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EXPERIMENTAL WIRELESS
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VOL. IV. JANUARY, 1927. No. 40.

# Editorial.

## A Simple Method of Measuring Modulation.

EVERY experimenter will welcome a method of determining the degree of modulation of the received waves, especially if the method calls for no very elaborate equipment. Such a method is described in an article by Mr. L. B. Turner in this number. The method has its limitations in that it measures the average value and not the momentary peaks which so often cause trouble, but a knowledge of the average modulation over an interval of a few seconds is of great interest in determining the relation between the modulation ratio and the quality of the reproduction. The time over which the average is taken depends on the sluggishness of the indicating instrument employed with the valve voltmeter. We have no doubt that many of our readers will try this method, and we shall welcome any interesting particulars of their observations, and especially of any modifications or improvements introduced into the method.

We are not in entire agreement with Mr. Turner's formula for the modulator ratio; in our opinion a simpler denominator gives a more accurate value. Our reasons for this opinion will be evident from the following considerations, assuming that one has already read Mr. Turner's article. It is found that the carrier wave alone causes the anode current to change from $i$ to $i-\delta i$; it is then found that with the aerial cut out, the same change of anode current can be produced by inserting a resistance $r$ in the anode circuit, and thus increasing its total external resistance from $r_0$ to $r_0+r$. Under these circumstances the change in the anode voltage of the valve is $ri-(r_0+r)\,\delta i$ and, as Mr. Turner says, the change $\delta i$ could have been produced by a change of anode voltage of this magnitude. He then says "or by a grid change $1/\mu$ times as great"; but this is not correct, because, owing to the external resistance $r_0$ in the anode circuit, the anode voltage is not constant, but changes with every change in $i$. To make the effect of this clear let us assume that the anode current is given by the equation $i=av_a+bv_g+c$ where $a$, $b$ and $c$ are constants and $v_a$ and $v_g$ are the anode and grid voltages; let $E$ be the E.M.F. of the anode battery and $r_0$ the external resistance of the anode circuit, then

$$a\,[E-ir_0]+bv_g+c=i.$$

Now let $v_g$ become $v_g-\delta v_g$; $i$ will decrease to $i-\delta i$ then

$$a\,[E-(i-\delta i)\,r_0]+b(v_g-\delta v_g)+c=i-\delta i.$$

(*Note.*—We are following the author's unusual procedure in assuming that $\delta i$ is essentially positive and writing $i-\delta i$ instead of $i+\delta i$ for the new value of current.)

In the other case the grid voltage is unchanged—the aerial being cut out—but the anode circuit external resistance is increased from $r_0$ to $r_0+r$, also causing $i$ to decrease to $i-\delta i$; we then have

$$a\,[E-(i-\delta i)(r_0+r)]+bv_g+c=i-\delta i.$$

From the 1st and 2nd equations we have

$$-a\delta i r_0 + b\delta v_g = \delta i$$

and from the 1st and 3rd equations we have

$$a[ir - \delta i(r_0 + r)] = \delta i.$$

Equating these two values of $\delta i$ we have

$$b\delta v_g = a[ir - \delta i(r_0 + r)] + a\delta i r_0$$

which, since $b/a = \mu$, may be written

$$\delta v_g = \frac{r(i - \delta i)}{\mu}$$

The expression for the modulation ratio will then be $\frac{\sqrt{2}\,e}{r(i - \delta i)}$ instead of $\frac{\sqrt{2}\,e}{ri - (r_0 + r)\delta i}$

There is thus no need to know $r_0$.

The effect on the values of the modulation ratio is seen from the following table:—

| Observation. | Modulation Ratio. | |
|---|---|---|
| | Turner. | Howe. |
| | per cent. | per cent. |
| 1 | 15 | 14 |
| 2 | 35 | 35 |
| 3 | 28 | 28 |
| 4 | 61 | 58 |
| 5 | 42 | 40 |
| 6 | 33 | 33 |
| 7 | 48 | 47 |
| 8 | 55 | 50 |
| 9 | 18 | 17 |

It will be seen that the values are lower than those given by Mr. Turner, but the difference is so small, in view of the very approximate nature of the measurements, that the additional accuracy would be hardly worth while were it not that the more accurate formula is the simpler of the two and requires the measurement of one less quantity.

## Classification of Articles and Abstracts.

IN our issue of October, 1924, a very instructive description was given of the Dewey Decimal System of Classification and the extension of it introduced by the Bureau of Standards. To make it more suitable for Radio Telegraphy some further modifications were introduced by Mr. P. K. Turner and since that time a number—we almost said a cryptic number—has appeared beside the title of every article. This number enabled the initiated to place the article in its correct niche in the Dewey Decimal System without reading it.

Since the arrangement was entered into whereby the abstracts prepared by the Radio Research Board of the Department of Scientific and Industrial Research are published in *E.W. & W.E.*, these abstracts have been split up into groups according to their Dewey classification, but this has not proved very satisfactory and after due consideration an improved method of grouping has been agreed upon and adopted in the present issue. Unlike a general library, we are not concerned with many branches of learning, but with one subject which can be conveniently grouped into a relatively small number of sections. We would point out, however, that any reader who uses the Dewey System, and is consequently familiar with the classification, can still apply it by reading through the abstract—a glance would often suffice—and noting the relevant number.

The headings under which the abstracts will be grouped are as follows:—

Propagation of Waves.
Direction Finding.
Atmospherics.
Properties of Circuits.
Valve Design and Thermionics.
Transmission.
Reception.
Measurements and Standards.
Subsidiary Equipment and Materials.
Stations; Design and Operation.
Miscellaneous.

# Telephone Transmitter Modulation Measured at the Receiving Station.

*By L. B. Turner, M.A., M.I.E.E.*

## 1. Introduction.

THE envelope of the shaded area in Fig. 1 represents the amplitude of high frequency current in the aerial of a wireless telephone transmitter when an acoustic tone of frequency $n$ is being transmitted. The high frequency amplitude is $a$ when the microphone is quiet, and fluctuates between $(a + \alpha)$ and $(a - \alpha)$ when the tone is played or sung to the microphone.

The ratio $\alpha/a$, called the modulation ratio, has great significance for the quality of reproduction by the receiver. However perfect the amplifiers and loud-speaker may be, they reproduce the harmonics of the transmitted tone which are manufactured in the rectifier. The strengths of these undesired harmonics relative to the strength of the desired fundamental decrease as the modulation ratio $\alpha/a$ is decreased. This is the ground for the term " over-modulation " as a fault at the transmitter. Over-modulation shows, of course, only during the relatively loud passages.

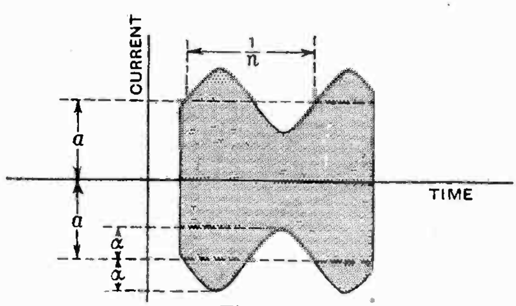



Fig. 1.

While the power capacity of the transmitting plant limits $a$, the strength of the received signal is proportional to $\alpha$. In the effort to provide good *strength* of signals, those in control of the transmitter are therefore tempted to make $\alpha$ larger than is consistent with good *quality*.

Doubtless every critical broadcast listener sometimes judges that his favourite transmitting station (Daventry, in the writer's case) is producing music of a quality distinctly below par—showing faults, that is, not attributable to the musical score or to the performers, but of the sort which would suggest misbehaviour of the receiver had not that erstwhile suspicionable new acquaintance developed gradually into a trustworthy friend. The writer has several times noticed —or fancied so—that on such occasions the strength of the signals was abnormally great. It seems probable that an abnormally high modulation ratio is responsible for such occurrences.

The writer does not know of any published statement of modulation ratios used in the British Broadcasting Company's stations. It has been stated, however, that in 1922-23 the modulation at KDKA, the Westinghouse Co.'s station at East Pittsburgh, reached from 50 per cent. to 90 per cent.*; and that at the Telefunken Co.'s stations in Germany "it has been found desirable to modulate only 55 per cent. for speech at the transmitter and only 35 per cent. for music."†

Experimentalists and others interested in the big question of quality of reproduction are vitally concerned with the transmitter's modulation ratio, and it is important for them to be able to determine it themselves. A simple method is here described. It requires very little apparatus not already incorporated in the ordinary triode receiver for use with headphones. The chief accessory is a triode voltmeter; but this is an instrument for measurements of all sorts which no wireless experimenter can afford to be without.

## 2. Apparatus and Procedure.

Fig. 2 is a complete circuit diagram.

RT is the normal rectifier triode, which may be for grid rectification as shown, or for anode rectification.

* C. M. Jansky, *Technological Papers of the Bureau of Standards*, No. 297, Oct., 1925.

† W. Schäffer, *Telefunken Zeitung*, No. 42, Jan., 1926, p. 22.

B is its anode battery.

Ch is an acoustic frequency choke, whose reactance is large compared with the A.C. resistance of RT. It may be the primary of a good triode transformer.

R is an adjustable resistance, such as an ordinary plug box, of value $r$.

H is a headphone of low resistance, or with a shunt of low resistance, for observing the music during the tests.

mA is a milliammeter, measuring the anode current $i$.

$\mu$A is a microammeter or galvanometer or low-reading milliammeter, indicating (and roughly measuring) small changes of $i$.

TV is a thermionic voltmeter, of a type unaffected by steady P.D. between its terminals. It reads the R.M.S. acoustic P.D. $e$ across Ch.

P is a potential divider, supplemented by cells C if necessary.

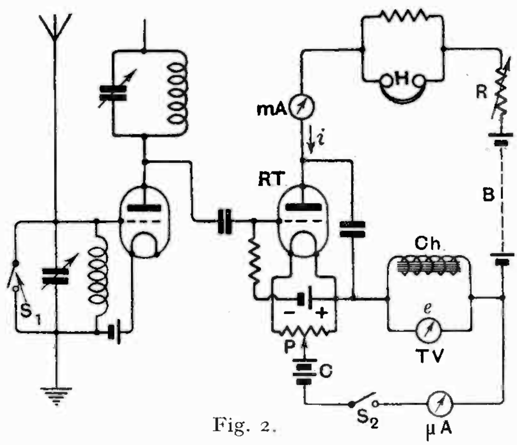



Fig. 2.

$S_1$ is a switch, cutting off the signals when closed.

$S_2$ is a switch, removing $\mu$A when open.

The receiver being tuned to the station under observation,* the procedure is as follows :—

I. Close $S_1$ and $S_2$ ; set R to zero ; and adjust P to bring $\mu$A to a convenient part of its scale.

II. During an interval in the programme when the microphone is quiescent,† open $S_1$ and observe the consequent change on $\mu$A. This is a measure of the change of anode current effected by the signal ; call it $\delta i$.

III. Close $S_1$, and adjust R (to a value $r$) to produce the same movement on $\mu$A as was produced by the signal in II.

IV. Open $S_1$ and $S_2$ ; listen in H, and at a selected passage in the music observe the voltmeter reading $e$. This is the P.D. produced by the modulation.

* This is best checked in operation II.

† This may actually be done when the microphone is quiescent or not ; quiescence makes no difference but it simplifies the argument to establish the formula.

The required modulation ratio is given approximately by the simple formula $\sqrt{2}\,e/ri$. A correction is necessary, however, for accurate results unless $\delta i$ is very small compared with $i$. It will be observed that the triode dimensions need not be known.

### 3. Derivation of the Formula.

Let $\mu$, $\rho$ be the amplification constant and the A.C. anode resistance of the triode. Let $r_0$ be the external resistance of the anode circuit—viz., that of the choke Ch shunted by the microammeter $\mu$A, plus that of the headphone H shunted by the small resistance.

The additional anode circuit drop effected in III is $ri—(r+r_0)\delta i$, which is approximately $ri$ if $\delta i$ is sufficiently small. Hence $\delta i$ in II would have been produced by an anode change $ri—(r+r_0)\delta i$, or a grid change $1/\mu$ times as great.*

The anode acoustic amplitude $\sqrt{2}\ e$ in IV (when the signal is substantially a single tone) gives $\sqrt{2}\,e/\mu$ as the grid acoustic amplitude, since the impedance of Ch is much greater than $\rho$.

Hence the modulation ratio is

$$\frac{\sqrt{2}\,e}{\mu} \div \frac{ri—(r+r_0)\delta i}{\mu}$$

$$= \frac{\sqrt{2}\,e}{ri-(r+r_0)\delta i}$$

Strictly the modulation ratio thus found is the ratio between the amplitude of the acoustic part of the rectified current and the steady part of the rectified current due to the carrier wave. It is this ratio which matters as regards quality of reproduction ; but it is equal to the transmitter modulation ratio only if rectified current is sensibly propor-

* In the grid rectifier case, this is the drop of grid potential actually effected by the carrier wave.

tional to high frequency amplitude. The good quality of musical reproduction usually obtainable, in the presence of high modulation ratios such as those recorded below, shows that this must be the case; and direct laboratory measurements have confirmed it.

## 4. Examples of Measurement.

The transmitter was Daventry ($\lambda$=1,600 m). The receiver was as in Fig. 2; the situation, Cambridge; the aerial, a poor one between low chimneys. Ch was the primary of a 1 : 2 transformer of good make; its resistance was 1,200 ohms. The headphone H was of high resistance, and was shunted by resistance varying between 0 and 500 ohms. The microammeter was an instrument with variable shunt, the resistance as used having values between 900 and 180 ohms. B gave about 105V. The amplification of the first triode was intentionally varied during the series of tests, by changes of triode and of its anode voltage.

Each observation was made at a relatively rather loud passage in the particular musical item.

With signals adequate for good headphone strength at the anode of a triode rectifier these measurements are made without difficulty. The procedure may obviously be varied in detail; and a correction may be applied if the impedance of the choke Ch is not indefinitely great compared with the anode A.C. resistance $\rho$. It is a help in arranging that the impedance of Ch is sufficiently large, especially when anode rectification is employed, to use for RT a triode with low A.C. anode resistance—*e.g.*, the triode which normally feeds the loud-speaker. Such a triode permits, too, a wider sweep of grid voltage without endangering the rectilinearity of rectifier response.

It is necessary to guard against high frequency P.D. reaching Ch and giving a reading on TV. If Ch is the primary of a transformer of known ratio, it is convenient to place TV across the secondary.

The writer has used the method only with grid rectification, the grid-leak being 1.5 megohms; but it does not appear that the substitution of anode rectification would raise any serious difficulty.

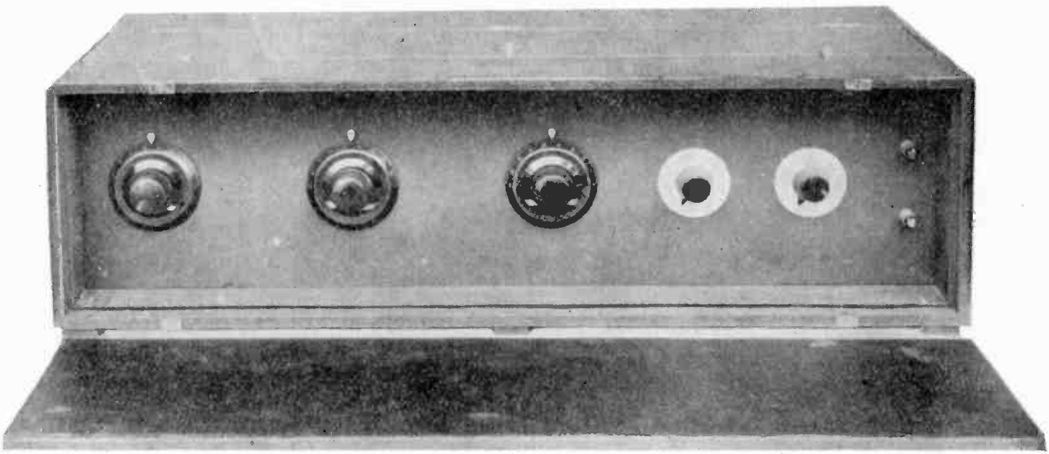
| Observation. | Triode. | $i$ (mA) | $\delta i$ (mA) | $r_0$ (ohms) | $r$ (ohms) | Musical item. | $e$ (volts) | Modulation ratio. |
|---|---|---|---|---|---|---|---|---|
| 1 | Dull emr. (0.06A) Nominal $\mu=10$ $\rho=25$ k$\Omega$ | 3.4 | 1.4 | 1,200 | 12,000 | Contralto | 2.4 | 15% |
| 2 | Do. | 3.4 | 0.31 | 500 | 2,240 | Cello | 1.7 | 35% |
| 3 | Do. | 3.4 | 0.31 | 500 | 2,240 | Quartet | 1.35 | 28% |
| 4 | G.E. Co.'s "D.E.4" Nominal $\mu=7$ $\rho=10$ k$\Omega$ | 7.7 | 0.21 | 500 | 260 | Tenor | 0.8 | 61% |
| 5 | Do. | 7.7 | 0.21 | 500 | 260 | Quartet | 0.55 | 42% |
| 6 | Do. | 7.1 | 0.22 | 830 | 600 | Big Ben, just after stroke | 0.95 | 33% |
| 7 | Do. | 7.7 | 0.69 | 180 | 920 | Tuning note 7 p.m., on 26 Aug., '26 | 2.15 | 48% |
| 8 | Do. | 7.0 | 0.40 | 830 | 560 | Do., on 28 Aug., '26 | 1.3 | 55% |
| 9 | Do. | 7.0 | 1.32 | 680 | 2,400 | Orchestra | 1.6 | 18% |

*Notes.*—Observations 3, 5 and 9: Not a single tone.
Observation 7: High frequency P.D. on grid=0.95 V (R.M.S.).
Observation 8: High frequency P.D. on grid=ca. 0.6 V (R.M.S.).

# A Five-Valve Receiver with Two H.F. Stages for 900-3,000 Metres.

*By W. James.*

THE five-valve receiver illustrated here was designed to receive Daventry and five or six of the European broadcast stations working between 900 and 3,000 metres. It might be thought that five is an extravagant number of valves to use for the purpose, as many of us can receive several of the long-wave stations with a two-valve set fitted with reaction. But five valves were used to make certain of receiving the stations even on a short indoor aerial, and good quality was considered essential. It was also thought that people living even thousands of miles away from, say, Daventry, would have a good chance of hearing this station under favourable conditions.



*The completed receiver. The three condensers tune the aerial coil and high-frequency transformers. Two filament rheostats are used, the left-hand one being a volume control.*

With five valves three tuned circuits can be used, thus giving good tuning; adjustable reaction can be dispensed with, and the three tuned circuits, with the two valves which form the high frequency amplifier, can be made perfectly stable, as there is no need to design them to give the utmost amplification. Such a high frequency amplifier can be calibrated, if necessary; in any case to tune it is easy as the individual stages are relatively broadly tuned and are free from interaction. Transformer coupling is used throughout, the two high-frequency transformers being home made and tuned by variable condensers, whilst the two low-frequency stages are coupled by good commercial instruments.

Referring to the circuit diagram of Fig. 1, $L_1$, $C_1$; $T_1$, $C_2$ and $T_2$, $C_3$ are the high-frequency couplings, $T_3$ and $T_4$ being the low-frequency couplings.

### High-Frequency Couplings.

If we take a valve having an amplification factor ($\mu$) of 6 and an A.C. resistance ($R_{AC}$) of 6,000 ohms, under working conditions, and we connect a tuned circuit to its anode, the maximum amplification obtainable is 6 and selectivity will be poor because of valve damping. To obtain practically the full amplification is easy, for we have only to provide a circuit having an effective resistance at resonance of, say, 10 times the A.C. resistance of the valve, or 60,000 ohms. It is clear that we could do better by employing a valve with a higher amplification factor and a correspondingly higher A.C. resistance. For instance, if the valve is changed for one having a $\mu$ of 20 and an $R_{AC}$ of 20,000 ohms, the tuned circuit remaining as before, the amplification obtained will be 15 and the selectivity will be better because now the tuned circuit is damped by a shunting resistance of 20,000 ohms instead of 6,000 ohms. Another advantage is that the 20,000 ohms valve does not take such a large anode current as the 6,000 ohms valve.

We will, therefore, use a high impedance valve; a good one is the Mullard PM5A, the average $\mu$ and $R_{AC}$ at 120 anode volts and —1.5 volts grid bias for six which were tested being 25 and 30,000 ohms.

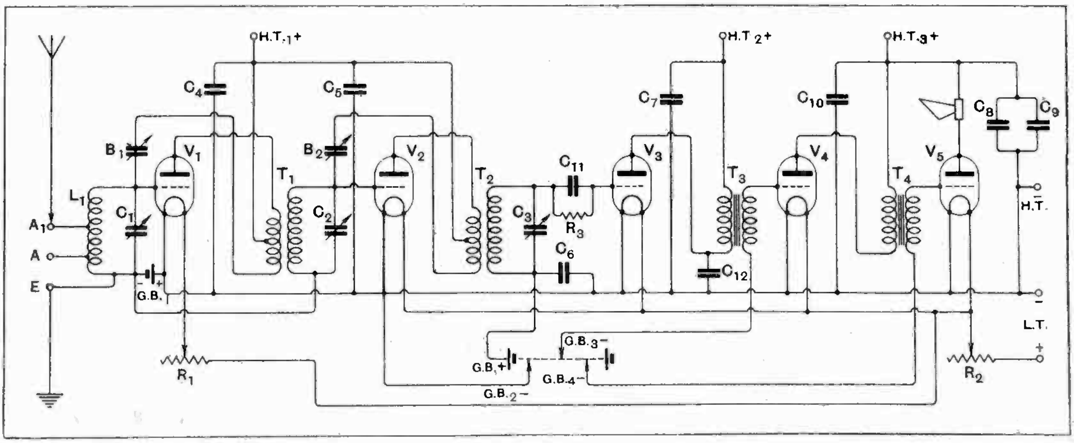



Fig. 1. *Circuit diagram.* $C_1$, $C_2$, $C_3$, $0.0005\mu F$; $C_4$, $C_5$, $C_6$, $C_7$, $1\mu F$; $C_8$, $C_9$, $C_{10}$, $2\mu F$; $C_{11}$, $0.00025\mu F$; $C_{12}$, $0.001\mu F$; $B_1$, $B_2$, *Gambrell balancing condensers*; $L_1$, *Lewcos coil No.* 300; $T_1$, $T_2$, *H.F. transformers with balancing windings*; $T_3$, $T_4$, *L.F. transformers with good characteristics*; $R_1$, *volume control of approximately* 30 *ohms*; $R_2$, *filament rheostat*; $R_3$, 1 *megohm grid-leak*; $V_1$, $V_2$, *valves of high* $\mu$ *and about* 30,000 *ohms* $R_{AC}$; $V_3$, $V_4$, *detector and L.F. valves which should be chosen with regard to the quality required*; $V_5$, *output valve of about* 3,000 *ohms*; $GB_1$, *single dry cell*; $GB+$ *to* $GB_4-$, *grid bias of about* 27 *volts.*

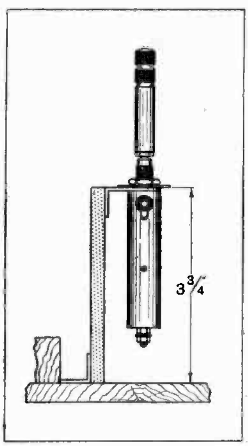


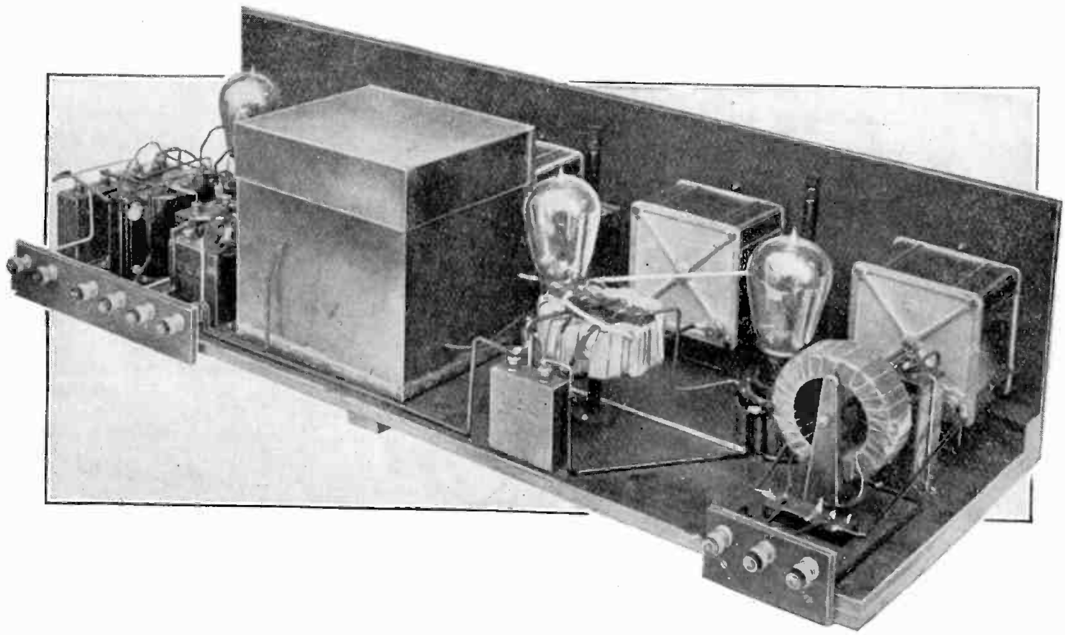

Fig. 2. *Method of mounting the Gambrell balancing condenser. The upright piece is of ebonite.*

But it is possible to increase the amplification and to improve the selectivity by further adapting the tuned circuit to the valve. It should be remembered that the maximum *power* is delivered to a circuit when the effective resistance of the circuit is equal to the $R_{AC}$ of the valve. The maximum is not very sharply defined, however, and it is possible to vary the ratio of the resistances to, say, 3 to 1 or $\frac{1}{3}$ without losing very much. This is an important point, as we require selectivity and stability as well as amplification.

Now it is an easy matter to provide a tuned circuit having an effective resistance of, say, 200,000 ohms at resonance, although from the discussion we see that there is not much use for it as it stands. But we can connect the anode of the valve to a portion of the tuned circuit, or what is really the same thing, we can use the tuned circuit as the secondary of a transformer and fit a primary to it. If, now, the circuit connected to the anode has an effective resistance approximately equal to the $R_{AC}$ of the valve, the valve is being used efficiently and the voltage across the tuned secondary will be larger than that across the primary winding because of transformer action. It should be noted that under these conditions the voltage across the anode circuit is divided approximately equally between the valve and its anode circuit, and that the best turns ratio of secondary and primary is about 2.6, giving an amplification of 32.5. Selectivity is correspondingly better owing to the reduction of valve damping. Under these conditions, that is with a transformer designed to match the valve and tuned to resonance, the amplification is a maximum.

having a secondary tuned by condenser $C_2$ and two primary windings ; one primary is connected to the anode of $V_1$ and to +H.T., while the other is connected to +H.T. and through the balancing condenser $B_1$ to the grid of $V_1$.

It is important to wind the two primary windings close together, for then the coupling will be tight and the balance will hold over the whole tuning range of the transformer.



*View of the back of the receiver, showing in particular the method of mounting the aerial coil (on the right) and the first H.F. transformer (between the two valves). The third tuned coupling and the detector valve is enclosed in the copper box. In front of the aerial coil are the aerial and earth terminals ; the battery terminals are on the left-hand side.*

**Obtaining Stability.**

If such a valve and transformer combination had a tuned grid circuit, the arrangement would undoubtedly oscillate violently even though the input and output circuits were completely screened. Valve capacity is the cause of the trouble and it is necessary to balance the anode-grid capacity.

There are several ways of doing this, but the one found most satisfactory consists of a winding tightly coupled to the primary of the transformer and connected to +H.T. and through a condenser of small capacity to the grid as in Fig. 1. Here valve $V_1$ is shown coupled to $V_2$ by transformer $T_1$, It is very difficult, however, to remove all couplings between the input and output circuits and there may be a tendency for the valve to oscillate. For this reason it is better to provide the transformer with a smaller primary, making its effective resistance when the transformer is tuned, say, $\frac{1}{3}$ of the $R_{AC}$ of the valve. The amplification will then be about 27.5 against 32.5, but selectivity is better and it will be very easy to stabilise the amplifier.

**H.F. Transformers.**

The coil $L_1$ and the secondary windings of transformers $T_1$ and $T_2$ are Lewcos No. 300

plug-in coils. These have an inductance of 4,800$\mu$H and a tuning range of 900 to 3,000 metres when shunted by a 0.0005$\mu$F variable condenser. At 2,320 metres the H.F. resistance of a Lewcos No. 300 coil is 28.2 ohms.

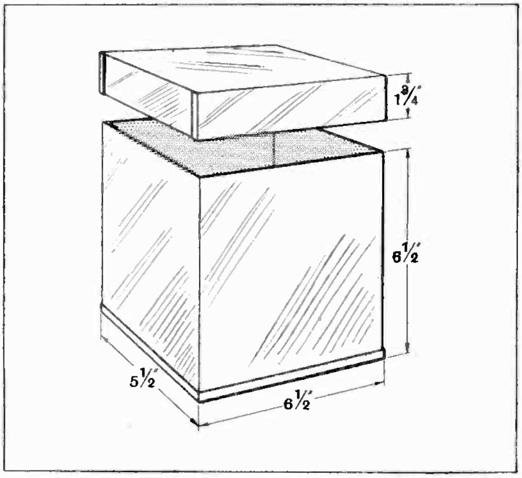



Fig. 3. *Details of the copper box which is of No. 24 gauge.*

Coil $L_1$ is tapped at the end of the first and second layers for the aerial connections $A$ and $A_1$, the beginning of the first layer (the inside one) being connected to the earth terminal $E$. As the coils are wound with enamel insulated Litzendraht cable, it is necessary to bare the wires very carefully, to solder on flexible wires, and to bind them in position with tape. The coil is mounted in an upright position and is provided with a connection strip consisting of a piece of ebonite with screws and soldering tags bolted in position as shown in the right-hand drawing of Fig. 5. This coil is the one seen at the left-hand end when looking over the front of the set. The coil plug is not used.

H.F. transformers $T_1$ and $T_2$ are wound in the same way, $T_1$ being mounted at right angles to the aerial coil, while $T_2$ and the detector valve is enclosed in a copper box. From the coil data the best ratio for the transformer $T_1$ when using the optimum coupling and allowing a load of 1.0 megohm across the condenser terminals, is 5.5 : 1, giving an amplification of about 34. Actually the two primary windings have 60 turns each of No. 40 D.S.C. wire.

Before winding the primaries, the coil plugs and outer coverings are removed; three or four layers of Empire cloth are then wrapped over the outer surface of the coil and over this 120 turns of No. 40 D.S.C. copper wire are wound to cover the whole surface except for about one-tenth of an inch at each edge. To the beginning of the winding a flexible wire is soldered and tied to the secondary coil with cotton; this end is the one which connects to the anode of the valve. At the 60th turn a second flexible wire is soldered and tied down; this has to be connected to +H.T. The end of the fine wire winding, at turn 120, is similarly finished off; this wire has to go to one side of a

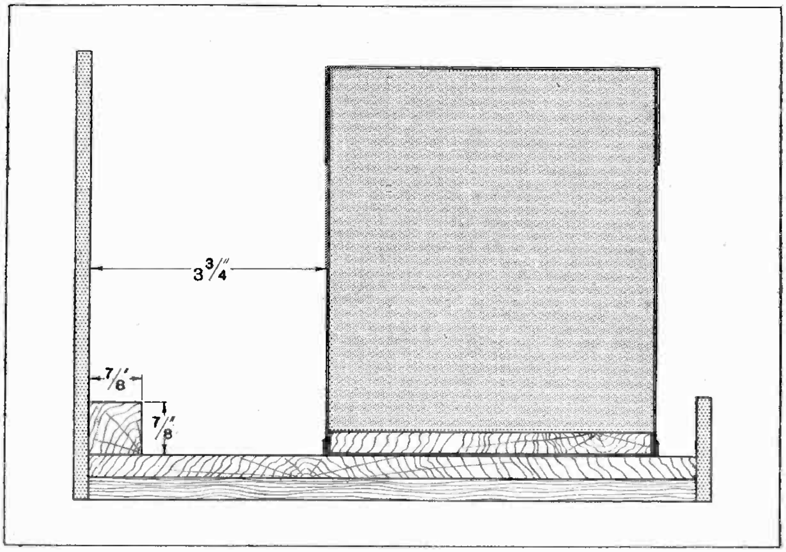



Fig. 4. *Position of copper box in the set. The parts enclosed in the box are mounted on the piece of wood. This drawing also shows the position of the baseboard, the end batten, the terminal strip, and the method of fixing the panel to the baseboard.*

balancing condenser. The primary windings (comprising the two coils) are wound in the same direction as the secondary, and the end of the secondary from the outside layer is the end that is connected to the grid bias. The primary windings are, therefore, wound over the portion of the secondary most nearly at earth potential.

Fine wire is used for the windings to keep down their size and to reduce their capacity to the secondary. Selectivity is adversely affected by the capacity of primary to secondary and so is amplification and it is important to reduce this capacity to as small a value as possible. This should not be done by increasing the distance between the two windings, for a weaker magnetic coupling has the effect of reducing the amplification at all points and certainly has the effect, in the transformers described, of making the amplification fall off seriously at the longer wavelengths. A weak magnetic coupling will improve selectivity, if only because valve damping is reduced.

**The H.F. Amplifier.**

The connections of Fig. 1 show that the grids of the H.F. valves, $V_1$ and $V_2$, are biased negatively by the battery $GB_1$; a single dry cell is used here.

A positive bias or a negative one can be given to the grid of the detector valve $V_3$ by appropriately connecting the grid return wire from the tuned circuit $T_2$ $C_3$. This wire has a plug marked $GB+$ and with the connections shown the grid has a positive bias. If the voltage between the connections $GB+$ and $GB_2$ is 6, the rectifier works exactly as it would if the grid return wire were connected directly to +L.T.; but the sensitivity of a grid circuit rectifier can often be improved by using a smaller voltage, such as 3 volts. However, from the point of view of quality it is generally preferable to connect the grid return wire to +6 volts and for the same reason a grid condenser $C_{11}$ of 0.00025$\mu$F and a grid-leak of 1 megohm is used. The sensitivity of the detector to weak signals is improved by using a higher value

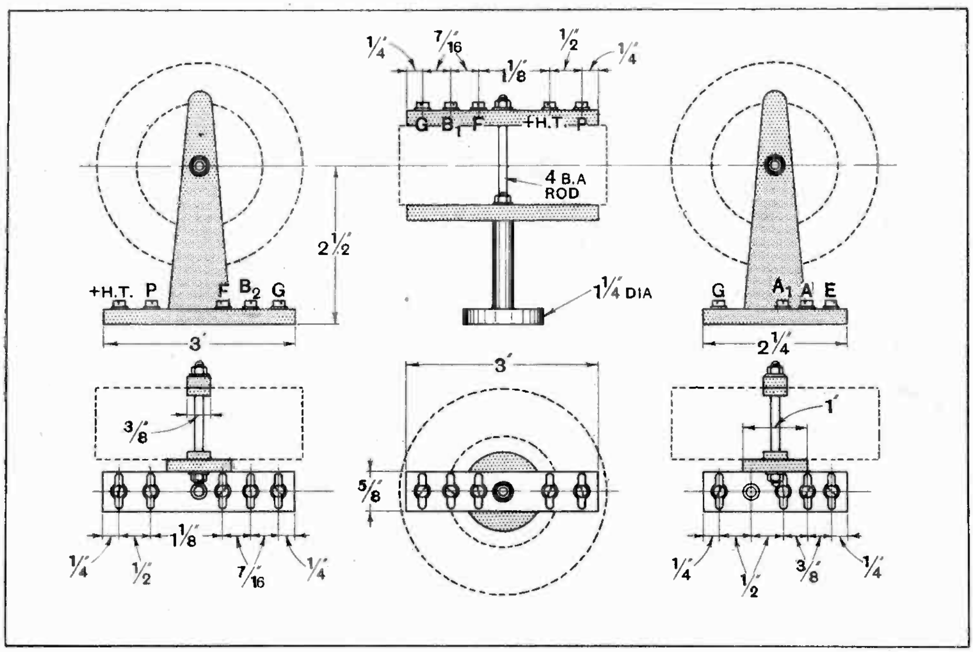



Fig. 5. *Details of the aerial coil (right); and the two H.F. transformers. The transformers consist of a Lewcos No. 300 plug-in type coil with primary and balancing windings. Connection strips are bolted in position and to the supports.*

of grid-leak and a little larger condenser, but at the expense of quality. Condenser $C_6$ shunts the grid bias of the rectifier.

Anode rectification can be obtained merely by connecting the grid return wire (marked $GB+$) to a point negative with respect to the filament, say 3 volts, and by adjusting the anode voltage at $HT_2+$.

The amount of the high frequency amplification obtained can be controlled in two ways: by varying the anode voltage at $H.T._1+$ or by varying the filament current of one or both H.F. valves. In each case, amplification is varied by altering the A.C. resistance of the H.F. valves; obviously, if the $R_{AC}$ of the valves is increased the amplification is reduced and, incidentally, the selectivity is improved.

In the circuit diagram the rheostat $R_1$ is shown connected to $V_1$. If this has a value of 30 ohms for a valve taking a current of about 0.25 ampere, or 50 ohms for a 0.1 ampere valve, a smooth control of volume is obtained. If the volume control so obtained is inadequate in any particular case, a 30 ohms rheostat can be connected to the two valves $V_1$ and $V_2$, so that both valves are controlled. This method seems much to be preferred to the alternative one of varying the anode voltage although the anode voltage would naturally be set at a value found most convenient.

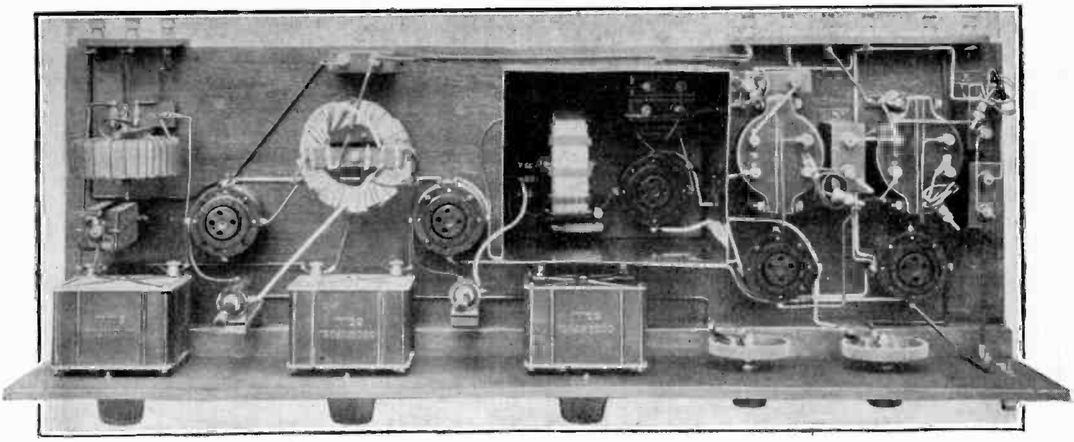
**The L.F. Amplifier.**

We can design the L.F. amplifier to give excellent quality regardless of the amplification obtained, or for maximum amplification. A person living a considerable distance from the stations he wishes to receive would naturally be more interested in getting the highest amplification with tolerable quality, as the signals received would probably be distorted to some extent in any case.

The quality of the amplification is determined by the valves and the couplings. If a valve having an $R_{AC}$ of, say, 25,000 ohms is used as a detector and a good low ratio transformer with a primary inductance of 50 henries or more is used, the quality should be quite good; and if the valve has an amplification factor of 20 the amplification is considerable.

It is advisable to use a low ratio transformer because of the effect of the anode by-pass condenser $C_{12}$ of $0.001\mu F$ and if the best quality is desired a valve having an $R_{AC}$ of, say, 6,000 to 10,000 ohms should be used as the detector.

To couple the fourth valve to the output valve a transformer having a primary inductance of similar value to $T_3$ may be used with a valve $V_4$ of 6,000 to 10,000 ohms suitably biased. Such a combination will usually give excellent quality when the output



*Plan view of the set with the cover removed from the copper box. Between the first and second tuning condensers is the balancing condenser ($B_1$), and between the second and third the other balancing condenser. The grid bias cell for the H.F. valves lies between the first tuning condenser and the aerial coil.*

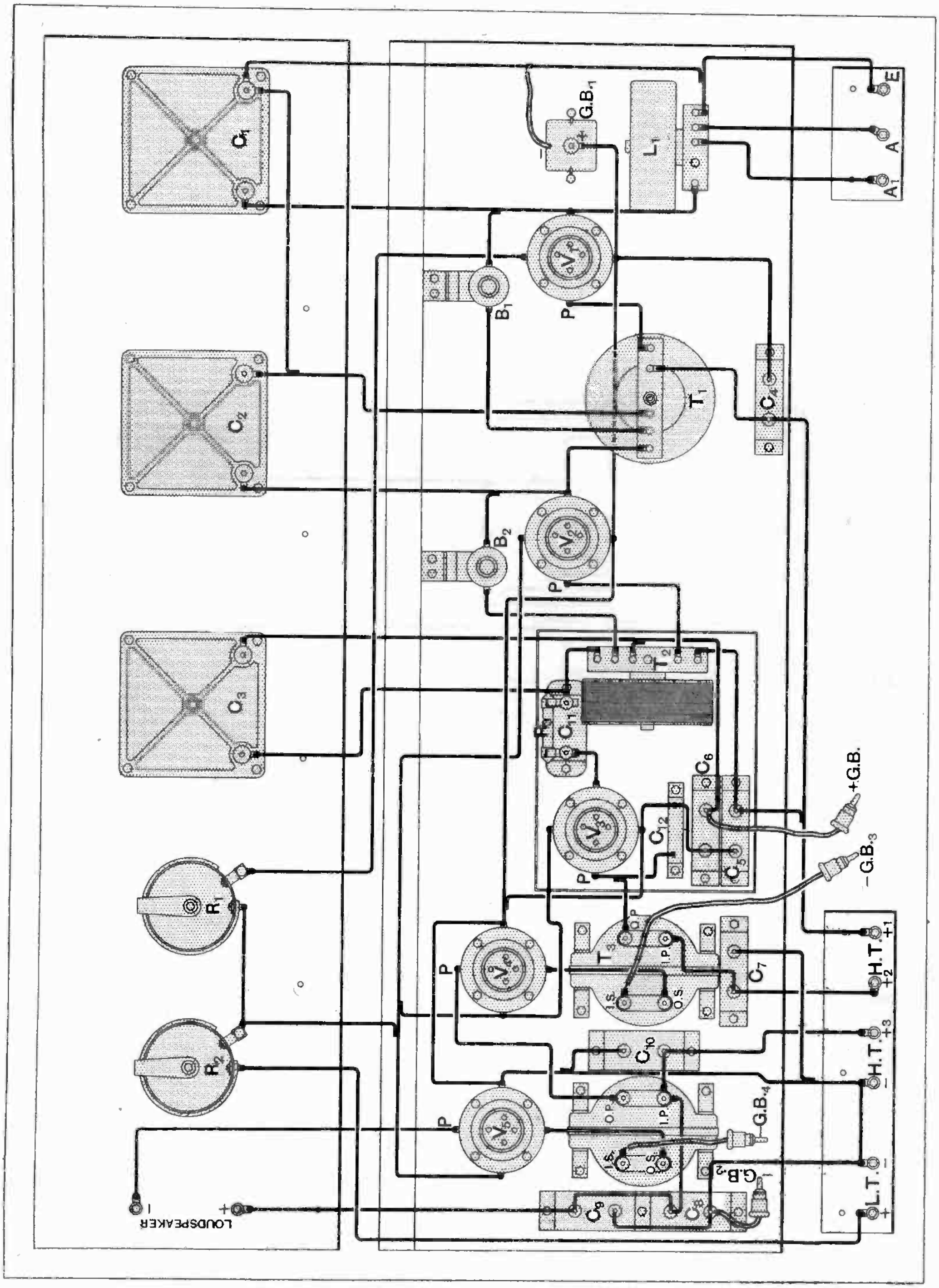


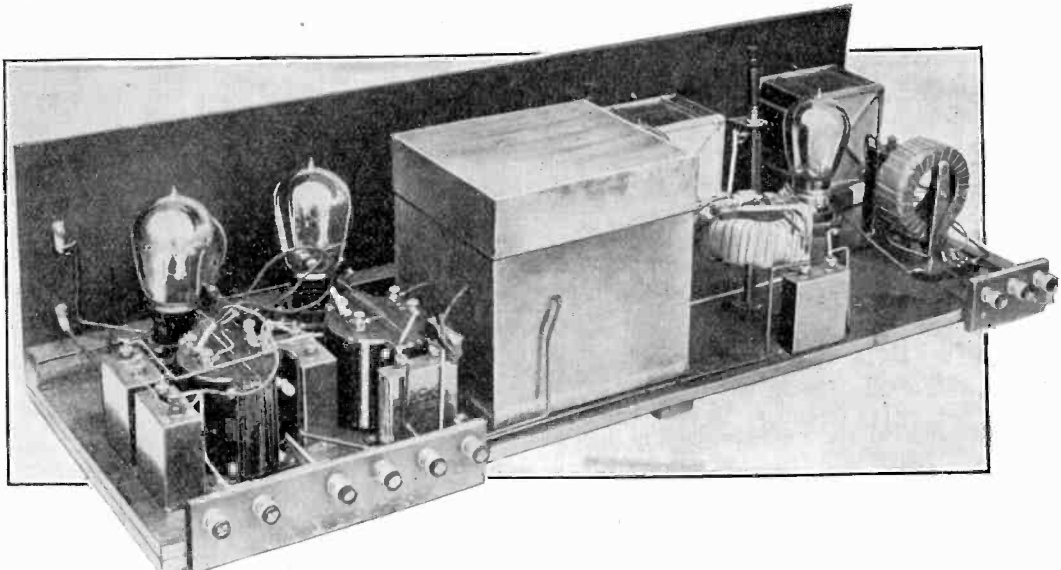

Fig. 7. *Wiring diagram. The drawing is to scale.*

valve $V_5$ is of the type having an $R_{AC}$ of about 3,000 ohms. There are two important points which should not be lost sight of however: the first is whether the loud-speaker is a faithful reproducer, and the second whether the anode battery will economically supply the current required. If the loud-speaker to be used will not reproduce the very low tones it is obviously not necessary to make the set amplify them fully as currents of the lower frequencies add to the filtering difficulties.

a wide range of frequencies more or less equally well and it can only do this when the primary is of adequate size. Resonance, of course, plays a part at the lower and higher frequencies, but experience shows that a transformer having a large primary inductance is necessary if the lower notes are to be faithfully amplified.

**Operation.**

The illustrations and drawings show the construction and wiring of the receiver and



*This view shows in greater detail the low-frequency end of the receiver. Notice the position of the two L.F. transformers, the two L.F. valves and the battery condensers.*

With regard to the second point, it has to be remembered that the last valve requires a steady anode current of 12 milliamperes or so if it is to deal with strong signals satisfactorily and that the remainder of the set can be designed to take a total current of between, say, 5 and 15 milliamperes. When a dry battery is used as the source of anode current it is usually necessary to keep the total current as small as possible. This can be done by using high impedance (low ratio) transformers at $T_3$ and $T_4$ and valves having an $R_{AC}$ of, say, 25,000 ohms at $V_3$ and $V_4$.

It should be noted that the remarks concerning H.F. transformers do not apply to low frequency transformers. A low frequency transformer is required to amplify

it is not necessary to enter into details. An ebonite panel 30 in. by $7\frac{1}{2}$ in. by $\frac{1}{4}$ in. is used, with a baseboard 30 in. by 10 in. by $\frac{1}{2}$ in. The components enclosed in the copper box are mounted on a base of wood and several of the wires can be put on before the base, with its components, is lowered in the box. Holes have to be drilled in the box to take the insulated connecting wires which pass from the inside of the box to apparatus outside.

The set is quite an easy one to build and operate. It should be remembered that the two H.F. transformers are designed to work with valves having an A.C. resistance of approximately 30,000 ohms; if valves having an $R_{AC}$ of much lower value than this are used, selectivity will suffer. On the other hand, if valves having a higher $R_{AC}$ are used, tuning will be sharper. Naturally,

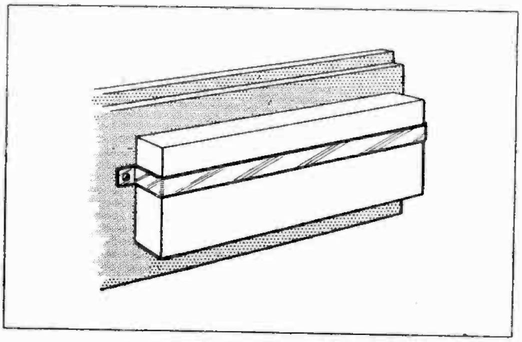


Fig. 6. *Method of fixing grid bias batteries to lid of case.*

for a given value of $R_{AC}$, the highest amplification factor is required. The valves recommended are Mullard PM5A's for the two high frequency stages, a PM5 for the detector and the first L.F., and a Mullard 256 for the output stage.

The total filament current is 0.65 ampere and used with 120 volts H.T. on all the valves except the detector, which can have about 36 volts, the total anode current is about 18 milliamperes when the grids are properly biased. With this combination of valves it is recommended that two low ratio transformers be used at $T_3$ and $T_4$. If maximum volume is required transformer $T_4$ may be of higher ratio and the output valve may be a PM6. It should be understood that any valves having characteristics similar to those recommended can be used with satisfaction in the receiver.

To balance the H.F. stages is an easy matter; the old-fashioned method of disconnecting one side of the filament circuit of the valve to be balanced is recommended.

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## Forthcoming Lectures.

A SERIES of six Lectures will be given on "Short Electric Waves Treated Experimentally," by J. H. Morrell, M.A.(Oxon )—of the Electrical Laboratories, Oxford—at East London College,* Mile End Road, E., commencing on Monday, 7th February, at 6 p.m.

The remaining lectures will be delivered at the same time and place on the five following Mondays.

The range of wavelengths to be dealt with is from 200 metres down to 1 metre, and numerous experiments will be demonstrated with the ultra-short waves to show such things as reflection, and measurement of wavelength on Lecher wires.

Amateurs who are interested in short waves will be well advised to attend these lectures, as they will be able to see how to make simple transmitters and receivers, using ordinary valves.

* Nearest station Stepney Green.

# The Delineation of Alternating Current Wave Forms.

*By H. A. Thomas, M.Sc.*
*(of the National Physical Laboratory.)*

### Introduction.

IN connection with many problems in which distortion is involved it is necessary to compare the input and output wave forms of an amplifier or of a transmitting system. The determination of the wave form given by an amplifier which has a sinusoidal input is a problem which must be solved if an analysis of the distorting members of the system is attempted.

For some time past, in connection with experimental work upon distortion in radio apparatus, including amplifiers, oscillators and modulating arrangements, the output wave form has been investigated, and it is felt that a description of the methods which have been adopted will be of value to those engaged upon similar work.

The simplest method is undoubtedly the application of the Einthoven galvanometer. This apparatus is capable of producing a photograph of waves which do not contain a harmonic higher than a frequency of about 600 per second.

### The Use of an Einthoven Galvanometer.

The method of applying this galvanometer to the case of an amplifier output is illustrated diagrammatically in Fig. 1. It will be seen that a pure audio-frequency oscillation is applied to the amplifier input by means of a tuned circuit loosely coupled to an oscillator. The output is passed through the galvanometer and the normal D.C. component of the anode current is balanced out by means of a 2-volt cell and a series resistance. The optical system is shown in Fig. 2 and consists of a powerful arc $A$, an objective at $B$, a microscope at $C$, a cylindrical condensing lens at $D$ projecting an enlarged image of the vibrating string on to the camera at $E$. This camera is of the high speed drum type produced by the American Bureau of Standards. It consists of a strip of bromide paper $3\frac{1}{2}$ inches wide and 1 metre long wound once around a drum which rotates at speeds up to six revolutions per second thus giving a peripheral motion of the film of 6 metres per second. The drum has

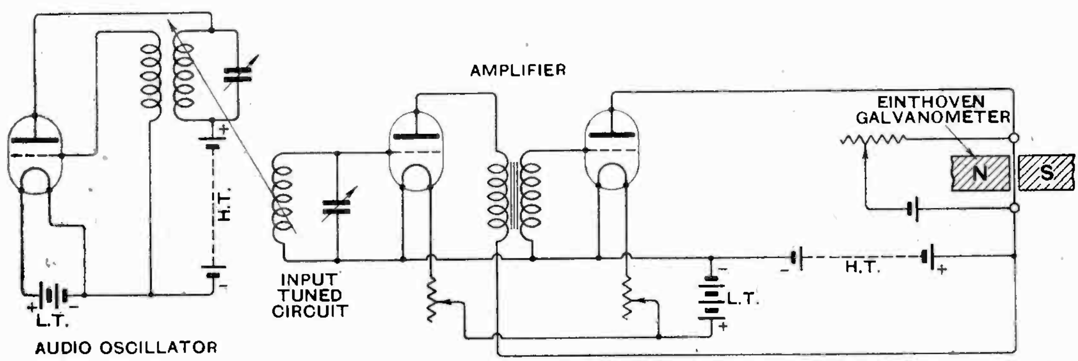


Fig. 1.

a lateral movement imparted by means of a worm which is magnetically locked when the shutter is opened by a local electrical circuit, thus producing a spiral photographic record about 3 metres long and 1 inch wide. Sufficient illumination can be obtained to give a very definite record of the movement of the string and examples of the type of record which can be obtained are shown in Fig. 3.

(c) Gives the same output with zero grid bias.

(d) Gives the same output with 4 volts negative grid bias.

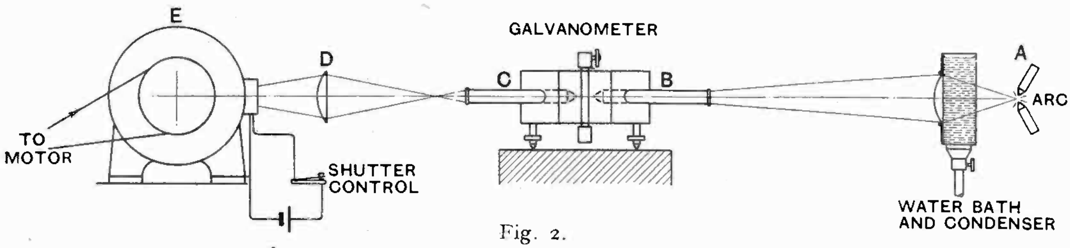

Fig. 2.

The results given are meant primarily to show the type of record that can be obtained and are not meant to indicate any conditions existing in the amplifier.

The string used can be made either of copper about 15$\mu$ in diameter or silvered quartz about 5$\mu$ in diameter. The latter has a much higher natural frequency and has a much greater resistance, but the optical definition is not so good as with the copper string.

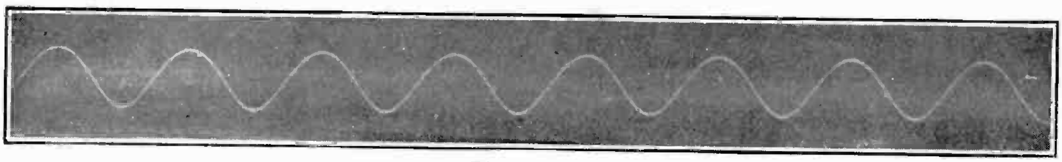
Fig. 3 (a).

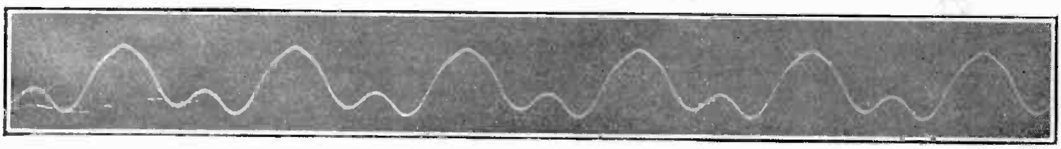
Fig. 3 (b)

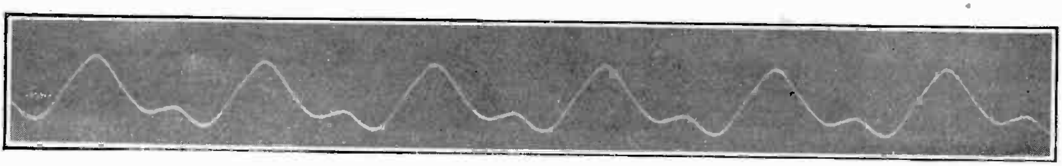
Fig 3 (c).

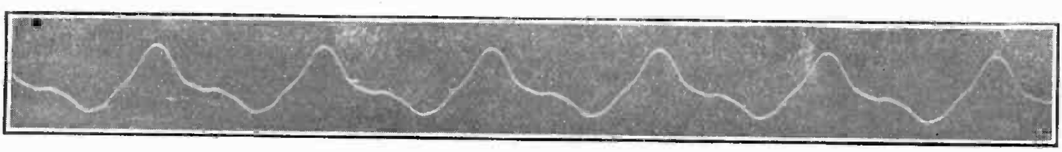
Fig 3 (d).

(a) Gives the sinusoidal input to an audio-frequency amplifier at a frequency of 160 cycles per second.

(b) Gives the output current of about 0.6 milliamp peak value obtained from this amplifier with 2 volts positive grid bias.

### The Use of the Cathode Ray Oscillograph.

For the analysis of frequencies higher than 300 periods per second, the natural frequency and decrement of the moving system are too low, and resort has to be made to the cathode ray oscillograph. The most practical form of oscillograph is the Johnson * tube for a low accelerating voltage, manufactured by the Western Electric Co. The filament of this tube takes about one ampere at 2 volts, and the high tension voltage is 300. The electron stream forming the moving figure may be resolved into a wave with a linear time base, and this can then be harmonically analysed.

The method of using the oscillograph in this way is shown in Fig. 4, the case given being for the determination of the output wave form obtained from an audio-frequency amplifier when the impressed voltage is sinusoidal. The input is applied, as in the previous case, using an Einthoven galvanometer as the recording instrument. The output must be applied to the oscillograph

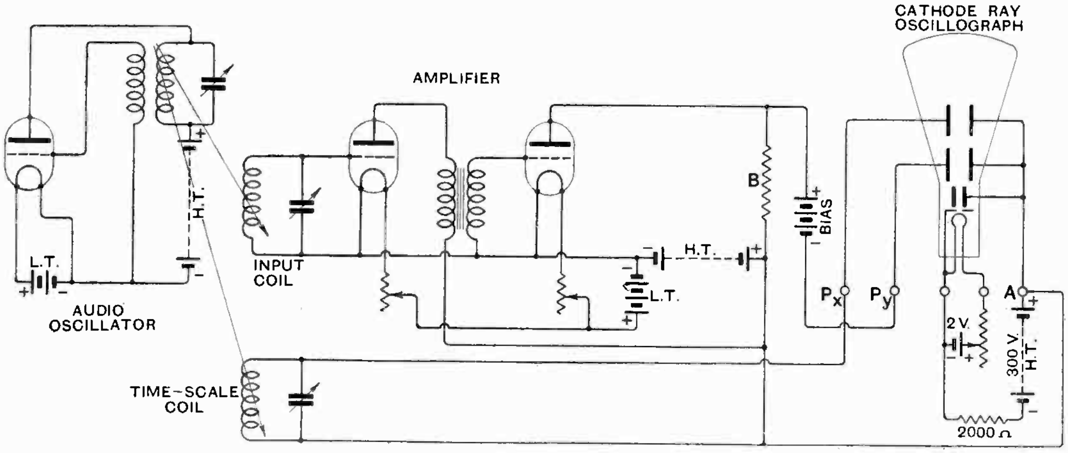


Fig. 4.

element is focused on to the fluorescent screen forming the back of the flask in which the filament, anode and deflecting plates are mounted.

Owing to the low anode voltage employed, the photographic sensitivity of this tube is far poorer than can be obtained with the Dufour 60,000-volt tube, or the Thomson 3,000 volt tube. This means that a single transient wave cannot be photographed and periodic phenomena only can be recorded, in which case a synchronised recurrence of the wave must be obtained giving a definite trace upon the screen. If the sinusoidal input is applied to one pair of plates of the oscillograph and the output is applied to the other pair of plates, the resultant cyclograph obtained will be a Lissajous figure. This in the form of potential and not current. To obtain this potential, a high resistance of 20,000 ohms was inserted in the anode circuit of the output valve, and one pair of plates from the oscillograph was connected across this resistance. To eliminate the normal D.C. voltage existing across this resistance due to the steady anode current component, a battery was inserted in one of the leads as shown at *B*. A record of the figure can be obtained by photographing the back of the flask or by holding bromide paper over the back of the flask. This latter method gives poorer results but is much simpler.

The analysis of the Lissajous figure must now be undertaken. In Fig. 5, let the closed curve represent the observed figure produced on the flask fluorescent screen by the electron stream, and let *AB* and *CD* be the two axes obtained by short circuiting first one and then the other pair of plates. Let *AB* be the time base executing a simple harmonic

* J. B. Johnson, *Physical Review*, 1921, Vol. 17, p. 420; and J. B. Johnson, *Journal of the Optical Society of America*, 1924, Vol. 9, p. 471.

motion about the point $O$. Draw two perpendiculars from the extremities of the curve on to the horizontal base line $AB$. The distance $OY$ gives the maximum amplitude of the time scale and $OX$ must equal $OY$. Now with centre $O$ construct a circle of radius $OY$. Divide this circle into any

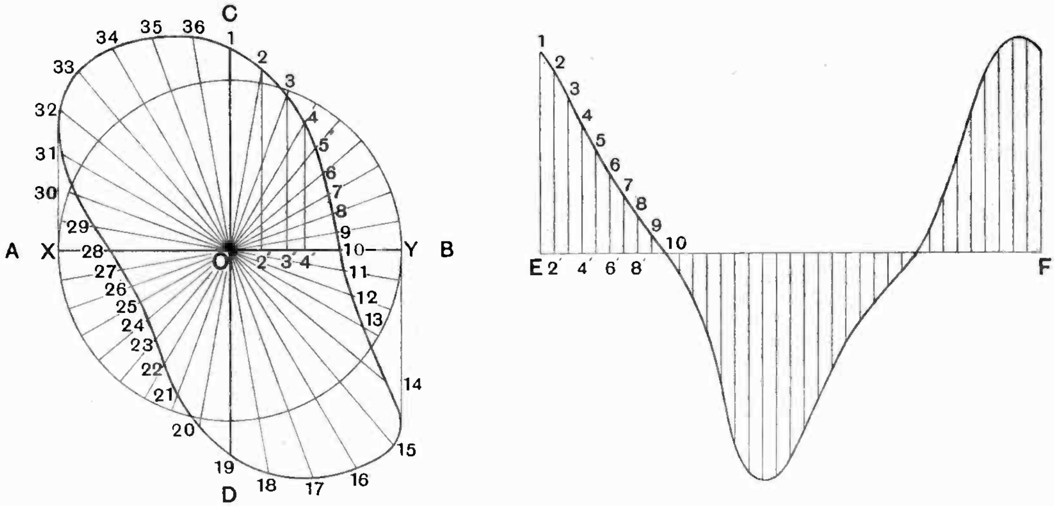


Fig. 5.

number of equal circumferential parts, say every 10 degrees. Join these points to the centre, and produce to meet the closed figure at the points 1, 2, 3, 4, etc. The magnitude of the E.M.F. applied at 10 degree intervals throughout the cycle is given by the perpendicular distance from the points 1, 2, 3, 4, etc., to the time base line $AB$. Divide a horizontal line $EF$ into 36 equal parts $E1'$, $1'2'$, $2'3'$, etc., each part representing an angle of 10 degrees. Erect vertically the distances $O1$, $22''$, $33''$, etc., from the points $E$, $1'$, $2'$, $3'$, etc. The locus of the extremities gives the applied wave plotted on a linear time base.

This wave has now to be analysed into its component harmonics. By Fourier's analysis, we know that any periodic function can be split up into a number of sine and cosine terms involving the fundamental frequency, and frequencies of twice, three times, four times this frequency, etc., and if sufficient terms be adopted the wave can be approximated to any required degree of accuracy. Thus the wave can be resolved into the following terms:—

$$y = f(\omega t) = A_0 + A_1 \sin \omega t + B_1 \cos \omega t + A_2 \sin 2\omega t + B_2 \cos 2\omega t + A_3 \sin 3\omega t + B_3 \cos 3\omega t + \ldots$$

where $\omega = 2\pi f$,

and $f$ = frequency.

The terms $(A_1 \sin \omega t + B_1 \cos \omega t)$ form the fundamental of the periodic function. This name is given to them because their period is the same as that of the original function $(y)$.

The terms $(A_2 \sin 2\omega t + B_2 \cos 2\omega t)$ form the second harmonic, the fundamental being

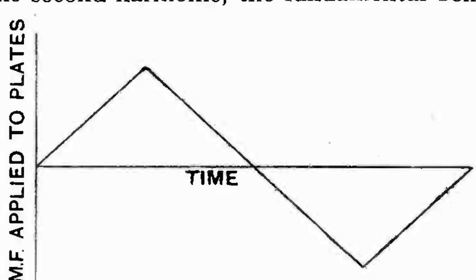


Fig. 6.

the first harmonic. Similarly $(A_3 \sin 3\omega t + B_3 \cos 3\omega t)$ is the third harmonic. The two terms of any harmonic can be combined into a single term, since

$$[A_n \sin n\, \omega t + B_n \cos n\, wt] = C_n \sin (n\, \omega t + \phi_n)$$

where $C_n = \sqrt{A_n^2 + B_n^2}$

$$\sin \phi_n = \frac{A_n}{C_n} \text{ and } \cos \phi_n = \frac{B_n}{C_n}$$

This condition is both necessary and sufficient to evaluate the angle $\phi_n$. The value of $A_0$ can be found by integrating the function $(y)$ over a complete period and dividing by the period, since the integral of a sine and a cosine term over any number of complete periods is zero.

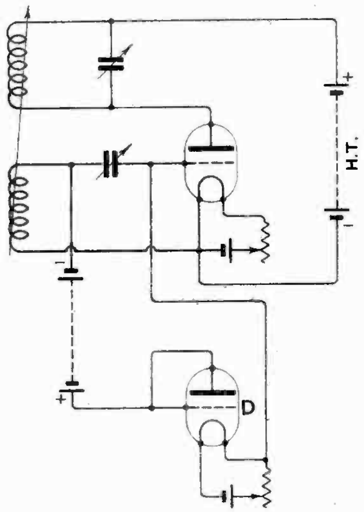


Fig. 7.

Thus to find the value of any other term, use is made of the following definite integrals

(a) $\int_0^T (\sin n\ \omega t \sin m\ \omega t)\, dt = 0$

where $T = \frac{2\pi}{\omega}$ = periodic time.

(b) $\int_0^T (\cos n\ \omega t \sin m\ \omega t)\, dt = 0.$

(c) $\int_0^T \sin^2 m\ \omega t\ dt = \frac{T}{2}$

(d) $\int_0^T \cos^2 m\ \omega t\ dt = \frac{T}{2}$

(e) $\int_0^T (\sin m\ \omega t \cos m\ \omega t)\, dt = 0.$

If every term of a Fourier's series is multiplied by $\sin m\ \omega t$ and integrated over a complete period, the result is therefore zero, except in the case of the term $A_m \sin m\ \omega t$ which gives $TA_m/2$.

Hence $A_m = \frac{2}{T}\int_0^T y \sin m\ \omega t\ dt.$

Similarly, by multiplying each term by $\cos m\ \omega t$ and integrating, it is found that

$$B_m = \frac{2}{T}\int_0^T y \cos m\ \omega t\ dt.$$

The area of the original wave about the zero axis is determined and divided by the length of the base line for one complete period. This gives the constant term $A_0$. The wave is now multiplied by $\sin \omega t$ for each 10° degrees and the area of the new curve

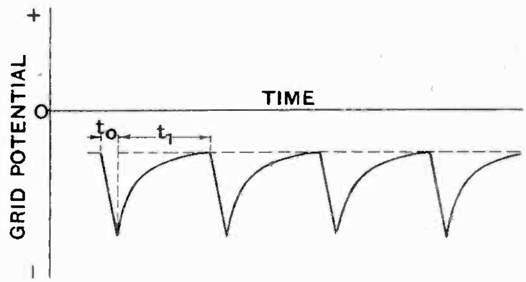


Fig. 8.

so produced is determined and divided by $T/2$ giving $A_1$. If the cosine curve is drawn, $B_1$ is determined.

In this way, by multiplying by $\sin 2\omega t$, $\cos 2\omega t$, $\sin 3\omega t$, $\cos 3\omega t$, etc., the values of $A_2$, $B_2$, $A_3$, $B_3$, etc., are obtained, and the resultant peak values of the harmonics $C_1$, $C_2$, $C_3$, etc., are given by

$$\sqrt{A_1^2 + B_1^2}\quad \sqrt{A_2^2 + B_2^2}\quad \sqrt{A_3^2 + B_3^2}, \text{etc.}$$

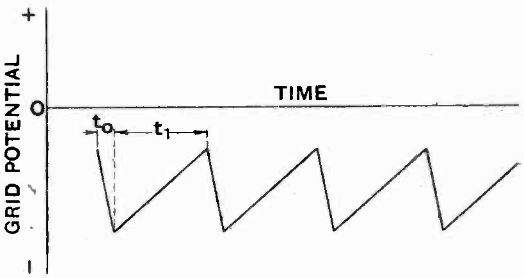


Fig. 9.

The phases are obtained as shown previously and thus the complete wave has been analysed into its constituent parts. The various ordinate methods for analysing waves employed in general electrical problems cannot be used, since these methods assume the two halves of the wave to be identical and thus neglect the even harmonics.

### The Time Base.

The chief difficulty of the method for practical analysis lies in the fact that the general type of wave cannot easily be appreciated until the Lissajous figure has been converted into a linear base wave. If we can produce the wave on a linear base scale directly by the oscillograph, the general types of distortion can be observed, and analysis need only be applied to the special cases of interest.

devised a purely electrical method of producing a uniform periodic motion of the electron stream. A condenser discharge is normally exponential in character if the leak through which the discharge takes place is constant in value. If however the leak resistance is proportional to the E.M.F. existing across it, the discharge is linear, and if the time deflecting plates are connected across the condenser, the beam will be deflected proportional to time. A saturated diode fulfils the necessary conditions, as its current will be constant with varying E.M.Fs. above the saturation value. In

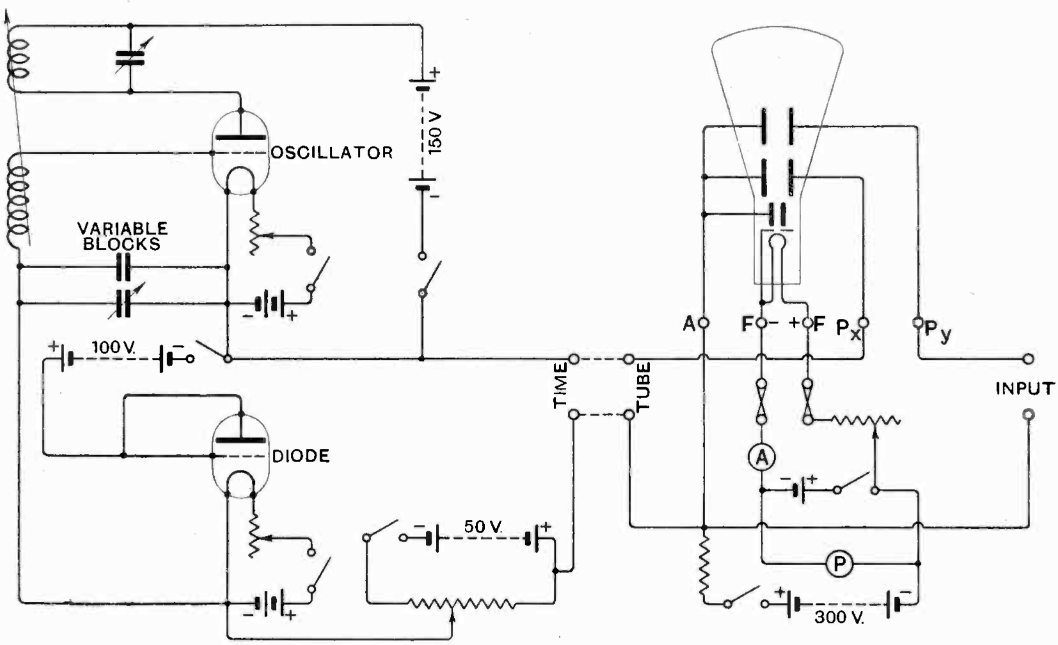


Fig. 10.

Various mechanical, optical and electrical devices have been suggested for this purpose, but with a low velocity electron stream as obtained from the Johnson tube, mechanically moved plates and rotating drum methods cannot be applied as the beam has not sufficient actinic value to produce an image with one passage across the plate. We must resort to a time scale consisting of a linear motion and return of the electron stream synchronised with the applied input so that the image is cyclographic. Rogowski* has

* W. Rogowski, *Archiv. für Elecktrotechnik*, 1920, Vol. 9, p. 115.

one method suggested by Rogowski, two opposed diodes were used and the condenser was alternately charged and discharged with constant current from an alternating source giving a triangular wave form as shown in Fig. 6.

A considerable improvement has been produced by E. V. Appleton, R. A. Watson Watt and J. F. Herd,* in which an oscillating triode is used as the generator of the alternating P.D. Referring to Fig. 7 we see that an oscillating system is used with a grid condenser and leak. The leak consists of

* British Patent No. 235,254, 11th Feb., 1924

a saturated diode *D* and the output deflecting voltage is taken from the grid condenser terminals. If the leak were constant in value we should have grid potential variations in terms of time as shown in Fig. 8.

teristic as shown during the time $t_1$. When the potential is sufficiently restored due to this leaking action, the oscillation again starts and we shall obtain a recurrence of the phenomena.

Now using a saturated diode for the leak,

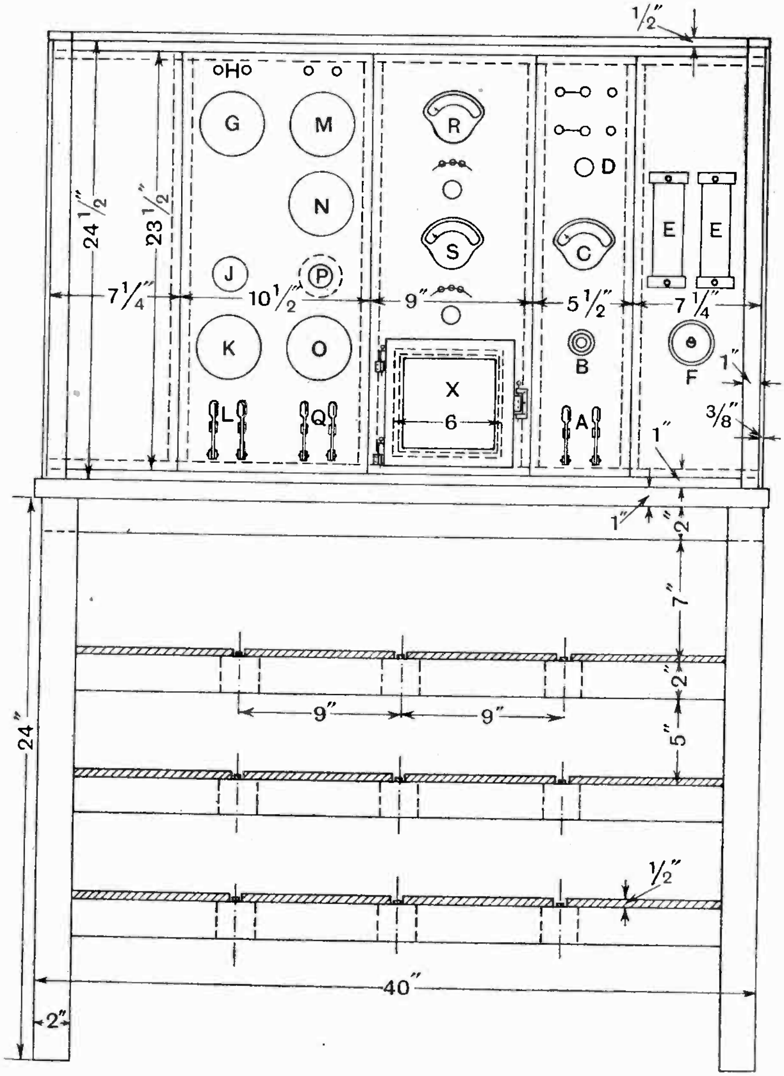


Fig. 11.

As the oscillations continue, the condenser becomes charged and the grid is rapidly depressed in voltage during the period $t_0$.

The grid is now so negative that the oscillation stops and the condenser discharges exponentially giving a grid voltage charac-

the discharge is linear (since the resistance is proportional to the E.M.F. applied) and we get the characteristic depicted in Fig. 9. The frequency of this discharge can be altered by means of the grid condenser, which is variable and the leak resistance which can be controlled by the filament rheostat of the diode, and if this frequency is a sub-multiple of the incoming wave applied to the other pair of plates, a recurrence of the time scale will duplicate the oscillogram and give a cyclographic record of as many waves as we please. Usually it is preferable to

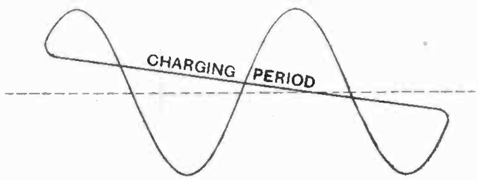


Fig. 12.

arrange that the time scale frequency is synchronised to one-half that of the incoming wave, thus giving two complete waves on the oscillograph screen. The period of charging the grid condenser will depend upon the main oscillator frequency and if this is high, the time of charging is about one-tenth of the time for leakage, *i.e.*, in Fig. 9$t_1/t_0 \doteqdot 10$.

The necessary condition is that the insulation of the grid condenser be very good. If a small constant shunt leak exists, the time scale cannot be made linear. The method has been adopted for the recording of wave forms of frequencies ranging from 30 p.p.s. to 1,000,000 p.p.s., and it is felt that a description of the apparatus may be of value to others engaged in similar types of work. The complete circuit diagram is shown in Fig. 10. The two deflecting plates are $A$ & $P_X$ and $A$ & $P_Y$. $A$ & $P_Y$ are connected to the input terminals and $A$ & $P_X$ to the tube terminals. These are connected by links to the timing mechanism. Switches are provided in the low and high tension circuits, and an ammeter in the filament circuit of the oscillograph. To give a static bias to the time scale plates to compensate for the normal negative potential existing across the grid of the oscillating triode, a potentiometer is connected in series with these leads.

The voltages of the three high tension batteries can be read by means of a voltmeter and the low tension batteries can also be tested in a similar manner.

The frequency of the time base is regulated by a fine drum type rheostat in the filament of the diode, and by block condensers and a vernier condenser acting as the grid condenser. The frequency of the oscillator is about $10^6$p.p.s., the high tension battery voltage being 150 using a T15 valve. The diode consists of a dull emitter valve with the grid connected to the anode and 100 volts high tension. The oscillograph filament takes 1 ampere at 2 volts and the anode is applied with 350 volts.

### The Complete Equipment.

The controlling apparatus is panel mounted, as shown in Fig. 11, which gives a detailed drawing of the complete assembly. The oscillograph tube is mounted in a wooden

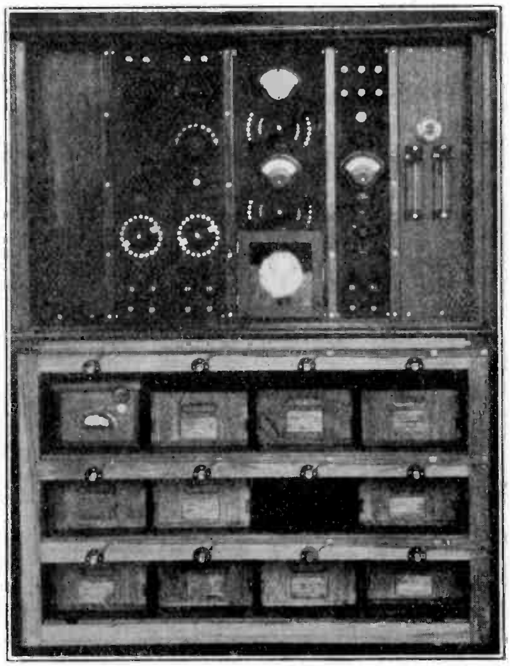

Fig. 13.

case with a window for protection as shown at $X$. The right hand panel controls the oscillograph and has a main switch $A$, rheostat $B$, ammeter $C$, and pilot lamp $D$. The static balancing potentiometer is shown at $E$ with switch $F$. The oscillator control is mounted on the left side of the left panel and consists of a variable condenser $G$ with terminals $H$ for extra capacity, a coupling control *J*, a coarse filament rheostat *K* and switch *L*. The diode controls are on the right hand side of this panel and consist of a variable condenser *M*, small fixed condensers *N*, a coarse filament rheostat *O*, a fine rheostat *P*, and a main switch *Q*. The high tension and low tension voltages are tested by means of the voltmeters and switches *R* and *S* respectively. Normally the terminals "*Time*" and "*Tube*" are connected together and the wave to be analysed is applied to the terminals marked "*Input*."

The voltage sensitivity of the oscillograph is about 1 mm. deflection per volt. The input required to give a figure 2 cms. high is therefore 20 volts and a figure of this size can be analysed with fair accuracy. The image is photographed and the negative is enlarged to about 2 feet square and traced. This figure can then be analysed harmonically. Fig. 12 gives a sketch of the image obtained with a sinusoidal input and shows the short return during the charging period of the leaky condenser.

The high tension supply consists of three separate insulated batteries of 350, 150 and 100 volts respectively. These are built of 50-volt accumulator units and each battery stands on glass. To charge these batteries without removal from their stand, a special switch is used mounted on the side of the battery stand. This switch isolates the three banks in the working position and puts all the batteries in parallel in the "*Charge*" position to be connected to 100-volt mains.

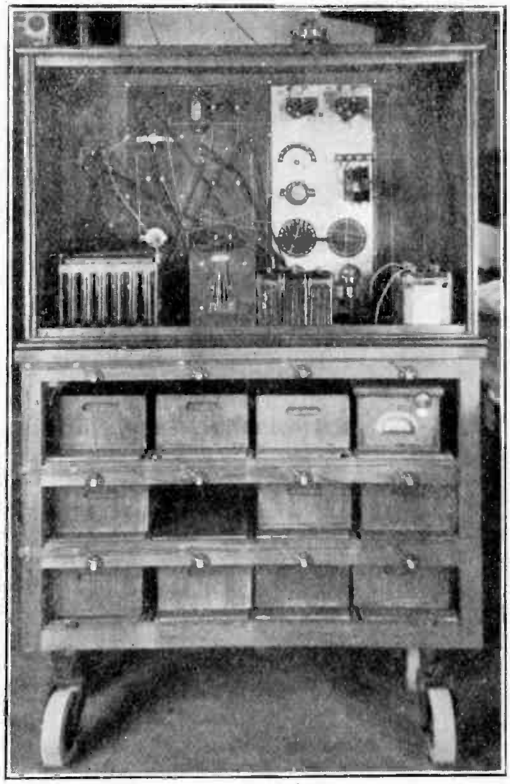

Fig. 14.

A photograph of the complete apparatus is shown in Fig. 13 and a view of the back of the panel in Fig. 14.

# Mathematics for Wireless Amateurs.

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

(*Continued from page* 762 *of December issue.*)

## 6. The Solution of Equations.

### (c) *Simultaneous Equations for Several Unknown Numbers.*

IT has already been indicated that if several unknown numbers have to be determined an equal number of separate and independent equations will be required. A perfectly general discussion of *m* equations of the nth degree would take the writer out of his depths and bore the reader intolerably, besides wasting his time. The solution of several first degree equations for an equal number of unknowns is, however, quite another matter, for it is comparatively simple and of great practical importance in applied electricity. As already mentioned, such equations arise from the application of Kirchhoff's Laws to direct or alternating current networks, and are therefore of particular interest to wireless amateurs.

To save time, space, and trouble the representative example of three equations for three unknowns will be considered. It will be found that the method is the same as that which has been applied to the solution of two equations for two unknowns. The method is, in fact, capable of indefinite extension. Take as the equations

$$x+2y+3z=4 \quad \ldots \quad (1)$$
$$2x+3y+4z=5 \quad \ldots \quad (2)$$
$$3x+6y+7z=6 \quad \ldots \quad (3)$$

Multiply (1) by 4 and (2) by 3 in order to make the coefficients of $z$ the same in each.

$$4x+8y+12z=16 \quad \ldots \quad (4)$$
$$6x+9y+12z=15 \quad \ldots \quad (5)$$

and by subtracting (4) from (5),

$$2x+y=-1 \quad \ldots \quad (6)$$

Another equation in $x$ and $y$ can be obtained from equations (2) and (3) in a similar manner, or from (1) and (3) if this is preferred for any reason. Multiplying (2) by 7 and (3) by 4,

$$14x+21y+28z=35 \quad \ldots \quad (7)$$
$$12x+24y+28z=24 \quad \ldots \quad (8)$$

and subtracting (8) from (7)

$$2x-3y=11 \quad \ldots \quad (9)$$

Also from (6)

$$2x+y=-1 \quad \ldots \quad (6)$$

In this case it happens that the coefficients of $x$ are the same in these two equations. If they were not the same operation would induce them to be so. As it is we can avail ourselves of their accommodating disposition by simply subtracting (6) from (9), giving

$$-4y=12 \quad \ldots \quad (10)$$

or

$$y=-3 \quad \ldots \quad (11)$$

Substituting this value for $y$ in (6),

$$2x-3=-1 \quad \ldots \quad (12)$$

or

$$x=1 \quad \ldots \quad (13)$$

Now, putting $x=1$ and $y=-3$ in (1)

$$1-6+3z=4 \quad \ldots \quad (14)$$

Therefore

$$z=3 \quad \ldots \quad (15)$$

and, rounding them up, we have as the simultaneous solutions of the three equations

$$x=\ \ 1$$
$$y=-3$$
$$z=\ \ 3$$

It may be pointed out as a matter of interest that the cartesian diagram already considered in its simplest form with the two $x$ and $y$ axes at right angles to each other can be completed by the addition of a third or $z$ axis at right angles to both, like the adjacent edges of a cube. Three co-ordinates, $x$, $y$, and $z$ will then define a point in space, just as two co-ordinates define a point in a plane in the simpler plane diagram. Further, just as

$$ax+by=c$$

defines a line in the $x$, $y$ plane, so

$$ax+by+cz=d$$

defines a plane in space. The solution obtained above for the three plane equations gives the co-ordinates of a point common to the three planes, *i.e.*, the point of intersection of the three planes If we could comprehend a fourth dimension the first degree equation in four unknowns could be similarly interpreted, but unfortunately (or perhaps fortunately) the mind budges like a mule at the prospect and refuses to carry us further, so there we have to leave the geometrical aspect of the matter.

That, however, would not prevent us from solving four such equations for four unknowns. From any two, one of the unknowns can be eliminated. From three different pairs the same unknown can be eliminated three times, giving three equations for three unknowns, which can be solved as above. And so on for any given number of unknowns.

To show how such equations can arise from the application of Kirchhoff's Laws to a network, let us write down the equations for the system shown in Fig. 14, which the reader will recognise as a Wheatstone bridge. The equations are

$$e - Bi_1 - R(i_1 - i_2) - S(i_1 - i_3) = 0$$
$$R(i_2 - i_1) + Pi_2 + G(i_2 - i_3) = 0$$
$$G(i_3 - i_2) + Qi_3 + S(i_3 - i_1) = 0$$

which can be re-arranged rather more tidily as

$$(B+R+S)i_1 \quad -Ri_2 \quad -Si_3 = e$$
$$-Ri_1 + (R+P+G)i_2 - Gi_3 = 0$$
$$-Si_1 \quad -Gi_2 + (G+Q+S)i_3 = 0$$

The reader is strongly advised to solve these equations for the three currents $i_1$, $i_2$, $i_3$, but is warned to secure largish sheets of paper for the purpose, owing to the unrestrained prolixity of literal expressions. In the present instance particular interest attaches to the current through the branch of resistance $G$, which represents the resistance of a galvanometer or similar measuring instrument. The reader should be able to show that this current, *i.e.*, $i_2 - i_3$, is given by

$$i_2 - i_3 = (RQ - SP)e/K$$

where $K$ is the simple but voluminous expression

$$K = BGP + BGQ + BGR + BGS + PQR + PQS + PRS + QRS + GPR + GQS + GPS + GQR + BPQ + BRS + BSP + BRQ.$$

This shows that the current through $G$ will be zero when

$$RQ - SP = 0$$

*i.e.*, when $\left(\dfrac{P}{Q} = \dfrac{R}{S}\right)$

which is the well-known balance condition for the simple resistance bridge.

Later on it will be found that even the most complicated networks carrying alternating currents can be similarly analysed, though for this purpose several additional ideas will be required, some of which will be introduced in the next section.

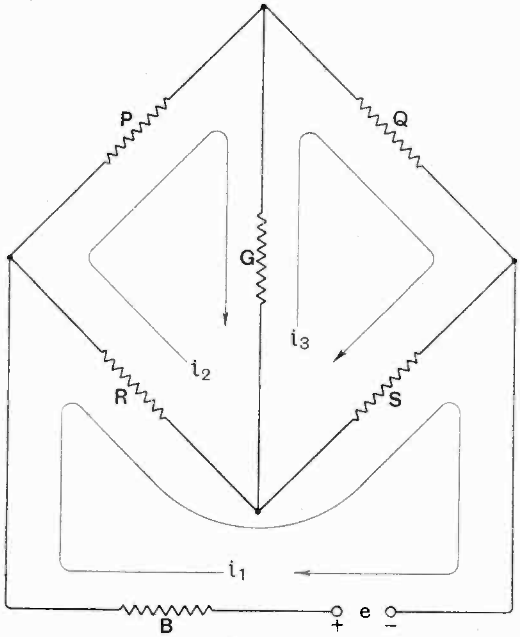


Fig. 14.

## 7. Complex Numbers.

### (A) *The Symbol "i"*

The reader has already a bowing acquaintance with $\sqrt{-1}$, and has possibly decided that this somewhat perplexing symbol, being devoid of that comfortable and concrete reality that attaches to real numbers, is not likely to count for much in practical politics. Associated with this symbol, however, are certain ideas which will eventually prove to be of very great value in connection with alternating current problems, so time will not be ill-spent in cultivating a somewhat closer acquaintance. It is, moreover, an intrinsically interesting symbol, and, under the pet name of "i" enjoyed what Prof. Whitehead described as a *succès de scandale* when it first made its appearance in mathematics.

At present all we know about it is the definition

$$\sqrt{-1} \times \sqrt{-1} = i \times i = i^2 = -1$$

and it is worth noting that this definition assumes the possibility of associating the symbol $i$ with the idea of multiplication, so that $ai \times bi$ for instance, can be taken to mean

$$a \times i \times b \times i = a \times b \times i \times i = abi^2 = -ab$$

This is an instance of that possibility envisaged in para. C3 of Section 3 (June, 1926), where ideas in themselves incomprehensible can be employed without violating one's intellectual self-respect, it being understood that any such incomprehensible operations stand not on their own merits but on the validity of the conclusions they lead to.

(B) *Addition of Complex Numbers.*

A group, such as $a+bi$ (or $a+ib$—it does not matter which way it is written), is called a complex number. Such numbers have been met with in the solution of quadratic equations in the preceding section. Such complex numbers can be compared with the "double groups" referred to in para. A2 of Section 3 (May, 1926), and in the addition of such complex numbers the same ideas will apply. That is to say, in $a+ib+c+id$, the numbers $a$ and $c$ can be added arithmetically, and the $b$ $i$'s can be added to the $d$ $i$'s, giving $(b+d)i$'s, so that

$$a+ib+c+id=(a+c)+i(b+d)$$

for instance

$$3+i4+7+i8=10+i12$$

and, of course, similarly for subtraction. In particular

$$(a+ib)+(a-ib)=2a$$
$$(a+ib)-(a-ib)=2ib$$

The first of these statements involves the idea that $i(b-b)$, *i.e.*, $i \times 0$ is 0, which is seen to be quite reasonable if $i \times 0$ is regarded as $\sqrt{-0}$, for $-0$ is by definition the same as $+0$.

(C) *Consider the statement*—

$$a+ib=0$$

where $a$ and $b$ are real numbers. Subtracting $ib$ from each side gives

$$a=-ib$$

But this is a contradiction in terms, for $a$ is a number and $ib$ is not. To make this clearer, squaring each side would give

$$a^2=(-ib)^2=(ib)^2=i^2 \times b^2=-1 \times b^2=-b^2$$

which is impossible since both $a^2$ and $b^2$ are necessarily positive numbers, whatever the signs of $a$ and $b$ may be. However the statement $a=-ib$ is not completely impossible, because it is true if both $a$ and $b$ are zero, *but only in this case.* The statement

$$a+ib=0$$

therefore implies $a=0$ and $b=0$

Further, if we are given that

$$x+iy=a+ib$$

subtracting $a+ib$ from each complex number will give

$$(x-a)+i(y-b)=0$$

so that $(x-a)=0$ and $(y-b)=0$

or $x=a$ and $y=b$

The original equation is therefore really equivalent to two separate equations. This process is referred to as equating the real and the imaginary parts.

(D) *The Multiplication of Complex Numbers.*

On the above understanding (para. A) with respect to the association of $i$ with the idea of multiplication, the multiplication of complex numbers follows the ordinary rules, *i.e.*,

$$\begin{aligned}(a+ib)(c+id) &= ac+ibc+aid+ibid \\ &= ac+ibc+iad+iibd \\ &= (ac-bd)+i(bc+ad)\end{aligned}$$

In particular

$$(a+ib)(a-ib)=a^2+b^2$$

Two complex numbers such as these, differing only in the sign of the imaginary part, are said to be mutually conjugate. Notice that the sum and the product of conjugates are wholly real. Notice further that in general the sums or products of complex numbers are other complex numbers, so that if $f(x)$ be any built-up number composed of various integral powers of $x$ associated with constant coefficients (*cf.* the general equation of the nth degree), then if $x$ be given a complex value $(a+ib)$, $f(a+ib)$ will be a complex number, *i.e.*,

$$f(a+ib)=P+iQ$$

just as $f(x)$ is a real number if $x$ is given any real value.

(E) *The Modulus of Complex Numbers.*

The modulus of $(a+ib)$ is the positive value of the square root of $(a^2+b^2)$, *i.e.*,

$$mod.(a+ib)=\sqrt{a^2+b^2}$$

For instance, the modulus of $(12+i5)$ is $\sqrt{12^2+5^2}$, *i.e.*, 13. Notice that the modulus of a complex number is the same as that of its conjugate.

A very useful property of moduli is that the modulus of the product of two complex numbers is the same as the product of their moduli. This is easily proved, for

$$mod.(a+ib)(c+id)=mod.(ac-bd)+i(bc+ad)$$
$$=\sqrt{(ac-bd)^2+(bc+ad)^2}$$
$$=\sqrt{a^2c^2+b^2d^2+b^2c^2+a^2d^2}$$
$$=\sqrt{(a^2+b^2)(c^2+d^2)}$$
$$=\sqrt{(a^2+b^2)}\sqrt{(c^2+d^2)}$$
$$=mod.(a+ib)\times mod.(c+id)$$

This can obviously be extended to the product of any number of complex numbers and thence to integral powers of complex numbers, so that

$$mod.(a+ib)^n=\{mod.(a+ib)\}^n=$$
$$\{\sqrt{a^2+b^2}\}^n=(a^2+b^2)^{n/2}$$

Further, this can be shown to be true for negative or fractional values of $n$,

*e.g.*, let $\qquad (a+ib)^{\frac{1}{m}}=P+iQ$

Then, from the definition of the fractional index

$$(a+ib)=(P+iQ)^m$$
$$mod.(a+ib)=mod.(P+iQ)^m=$$
$$\{mod.(P+iQ)\}^m=\{\sqrt{P^2+Q^2}\}^m$$

Therefore $\qquad \sqrt{a^2+b^2}=\{\sqrt{P^2+Q^2}\}^m$

whence $\qquad \{\sqrt{a^2+b^2}\}^{\frac{1}{m}}=\sqrt{P^2+Q^2}$

or $\qquad \{mod.(a+ib)\}^{\frac{1}{m}}=mod.(a+ib)^{\frac{1}{m}}$

and similarly for the general fractional index and for negative indices. The modulus of a more or less complicated complex number can thus be written down at sight. For instance,

$$mod.\frac{(a+ib)^m(c-id)^{p/q}}{(e+if)^r}=\frac{\sqrt{\{a^2+b^2\}^m\{\sqrt{c^2+d^2}\}^{p/q}}}{\{\sqrt{e^2+f^2}\}^r}$$

Is the modulus of the sum of two complex numbers the same as the sum of their moduli? It isn't, but the reader is advised to prove this for himself.

### (F) *Application to the General Equation of the nth Degree.*

Complex numbers were first encountered in connection with the solution of quadratic equations, and it was indicated that they would also occur in the solution of the general equation of the nth degree. It was further stated that complex roots would always occur in pairs (of conjugates). This can now be proved quite simply. First it is required to show that if

$$(a+ib)^n=P+iQ$$

then $\qquad (a-ib)^n=P-iQ$

If $\qquad (a+ib)^n=P+iQ$

$$\frac{1}{(a+ib)^n}=\frac{1}{P+iQ}$$

therefore $\qquad \dfrac{(a-ib)^n}{(a+ib)^n(a-ib)^n}=\dfrac{(P-iQ)}{(P+iQ)(P-iQ)}$

*i.e.*, $\qquad \dfrac{(a+ib)^n}{\{(a+ib)(a-ib)\}^n}=\dfrac{(P-iQ)}{P^2+Q^2}$

or $\qquad \dfrac{(a-ib)^n}{(a^2+b^2)^n}=\dfrac{P-iQ}{P^2+Q^2}$

But since

$$(a+ib)^n=P+iQ,\ (\sqrt{a^2+b^2})^n=\sqrt{P^2+Q^2},$$

as shown above, so that

$$(a^2+b^2)^n=P^2+Q^2$$

Therefore $\qquad (a-ib)^n=P-iQ$

Consider now the general equation of the nth degree, *i.e.*,

$$f(x)=ax^n+bx^{n-1}+cx^{n-2}+dx^{n-3}+\text{etc.}\ldots k=0$$

For any complex value $(\alpha+i\beta)$ of $x$ each separate power of $x$ will give rise to a complex number of the form $P+iQ$, and the sum of all these will be some complex number, say, $M+jN$. It obviously follows from the above that for the conjugate value $(\alpha-i\beta)$ for $x$, the sum of all the separate terms will be $M-jN$, *i.e.*, if

$$f(\alpha+i\beta)=M+jN$$
$$f(\alpha-i\beta)=M-jN$$

Now suppose that $(a+i\beta)$ is known to be a root of the equation, so that

$$f(\alpha+i\beta)=M+jN=0$$

Then, from para. C of this section,

$$M=0 \text{ and } N=0$$

so that $\qquad f(\alpha-i\beta)=M-jN=0$

Therefore $(\alpha-i\beta)$ must also be a root of the equation.

### (G) *The Square Root of a Complex Number.*

If $x+iy$ be the square root of $a+ib$, then, by definition,

$$(x+iy)^2=a+ib.$$

For many purposes it will be necessary to know $x$ and $y$ in terms of $a$ and $b$, *i.e.*, to find the real and imaginary parts of $(a+ib)^{\frac{1}{2}}$. It can be done in this way. Multiplying $x+iy$ by itself as shown in para. D.

$$(x+iy)^2=(x+iy)(x+iy)=$$
$$x^2-y^2+2ixy=a+ib$$

therefore, as shown in para. C,

$$x^2-y^2=a$$

and $$2xy=b$$

These two equations can be solved for $x$ and $y$ by methods already described. In this particular case, however, the work can be shortened by making use of the fact that the square of the modulus of $x+iy$ will be equal to the modulus of $a+ib$ (see para. E), so that

$$x^2+y^2=+\sqrt{a^2+b^2}.$$

For shortness, and also to avoid typographical complication later on, we will write $r$ for $+\sqrt{a^2+b^2}$, so that we have the two equations

$$x^2+y^2=r$$
$$x^2-y^2=a$$

whence, by addition and subtraction,

$$x^2=\tfrac{1}{2}(r+a)$$
$$y^2=\tfrac{1}{2}(r-a)$$

*i.e.*, $$x=\pm\sqrt{\tfrac{1}{2}(r+a)}$$
$$y=\pm\sqrt{\tfrac{1}{2}(r-a)}$$

Thus $x$ and $y$ are determined. In the matter of signs we seem to have an *embarras de richesse*, but the apparent superfluity can be disposed of in this way: Since $2xy=b$, $x$ and $y$ must be of the same sign if $b$ is positive and *vice versa*. Therefore if $b$ is positive

$$\sqrt{a+ib}=\pm\{\sqrt{\tfrac{1}{2}(r+a)}+i\sqrt{\tfrac{1}{2}(r-a)}\}$$

and if $b$ is negative

$$\sqrt{a+ib}=\pm\{\sqrt{\tfrac{1}{2}(r+a)}-i\sqrt{\tfrac{1}{2}(r-a)}\}$$

To take a simple example, consider $\sqrt{3+i4}$. Here $a$ is 3 and $b$ 4, so that $r$ is $+\sqrt{9+16}=5$, $r-a$ is 2 and $r+a$ is 8.

Therefore

$$\sqrt{3+i4}=\pm\{\sqrt{\tfrac{1}{2}\times 8}+i\sqrt{\tfrac{1}{2}\times 2}\}$$
$$=\pm(2+i)$$

and if the reader has any doubts about it he can square $\pm(2+i)$ to make sure.

There is a peculiar fascination about the subject of complex numbers, but this, unfortuntaely, is all the space that can be allowed for it at present. Once more the reader is cautioned against dismissing the subject as academic on the grounds that an imaginary quantity cannot have any practical significance. Though academic in appearance, these same ideas can, as it were, doff hood and gown and set about a job of real work with a pick and shovel. We shall see them at it later on.

## Examples.—Simultaneous Equations for Several Unknowns.

1. Solve the equations :—

(a) $x+y+z=12$
$x+2y+3z=26$
$3x+2y+z=22$

(b) $x+y=2z$
$5x+4y+3z=12$
$21x-20y-2z=-1$

(c) $43x+19y+10z=100$
$100x+y-3z+30=0$
$x-y+z=10$

2. Solve :—

$w+x+y=6$
$2x+3y+4z=29$
$4y+2z-3w=17$
$8z-5w+7x=41$

3. Solve the equations :—

$mx+ny+z=(1+m+n)a+(3+m+n)b$
$2x+3y-5z=-7b$
$5x+8y-7z=6a$

## Complex Numbers.

4. Show that :—

$$\frac{a+ib}{c+id}=\frac{ac+bd}{c^2+d^2}+i\,\frac{bc-ad}{c^2+d^2}$$

5. Find the moduli of :—

(a) $\dfrac{(3+i)(7-i)}{(2-i)}$

(b) $\dfrac{(3-4i)}{(3+4i)}+\dfrac{(12-5i)}{(12+5i)}$

6. Show that :—

$$\sqrt{i}=\pm(1+i)/\sqrt{2}$$
$$\sqrt{-i}=\pm(1-i)/\sqrt{2}$$

and hence show that the eight eighth roots of unity are :—

$$\pm 1,\ \pm i,\ (1\pm i)/\sqrt{2},\ \pm(1-i)/\sqrt{2}$$

## Answers to Examples in December Issue.

(1) $-2, 9, -3$.

(2) $1-2i$, $1+2i$, 4, 30.

(3) 0.

(4a) $x=1$, $y=81$.

(4b) $x=.62$, $y=.18$.

(5a) $x=3, y=2$ ; $x=2$, $y=3$.

(5b) $x=1$, $y=3$ ; $x=-1\frac{1}{5}$, $y=-3\frac{3}{5}$ ; $x=-3$, $y=3$ ; $x=2$, $y=-2$.

(5c) $x=4$, $y=3$ ; $x=-4$, $y=-3$ ; $x=\frac{7\sqrt{3}}{2}$, $y=-\frac{5\sqrt{3}}{6}$ ; $x=-\frac{7\sqrt{3}}{2}$ ; $y=\frac{5\sqrt{3}}{6}$.

# Quartz Crystals and their Practical Application to Wireless Circuits.

A Paper read before the Radio Society of Great Britain, on 24th November, 1926, by A. HINDERLICH, M.A.

The phenomena of the piezo-electric quartz are considered with special reference to radio transmitting stations. The technique of accurate grinding is described. Several control circuits for low and high power transmitters are given.

## I.—Historical.

IN 1880, P. and J. Curie* discovered that a plate of cut quartz, when stretched, acquired a charge upon the surfaces.

In 1922, Cady† published his paper on "The Piezo-Electric Resonator," which contained sufficient practical information about oscillators to stimulate amateur research.

Since the end of 1925, most issues of *Q.S.T.* have contained some reference to quartz control as applied in amateur practice in America.

In 1926, Goyder‡ published the first account of a complete station suited to English practice, and Dye§ gave his classical paper on the theory of the resonator.

## II.—Properties of Quartz.

Although a use may be found for almost any piece of quartz whose faces are approximately flat and parallel, it is most essential, in order that consistent results may be secured, for great attention to be paid to certain practical rules.

In Fig. 1 the outline represents a section across a natural quartz crystal at right angles to the optic axis. The dotted lines are representative axes. Any line at right angles to the sides, or parallel to the sides, is an axis.

A rectangular plate cut as shown at *A* will have three dimensions, one parallel to the sides, one at right angles to the sides, and one parallel to the optic axis. (If the cut be oblique, or if the crystal be an optical twin, all manner of components will be involved.) Oscillations may take place, according to Hund,* along all these axes, at three different fundamentals. A rough approximation is :—

$$\lambda \text{ (metres)} = \begin{Bmatrix}\text{Dimension in} \\ \text{millimetres}\end{Bmatrix} \times 105 \text{ or } 150$$

Hund has determined the three fundamentals and their corresponding harmonics for a set of similar resonators. When used as oscillators, I find, as a general rule, that it is exceedingly difficult to obtain more than one fundamental (accompanied of course by its harmonics) out of a given specimen of quartz.

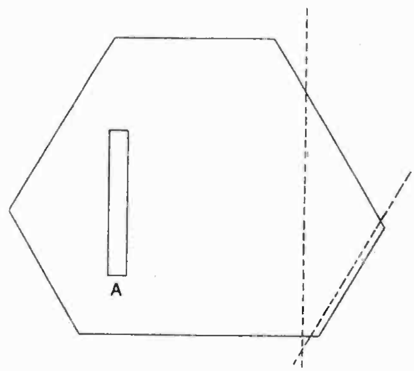


Fig. 1.

Whilst oscillating, the quartz plates expand and contract by a few millionths of an inch. It is a common experience for an oscillator to give a reduced output after a while, which

* *Comptes Rendus*, 91, pp. 294, 383.

† *Proc. Inst. Radio Engineers*, New York, April, 1922.

‡ *E.W. & W.E.*, February and March, 1926.

§ *Proc. Physical Society of London*, August, 1926.

* *Proc. Inst. Radio Engineers*, New York, August, 1926.

can be cured by tapping the holder, and so shifting the contact to a different position. That is the practical remedy—the theoretical one would be to avoid friction by making contact at an antinode. This can be effected in two ways. The first is to balance the quartz on edge between vertical electrodes, so that the motion of the quartz is chiefly vertical. The second is to have the electrodes horizontal, but only in contact at an antinode. While very difficult in theory, the desired result may be readily secured by exploration with electrodes that are not quite flat, but provided with a slight projection in the middle. The best position is found while watching the output. Another remedy is the cork tripod as used by Dye.

According to Clayton,* the 150-metre per millimetre cut of quartz shows the maximum piezo-electric effect, with slight temperature co-efficient, while the 105-cut yields crystals with slightly lower piezo-electric effects, but with zero temperature co-efficients.

Grinding may easily be performed in the following manner. Upon a sheet of clean, flat glass is placed some thin paste of abrasive and water. The finger-tips are placed upon the quartz firmly, so as not to scratch the upper surface with loose abrasive. Either of the sequences shown in Fig. 2 may be followed to give an equal amount of grinding to each part of the quartz. The diagram shows the plate as stationary, but in practice a right-handed man would rotate the quartz clockwise through 45 deg. after applying the finger-tips.

The quartz should be moved all over 30 square inches of glass surface or more, with a gentle pressure to allow a supply of abrasive to come underneath, alternating with heavy pressure to perform the actual grinding. With crystals of over 90 metres, pressures over 8 ounces are quite permissible.

With each grade of abrasive, the work should finish in time to allow of at least one minute's work with the succeeding grades.

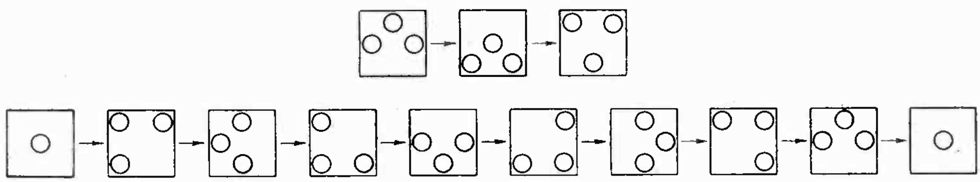

Fig. 2.

**III.—Manipulation.**

The cutting of quartz plates out of the rough has been described by Cady, Goyder and others. It is a most laborious task, not to be lightly undertaken without the full mechanical and optical equipment.

By improving the polish of the surfaces, an improvement in oscillating properties may be expected. As the user will often wish to effect a small reduction in the wavelength of his specimen, the process will now be described in some detail.

The most useful abrasives, together with the rate of reduction of wavelength using safe pressure, are listed below :—

Carborundum F .. 2 metres per minute
Carborundum 3F .. 1 metre per minute
Sira (putty) powder ½ metre per minute
Rouge, jeweller's.
Rouge, precipitated.

* *T. & R. Bulletin*, September, 1926.

It will not be possible to use rouge upon glass. To obtain a brilliant polish, the quartz is stuck upon a firm support (such as a sheet of flat glass) with wax, and then the rouge is applied upon a cork or leather pad. This method may also be used for grinding, as there is little or no danger of fracture, but there is a greatly increased chance of grinding the plate wedge shape.

Although a quartz plate *may* function quite well though the thickness vary as much as 25 per cent., it will probably work better if the thickness be the same all over (both faces plane and parallel). One often finds that after removing a high spot by local grinding the wavelength is scarcely affected, but it also happens that what was intended to be a slight reduction proves to be a serious one. This experience is quite common with crystals below 60 metres, as they are sufficiently flexible to allow of half a thousandth of an inch being taken off wherever required by simple local pressure with a finger-tip.

On testing out the crystal with a small top electrode, two spots may be found, well separated, each giving a large output but slightly different wavelengths owing to local variations in thickness. Such specimens are best divided so as to give one good spot in each piece. The method is to back the

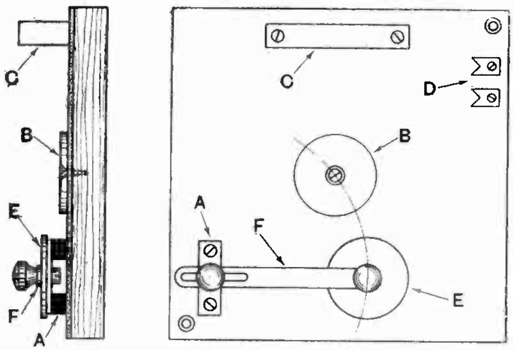


Fig. 3.

quartz with glass and wax, score deeply along the desired line with a glazier's diamond, stick each portion on to a separate piece of glass, and then snap along the scored line.

## IV.—Mountings.

An experimental mounting is best constructed according to Fig. 3. A dry wood block, at least 5 in. square, is screwed to the bench. Upon it is placed a piece of felt or velvet of similar size. Then the components sketched are screwed to the wood through the cloth: A is an insulated knob and screw, held away from the cloth by an insulating block; B is the bottom electrode (which for rectangular quartz is preferably of rather smaller diameter than the diagonal) provided with a connecting lead soldered to the underside. It is best attached by a woodscrew, taking great care that neither screw nor burrs project; C is a simple distance-piece that may be wanted later to apply pressure; E is the top electrode complete with screw. Several of these of different sizes and weights should be provided. Another insulated knob fixes the top electrode to F which is a strip of thin copper foil, reinforced at the ends and provided with a round hole to take E and a slot to fit A and so enable the top electrode to be held in any position relative to the quartz; D are two corner pieces to hold the quartz in the correct position, and cannot be fixed till later.

Such a mounting will often serve for continuous use when provided with a stout lid. A permanent mounting can only be designed when the idiosyncrasies of the particular quartz specimen have been determined.

## V.—Quartz Resonators.

Such an exhaustive account of this subject has already appeared in Dye's classical paper before the Physical Society of London, that only a bare outline of the method will be given here. The fundamental circuit is that shown in Fig. 4.

Current from a variable source flows in the coil $L$ which is coupled to the tuned circuit $L_1C_1$, with which is associated the mounted quartz and a current measuring device.

On taking the resonance curve (*i.e.*, frequency plotted against current), a steep crevasse appears at the quartz response frequency. From the shape of the crevasse, Dye deduces the damping of the quartz, and the exact response frequency to an accuracy of one part in ten million.

A less sensitive but more robust method developed in Germany utilises the rise in voltage across the quartz at resonance to produce a luminous glow in rarefied neon gas.

For everyday measurements, the circuit can be used as a simple absorption wavemeter by dispensing with the condenser and the current measuring device. It is often sufficient, as was pointed out by Goyder, merely to lay the unmounted quartz on one of the coils of an oscillating receiver to get the characteristic ringing clicks whenever the receiver frequency passes through a quartz harmonic.

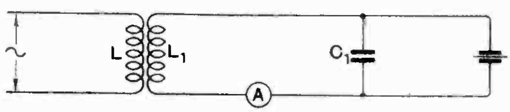


Fig. 4.

It should be noted that resonators only give the average frequency variation over a considerable period of time (say $\frac{1}{16}$ second). They would not even indicate the commonest source of trouble with transmitters (frequency modulation of plate supply) for which quartz, properly applied, is a certain cure.

## VI.—Quartz Oscillators.

Quartz, when made to control the frequency of transmitting stations, will revolutionise the technique of radio engineering on account of the vastly increased steadiness of the emitted wave thereby afforded. This is only possible on account of the fact that the vibrations are purely mechanical, and thus of a totally different nature to the electrical vibrations hitherto used, and hence only indirectly affected by variations in the electrical portion of the circuit.

Fig. 5 shows the fundamental quartz oscillator circuit. $C_1$ represents the quartz mounted between two metal electrodes, $L_1$ is variously called a pick-up, sensitising, reaction or phasing coil, coupled to the plate coil $L_2$, the latter being tuned to the quartz frequency by the variable condenser $C_2$. $C_3$ is the usual radio-frequency by-pass condenser.

My theory of operation is as follows: Any slight shock to the electrical system (such as switching on) produces a damped oscillation in the tuned plate circuit $L_2C_2$. This induces a corresponding voltage in the grid circuit, but unless the grid circuit happens to be tuned to the plate circuit, merely assists in damping out the oscillations. If $L_1C_1$ (the quartz being considered

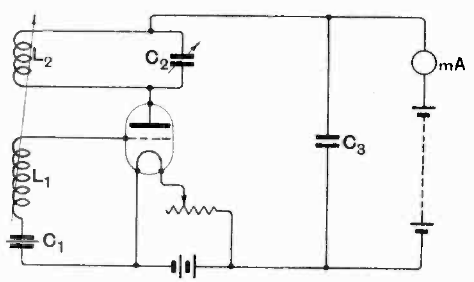


Fig. 5.

as an ordinary condenser) are in tune with the plate, we get ordinary self-oscillation. But if the voltage induced into the grid circuit is of nearly the same frequency as that of the quartz, then the voltage across the quartz actually increases, though the exciting voltage be dying away. This is because the energy supplied to the quartz is utilised by it in overcoming its damping, while the voltage generated only has to supply the losses in the high resistance of the valve filament-grid circuit. The fact that the voltage on the grid is building up in the correct phase enables more current to flow in the plate circuit, and in this manner the oscillations build up until the losses in

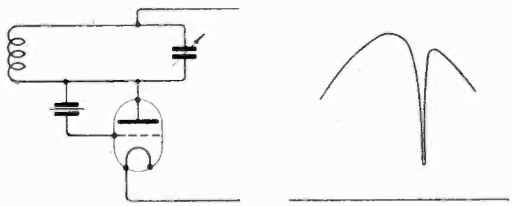


Fig. 6.

the grid circuit (whether due to radiation, resistance or damping of the crystal) exactly equal the power supplied.

It is a fortunate circumstance that the coil $L_1$ need not always have a separate existence, the necessary energy then being supplied either through the inductance of the wiring, or through the valve grid-anode capacity. In this case, outside disturbances can hardly enter into the grid circuit, as there is practically nothing for them to be coupled to. If the phasing coil be large, then it is possible to accelerate or retard the speed of vibration of the quartz by a very small amount.

The circuit just described may be improved in practice in many ways, chief of which is the permanent biasing of the grid through a radio-frequency choke. In some cases this R.F. choke appears to fulfil the functions of the phasing coil, without the disadvantage of causing frequency drift.

The circuits shown in Figs. 6, 7 and 8 have their special applications, and are all extremely steady.

A different class of circuit is shown in Fig. 9. It is a well-tried and popular transmitting circuit, across whose grid has been placed the mounted quartz. In this case (after retuning to allow for the added capacity) the quartz behaves like a self-adjusting condenser of a few $\mu\mu F$. Within a band of several thousand cycles around its response frequency, the quartz holds the transmitter perfectly steady. Outside these limits, the arrangement reverts to an ordinary tuned-grid transmitter.

There is one most important point about which information is at present entirely lacking, and that is the criterion for breakdown of the quartz. Using the Fig. 5 circuit. I have cracked a 135-metre specimen with 700 plate volts. I have been informed that some thick specimens in the same circuit have cracked with only 150 volts on the plate. Doubtless similar experiences have led to the American rule-of-thumb, "Don't use more than 400 plate volts." However, Ridley* using the circuit of Fig. 9, with a 135-metre crystal and grid and plate circuits tuned to 45 metres, has successfully controlled a transmitter using 2,000 plate volts.

### VII.—Accuracy.

As this term is frequently used in connection with quartz technique, care must be taken to examine the accuracies involved, in order not to cause confusion or needless expense by demanding unnecessarily accurate work.

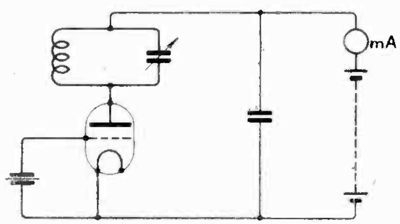


Fig. 7.

($\alpha$) *Accuracy of Measurement.*—As already stated the frequency of a quartz resonator may be measured to a fraction of one part in a million if required, on radio frequencies. Such a determination is extremely laborious, and for ordinary purposes within 100 cycles is good enough.

($\beta$) *Accuracy of Setting-up, i.e.*, how closely a station may be established upon a given wavelength.—This again may be anything that is desired, but for broadcast work, within 300 cycles is all that is required. For the shorter wavelengths that are not yet so congested, one-tenth of 1 per cent of it is often ample.

($\gamma$) *Accuracy of Operation*, which may be sub-divided into two main divisions :—

1. Temperature variations.—Although theoretically a crystal may be cut to have zero temperature co-efficient, a value of a few parts in a million per degree centigrade may be expected, accompanied by a possible temperature rise of 50°C. But when the cut is for maximum output, the frequency variation may reach several thousand cycles. Being a slow drift in

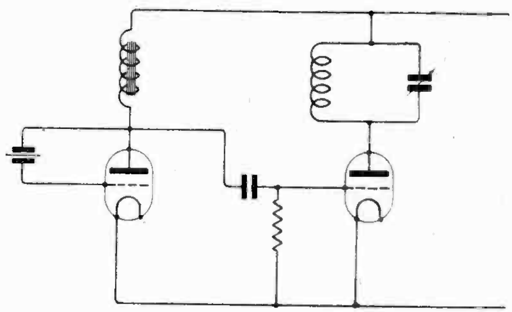

Fig. 8.

one direction, this may be allowed for very simply by allowing the crystal to attain working temperature before transmission begins.

2. Other causes.—These are chiefly changes in location or pressure of the electrodes, to be avoided if present by careful attention to the design, and residual coupling to the grid circuit consequent upon large changes in the main circuit.

### VIII.—Quartz Testing.

It is not to be expected that immediate results will follow from a quartz crystal connected up among components selected at

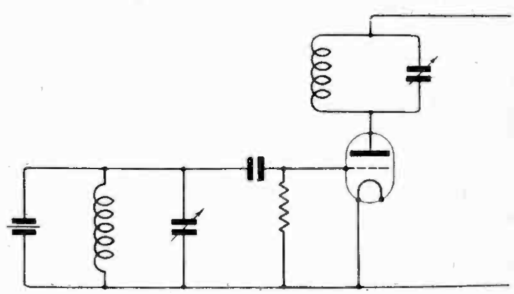

Fig. 9.

random, but until sufficient research has been carried out into the precise circuit conditions, it will often be necessary to go through a good deal of the procedure about to be given, merely to get the quartz to work at all, and thus to show the way for further improvements.

* *Modern Wireless*, December, 1926.

Connect up the circuit of Fig. 7, paying great attention to the components as specified.

*Valve.*—Receiving type of about 10,000 ohms impedance.

*Coils.*—Wound basket or Lorenz fashion, *not* spaced. The plate coil to give the expected wavelength with the condenser three-quarters in.

*Condensers.*—Plate of .001 or .0005$\mu\mu$F maximum. By-pass, .006 to .001$\mu\mu$F.

*Electrodes.*—Not too flat. The finish obtained by rubbing upon very fine emery paper on a board is often best.

Connect up as follows.—Bottom electrode to negative filament, top electrode to grid by means of 36 S.W.G. wire or finer. Place the quartz in position, and connect up the batteries.

Now vary the plate condenser very slowly from minimum to maximum, keeping careful watch upon the milliammeter needle. (Slowly means taking 30 seconds for the traverse.) Probably nothing will happen. Now connect as in Fig. 6, temporarily insulating the crystal holder from the bench, which is at earth potential. Bring the plate condenser slowly back from maximum to minimum. If nothing has happened, connect as in Fig. 5, using the smallest available coil (say 2 or 3 turns) very tightly coupled to the plate coil. Again bring the condenser from minimum to maximum very slowly, then reset the condenser to minimum, reverse the phasing coil, and repeat. Next try successively larger sizes of phasing coil, reversing them every time. Eventually a size will be reached such that the needle drops back immediately the coil is plugged in with the plate condenser at minimum. That is probably ordinary self-oscillation, which will occur just the same when paper or mica is substituted for the quartz. Measure the wavelength of the self-oscillation —as long as it is below that expected of the quartz all is well.

In the extreme case of self-oscillation occurring at about 5 per cent. lower wavelength than the quartz, the behaviour of the milliammeter needle will be thus: A moderate drop due to self-oscillation, a slow fall with a sudden jerk in it as the plate capacity is increased, a slow rise, perhaps a jerk upwards as self-oscillation almost ceases, but certainly another fall followed by a very sudden rise. The latter is due to the crystal.*

At whatever stage oscillations are observed, the coupling between the coils must immediately be loosened until they are very feeble, and the plate circuit retuned. Now try moving the top electrode relative to the quartz. Probably another position will be found, giving stronger oscillations. Again loosen the coupling and retune, and move the electrodes about until this avenue of improvement has been thoroughly explored. Now try a smaller phasing coil, tightly coupled. Once oscillations occur for practically the same plate condenser setting, but with different sizes of phasing coil, they are undoubtedly due to the quartz.

It may be that pressure on the quartz is wanted. With the holder described, it may be conveniently applied by means of weights resting upon a small box placed over the distance piece and knob of the top electrode.

Once a phasing coil can be used that does not cause self-oscillation wherever the plate condenser may be set, it is time to try other expedients, such as :—

1. Top electrodes of different areas, shapes and weights.
2. Different sizes of plate coil.
3. Other valves.
4. The effect of grid bias.
5. Different H.F. chokes to the grid bias.
6. Letting the quartz oscillate for several hours.

The golden rule to avoid cracking a crystal is: "When using a reaction coil, never allow the plate current to stay below one-third of normal for the briefest fraction of a second." Detune at once, and use looser coupling or a smaller reaction coil.

When the correct position of the quartz relative to the bottom electrode has been determined, it should be permanently located by screwing on the two corner pieces. Before making a new top electrode of correct size and weight, it is worth trying whether any output can be obtained with a minute air-gap between the quartz and the electrode. The increase in reliability may more than compensate for the reduced output.

* The quartz plate used for the demonstration had a frequency of 12,000,000 cycles.

With an amplifier following the crystal-controlled valve, the power radiated into the wiring of the grid connection is sometimes sufficient to permit the removal of the

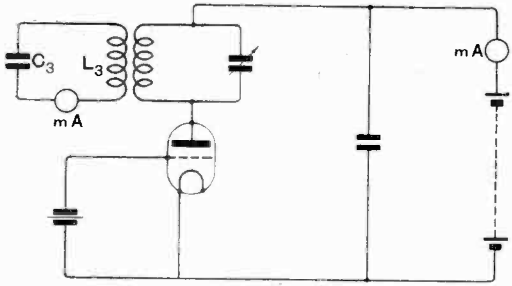


Fig. 10.

phasing coil, even though the latter be required for starting-up.

No great difficulty is found in getting the thicker quartz plates to oscillate. It is metres that call for some or all of the procedure just described. In any case, the time is well spent, for upon the adjustments so made once and for all will depend the technical excellence of the whole transmitter.

## IX.—Elementary Applications.

The method of obtaining resonance points has already been mentioned.

Fig. 10 shows a testing arrangement due to Mr. Tingey. The quartz-controlled transmitter works on a fairly high wavelength, and the current in $L_3C_3$ is read on the measuring device *mA*. To use with batches of coils, a standard coil is placed for $L_3$, and a fairly large condenser $C_3$ is adjusted to give maximum current. $C_3$ is now left alone, and further coils can be adjusted to identical inductance by varying the turns to give maximum current in *mA*. Alternatively, if $L_3$ be large and kept fixed, small condensers may very rapidly be calibrated by placing them in parallel with $C_3$ and noting the reduction in capacity of $C_3$ necessary to bring the circuit into resonance again.

The circuits of Figs. 5 to 9 form extremely accurate frequency standards. The beat notes between the crystal fundamental and the receiver harmonics, or *vice versa*, occur over a wide range. Harmonics up to the tenth may usually be picked up at a distance of several feet, and higher harmonics with closer coupling. For example, a crystal of fundamental 823.6 kilocycles gives a direct calibration of the receiver upon such useful points as 45.53, 40.47, 36.42, 33.11 metres with ease and certainty, which far exceeds the accuracy of a heterodyne wavemeter. Upon important occasions, it takes just two minutes to confirm the receiver calibration, while a new receiver may be accurately calibrated in an hour.

## X.—Advanced Applications.

The application of quartz frequency control to transmitting stations still offers a wide field. It has been proved by Goyder that crystal control permits the use of self-rectified A.C. on morse, or rectified smoothed A.C. on 45-metre telephony, yielding better signals than hitherto obtainable with a carefully and generously smoothed supply. The troubles known as rough notes, key thump and swinging of morse signals or mush and distortion of telephony, are readily cured.

The circuits already described form the nucleus of excellent transmitters for low powers of 5 to 8 watts, either by adding a key and/or microphone after the manner indicated in Fig. 11, or preferably by using one stage of amplification, however modest, so as to leave the crystal oscillating continuously and modulating the second valve.

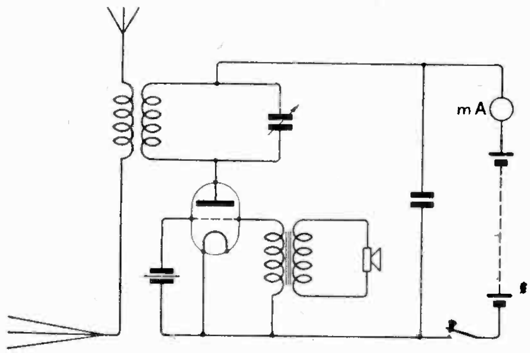


Fig. 11.

The great difficulty hitherto has been to apply the small power handled by the quartz-controlled valve to much larger transmitters. The old methods available were :—

1. The system of Fig. 9, which has not yet been fully investigated.

2. A system of H.F. amplification and frequency-doubling, to avoid the tremendous difficulties of constructing a straight H.F. amplifier on short waves.

A brilliant solution of the difficulty has been found by Mr. C. W. Goyder.* He uses a chain of self-oscillating valves, each handling about six times the power of the preceding one. In the ordinary way, such an arrangement would be hopelessly unstable, because the largest valve could hardly be prevented from feeding back energy to the grid coil of the preceding valve, and so on. But if the grid circuit of the first valve only contains mounted quartz, there is no grid coil to pick up the energy, and even if any energy should be induced, it would only affect the quartz frequency to a perfectly negligible extent. Consequently, the plate coil of the crystal-controlled valve can only contain oscillations at the one frequency dictated by the quartz. These oscillations are applied to the grid coil of the succeeding valve, which, though it be self-oscillating, will be held in exact synchronism over a band of several thousand cycles (or more than enough for practical purposes) and so on through succeeding valves. Should anything happen to one of the control valves, the main valve will continue to function uncontrolled. There is thus no increased risk of breakdown—all that would happen would be a falling off in quality to the standard existing before quartz control was applied.

## DISCUSSION.

**Mr. C. W. Goyder:** It has been mentioned that when a quartz crystal is held near the coil of an oscillating receiver and the condenser is varied, clicks are heard at the resonant points of the crystal. I have found this effect very useful when grinding crystals. During any stage of the grinding the crystal can be held near the receiver and the approximate wavelength found without the trouble and time which would be required to clean the crystal thoroughly, and make it oscillate. This effect is due to the field around the receiver coil when it is oscillating. With the ordinary type of low loss spaced coil the field is strong enough quite a few inches away from the receiver. With concentrated windings, such as basket coils, it is not so easy to get a good click.

The method to follow is first to make the thick crystal oscillate and find the wavelength on the receiver, then hold the crystal near the receiver coil so that the resonance click can be found corresponding to this wavelength. The resonance may not be on exactly the same adjustment of the condenser as the oscillation. Now grind the crystal and every five minutes hold it near the receiver and find the resonance click, you will gradually get close to the wavelength you want. It is then advisable to clean the crystal thoroughly and measure up the surface at various points to see if the faces are parallel. It is important to clean the crystal well or you will get carborundum grains between the micrometer and crystal and then when the micrometer is screwed up they will scratch the surface of the crystal. I have ground crystals down from 130 metres to 90 and 100 to 60 quite successfully. Incidentally, the resonance click you get by holding any crystal near an oscillating receiver is a good test of the quality of the crystal. I can usually tell whether a crystal will oscillate just from this test.

I have been experimenting with crystals to see how long they will oscillate if left alone. They usually go for 8 hours or so and then stop. Sometimes they will start oscillating every time the valve is lit up, but sooner or later the valve is lit up and nothing happens. I have found the trouble to be that the crystal sticks to the bottom surface of the holder and has to be pushed before it will start again. This does not matter for ordinary work as it is quite easy to push the crystal occasionally, but for reliable work it is rather annoying. I find that a very thin piece of mica fixed on to each corner of the crystal prevents this sticking. It is worth doing this if the crystal is put in a holder or position where it is difficult to get at. The reason for this trouble seems to be that the air film under the crystal is gradually shoved out until it comes in direct contact with the metal. It is more noticeable when the surfaces are very true.

I noticed in an American paper that the Bureau of Standards have tried spluttering the faces of the crystal with a very thin layer of metal. A connection is made on to the faces with a wire at the corner of the crystal. This seems an ideal way of getting out of difficulties met with in crystal holders. The coating of the metal on the crystal has very little effect ; it does lower the natural frequency a little, as might be expected.

The type of valve used with a crystal has quite a large effect. I have tried quite a number. The valve with a very low internal resistance certainly is not good. I have tried this type and could not get the crystal to oscillate. Valves with very high internal resistance work quite well but the power is low unless the H.T. is increased a lot. The correct value seems to be around 8,000 ohms. The mutual conductance seems to be quite an important factor. The higher it is the better. If it is not given with the valve you can get it by dividing the amplification factor by the resistance. Of a number of valves tested the one with the highest mutual conductance was the best.

The success of a set using the harmonic of the crystal and the harmonic of the amplifiers depends very largely on the strength of the harmonics. The valves should be worked in quite different ways, depending on whether you want even or odd harmonics. The condition for strong odd harmonics is that the positive and negative half cycles of the oscillation be distorted in the same manner. To get this condition with a valve the obvious way is to make the grid voltage swing the anode current above the saturation point for the positive half cycle and below zero plate current for the negative half. This gives almost equal distortion for both

* *E.W. & W.E.*, December, 1926. *T. & R. Bulletin*, December, 1926.

half cycles. To get this condition the filament should be turned down until saturation sets in with a low plate current and then the grid can be biased to work halfway between zero plate current and saturation.

Things are much easier in the case of even harmonics, as you get a strong even harmonic by distorting the positive and negative half cycle unequally. This can be done very simply by using a high negative bias on the grid. You get the strong even harmonic and at the same time the efficiency is much higher than you can get using an odd harmonic. So if you want to use the harmonic of a crystal for the 45-metre band it is better to get a 90 or 180-metre crystal rather than a 135.

The most noticeable effect of a crystal-controlled transmitter in the case of telephony is that the speech quality is better, and mush and ripple from the high tension supply is greatly reduced. Recently I tried an experiment with two separate stations, one in Ireland and the other in the North, using first a crystal-controlled set and then an ordinary self-excited circuit. In both cases the speech quality was much better and the H.T. ripple and mush was reduced when using the crystal. This effect is quite understandable as the crystal prevents the small changes of frequency which are bound to occur with any other kind of circuit, due to the modulation and variations in the H.T. voltage. The same effect makes it possible to use partially rectified A.C. and yet get a very good note.

I think Mr. Hinderlich has helped us greatly by his work on crystals. I shall never forget the trouble I had in getting my first crystal. It took me several weeks to find a natural quartz crystal, then I had to find someone who would cut the slice out, and then show them how to do it, and finally came the grinding part of the job, which took a long time. I am only too thankful that it did work in the end. Nowadays Mr. Hinderlich walks around with a boxful of crystals in his pocket. He has just sent me a beautiful crystal, working on its fundamental on 33 metres, it is only one-third of a millimetre thick. I think turning out a good crystal as thin as that is a work of art.

**Mr. W. K. Alford:** I should like to add my appreciation of the very interesting lecture we have heard. The great thing about the author's quartz control of transmitters and resonators is, I think, that it really affects us all to a greater extent than anybody realises. A great deal has been said about interference and although Mr. Hinderlich has not actually mentioned this point, I think—and I expect everybody is aware of it—the quartz oscillator supplies a wonderful solution for the elimination of broadcast difficulties, apart from our own experimental activities. I just mention this in passing, but it rather emphasises that it is a physical phenomenon which has apparently outlived radio as a science in the service of man, and it is very wonderful to think that it is now coming into its own as probably one of the greatest assets we can have in radio. I do not think there is anything to say on the actual technique of the subject of the lecture. Mr. Hinderlich has dealt fairly deeply with it and sufficiently deeply for those interested to start immediately on an investigation of their own. There is one great thing about these quartz crystals as oscillators or resonators and that is you have extremely little difficulty in deciding whether you have a good or a bad crystal. A man who has investigated the phenomena for the first time can quickly spot whether his crystal is going to oscillate or whether it is a "dud" crystal without having any deep technical information on the subject. The average person can get a start, as it were, in studying these piezo-electric effects. Mr. Goyder mentioned the fact of his buying quartz in some distant part and having to grind it. I remember I did the same thing, but I went a stage worse than Mr. Goyder and attempted to cut it, and I am very proud to say that I did cut it. I cut it into a strip roughly $\frac{1}{10}$ inch thick and it did not break but it took me roughly ten days. It was done with the aid of a hacksaw blade and 00 carborundum but the irony of it was that the crystal was a dud one after all! When you think of the work attached to the grinding of these crystals and what appears to be excessive price for a miserable piece of silica matter, perhaps having the wrong composition, we get some excuse for the price which is charged for these things.

**Mr. G. G. Blake:** There are one or two points on which I should like information from Mr. Hinderlich. Some time ago I saw in a paper that these crystals have been employed as couplings between stages of an amplifier, if Mr. Hinderlich is familiar with this application, I think a diagram showing how they can best be employed for this purpose would be useful. In 1922 or 1923, Langevin in France, using ultra-sonic sound waves employed a quartz crystal as transmitter and receiver. I do not know what circuit he used but in the transmitter he caused a crystal to oscillate and at the receiving end, when the sound waves arrived through water, I believe the sound waves caused the receiving crystal to oscillate and produce electrical oscillations which he then amplified. In 1925, Giebe and Scheibe in Germany made use of what they called a luminous piezo-electric effect, but although I looked it up in the library here this evening I was unable to find very much about it. There was a brief account in *Science Abstracts* for 1925 and 1926, and I saw that they used quartz rods 8 cm. long, and these when caused to oscillate, apparently glowed. It is stated that they were able to reproduce not only the fundamental frequency but in addition all the odd harmonics up to the 21st were observed and photographs were taken.

**Mr. E. H. Robinson:** I have been very interested in the whole lecture and I think it has been extremely useful to have all this matter put before us so clearly and concisely. I am afraid I have not anything to add by way of information as I have done practically nothing in quartz crystal work. It seems to me, however, that one enormous advantage of the quartz oscillator, especially the type in which you put the quartz in the grid circuit without any reaction coupling, or any apparent reaction coupling, is that it enables you to evade the reaction patents very nicely. I do not know if Mr. Hinderlich knows of any patent which covers the use of an oscillator in this way but it could be used commercially, I think.

**Mr. E. J. Simmonds:** Much attention seems to be given to the production of fundamental crystals for short waves, but I think there are disadvantages, because below 50 metres they become very fragile, the percentage of crystals with good oscillating properties is small, whilst the power which such thin crystal handles is much reduced. There seems to be an idea that it is difficult to set up high frequency stages to multiply the original frequencies from long wave crystals. I do not think there are many difficulties, and perhaps an idea of what I do in my own station may be interesting. I am transmitting actually on 32.25 metres using an 129-metre crystal with intermediate frequency doubling stages, and the total amount of energy used in these two stages (the original crystal stage and frequency doubling stage) is 8 watts, and I find that I can with this arrangement efficiently control a 250-watt valve up to 200 watts input, that is the 250-watt valve is just under neutralised, and the output from the crystal amplifier is impressed on the grid circuit of the 250-watt valve.

I think that because this power stage is actually under-neutralised, most of the energy to swing the grid is supplied by the valve itself, and what actually happens is that the crystal amplifier with 5 watts in the frequency doubling stage is sufficient to trigger the grid of the power amplifier stage, and thus stabilise it.

I think that has some advantages over the self-oscillating systems using fundamental crystals, because I have observed in one or two stations using this arrangement of stabilisation all working on the fundamental, if the power valves are working somewhere near the full dissipation, the anodes are bound to heat up to a considerable extent and get a change of inter-electrode capacity and a consequent frequency change in the relative circuits.

I know that the one or two stations using this method have to adjust their circuits as the valves heat up until they come to stability. On the system I use, I do not have that difficulty because the last stage is already neutralised. An interesting system was described by Hund in a paper read before the I.R.E. in November, 1925. He describes a system of chain amplifiers with, I think, 20 to 25 watts to control 200 watts, and so on in that ratio, but the point was, that the grids of all the amplifiers had a large negative bias, so that until the crystal started oscillating, there would be no plate feed current to the valves at all, and there would be no tendency to self oscillation, the whole thing being controlled by the original crystal. Mr. Hinderlich mentioned somewhere that a quartz plate in the thickness of which there was a difference of 25 per cent. in the different parts was quite satisfactory. This seems contradictory, because Hund also mentions the application of quartz crystals ground with a minute step, the idea being to produce two radio frequencies, closely related, from the same crystal, and thus obtain a resultant audio frequency, which might have a large number of applications. I find it is preferable to use crystals with good self-oscillating properties, and strongly depreciate the use of crystals which require any form of magnetic reaction to make them work. I find it is better to use a crystal of comparatively long wavelength, as it is easier to get good specimens, and thus dispense with the reaction coil, or any form of choke in the grid circuit. In the low power tests on 45m., I used a crystal which required magnetic reaction to maintain oscillation, and every time I started up I got a fresh frequency. Many crystals used with reaction will often stabilise the frequency at a number of points, and it is troublesome to have to retune every time.

There is also the question of calibration from a fixed crystal standard of long wavelength. I use an N.P.L. calibrated crystal with a frequency of 530,600 cycles approximately. The crystal is permanently fixed up in an oscillating circuit, and it is quite simple and easy to read the harmonics right down to the 25th, which provide a large number of plot points on the short wavelengths.

**Mr. A. E. Underdown:** I am particularly interested in this lecture as I have been engaged in experiments of this nature myself for some months.

In the first place, I should like to ask Mr. Hinderlich whether he is absolutely certain about the 150 and 105 factors, and if he can give me any information as to how a crystal responding to a wavelength of 150 metres per mm. of thickness differs from one of 105 metres per mm.?

Also, the band of control, Mr. Hinderlich says, is something of the order of a few kilocycles, but I should like to know what wavelength he had in mind as a band of a few kilocycles is not very large when dealing with very high frequencies. For a 300-metre crystal, the oscillating circuit would be tuned to a frequency in the neighbourhood of one million cycles per second, and presumably if that circuit is adjusted to more than two or three kilocycles above one million, *i.e.*, the resonant frequency of the crystal, it will fail to control. I should like to know the maximum percentage of frequency difference between the tuned circuit and crystal with which it is possible to work. At 300 metres I have been able to work with the oscillatory circuit tuned to 285 metres, *i.e.*, 50 kilocycles away from the fundamental frequency of the crystal.

With regard to permanent holders, I have a circuit arrangement with which I seem to be able to make practically any crystal oscillate and its reliability of control has made it possible to design a simple and robust crystal holder with a comparatively large air-gap. Scrap pieces of quartz have been ground down roughly irrespective of their surfaces, and they have oscillated quite readily without any trouble.

Most quartz crystal enthusiasts seem to be following up the American methods of crystal control, but I have found that, without the aid of reaction, control is generally more or less uncertain I have departed from the usual lines of working and with my arrangement it is possible to control with an air-gap of over 2 mm. between the crystal and electrodes; the usual air-gap employed is about 0.1 mm. to 0.2 mm., unless the crystal is actually in contact with the electrodes.

I have had very little experience with the disc type of resonator which makes use of the transverse vibrations—my experiments having been confined to the rectangular type employing the longitudinal vibrations. You will probably raise the question of the control of short waves. Well, it is possible to make a tiny piece of quartz about 2 mm. square and 1.5 mm. thick oscillate on a wavelength of about 250 metres. A small piece may be cut or even chipped off an odd bit of quartz and ground down to the required size, when it will be almost sure to function.

Another point is in connection with broadcasting. A week or so ago I read a statement to the effect that the B.B.C. did not intend to make use of crystal control because, in their opinion, it was rather unreliable and not so accurate as some people were led to believe. I should like to hear what Mr. Hinderlich has to say on this point, because I have had extraordinarily good results and in some of my measurements the high tension, low tension and even the gap between the electrodes were varied appreciably without affecting the frequency more than 20 to 30 cycles in a million. This order of constancy, however, could not be expected where the air-gap is exceedingly small.

**Mr. A. D. Gay :** There are one or two points I should like to endorse, particularly with regard to the vagaries of crystals when they are used with a reaction coil. I also have found that you are never quite sure whether you are going to start up on the same wavelength you were last using. But it is quite a definite control, and by using that form of control you can get a number of steps all of which seem to give good outputs ; there is no doubt about the controlling effect, because if you use a valve rectified supply with practically no smoothing you get pure D.C., and there is a great advantage in that. Mr. Hinderlich mentioned the condenser across the plate coil ; did he say it should be about two-thirds ?

**Mr. Hinderlich :** Yes.

**Mr. Gay :** I do not quite agree there, because I have tested a large number of crystals and have found that if you do not go above 5 degrees of the condenser certain crystals will oscillate, whereas if you put in a smaller coil and put in more condenser the crystals will not oscillate. I found on several occasions that it was necessary to keep the capacity at a minimum, and I should like to know whether, in that circuit in which Mr. Hinderlich showed two valves, the choke is an audio-frequency choke ; the author drew it as an iron-core choke, and I wondered whether that was a mistake. With regard to Mr. Underdown's remarks about making any odd pieces of quartz oscillate ; I have not made them oscillate except with a reaction coil, and then I have found that the effect of those pieces of quartz is more an absorption effect than an oscillating effect, because I have actually found no current that one could measure by ordinary means passing through the crystal. When a crystal is used and is properly oscillating you get quite an appreciable current, but it is very minute when you are using it in an absorption circuit.

**Mr. S. Ward :** I think the remarks of the lecturer to-night have been of very considerable interest to everyone, and especially to me. I have carried out a certain amount of investigation into quartz crystals, and there are one or two points which I should like to mention. Mr. Hinderlich did not say very much about the question of gap. I have made several experiments on that, and I find that most crystals work best with a gap. That has been my experience in testing a number of them, and the method I have used for getting and measuring the gap is to fit up an ordinary 2 in. micrometer held in a vertical position by means of a clamp, and to fit a little disc platform on to the lower anvil and a similar one on to the top portion, one of them being insulated, of course. By that means one is able to measure the thickness of the crystal and also to measure the gap, and most of the crystals which I have tried certainly work best with a gap of anything up to 0.005 in. The output is increased up to a certain point, possibly about 0.003 in. in most crystals I have tested. Beyond that it begins to fall off, and generally at round about 0.005 in. or 0.006 in. it ceases to function. In most cases I have found it necessary to use a reaction coil to get the crystal to start. Sometimes, as Mr. Hinderlich has mentioned, it would carry on after starting with a coil. I like the fundamental circuit he has given, because it seems to have one advantage, in that the absence of a grid-leak really means that you have a very high grid-leak, and, as soon as the valve oscillates, its anode current goes down very considerably, which is a great advantage. When the valve is not oscillating, and you are using an ordinary dull emitter valve, the anode current is considerable—not that that matters very much unless you happen to be using fairly high plate voltage. Another point Mr. Hinderlich mentioned was that the polishing of the crystal would probably increase output. I thought the same thing myself, and so I took one crystal, which was rectangular in shape—its length being about twice its breadth, and its thickness about 1 mm. or so, perfectly plain and parallel—cut it in halves and polished one half, but could not find any difference between the two halves. That is the only one I have treated in that way, and I have found no difference whatever ; both halves apparently worked quite well. The question of a chain of amplifiers in controlling the transmitter seems to be rather an important one, because a lot of people have tried making up these high frequency amplifiers, and the great difficulty which one would expect to come up against is the question of the feed back, as mentioned by several speakers.

Neutralising is one way of doing it, but it always seems to me much more satisfactory to use the frequency-doubling method, which, if properly arranged, can be used entirely without any neutralisation. If the harmonics exist in each circuit and you pick each one out independently, making each circuit a distorting circuit, it is not necessary to neutralise each stage. One starts with a large, thick crystal, and goes down in wavelength each time, doubling the frequency at each stage. That seems to be a much more satisfactory method of working than to amplify from the fundamental with neutralisation at each stage. There is one other point I should like to mention, and that is the use of Rochelle salt in place of quartz. I do not know how many people have tried it, but it is a thoroughly unsatisfactory substance to use. It looks very nice ; it has good resonating properties, it is very cheap, and it is very easy to work, but it is thoroughly unsatisfactory as an oscillator and it is very difficult to prevent the stuff changing owing to its hygroscopic properties. You cannot keep it constant for any length of time ; it is very erratic. The production of crystals is a matter of some difficulty, but they can be obtained, and I do not recommend anybody to try to use Rochelle salt in place of quartz.

**Captain Robinson :** I only wanted to say that I quite agree with Mr. Goyder as regards the relationship between capacity and inductance in crystal controlled circuits. I have found that the three or four crystals I have had have all oscillated best when the capacity was small and the inductance large. I believe the author disagrees with that. It may just happen that the few crystals I have experimented with work better that way.

**Mr. G. G. Blake :** Possibly these crystals may suffer from fatigue and I should very much like to know if you, sir, or anybody who has been working with them, has come across this drawback. It seems to me rather an important thing for us to know whether in use these crystals do suffer from fatigue.

**Mr. Underdown :** I have found that to be the case.

**Mr. Robinson :** I find that some will work one day and will not work the next and so on.

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**Mr. Hinderlich,** replying to the discussion, said: I have tried to cover the whole ground in this paper by giving references to published papers that cover parts, and so I find that I have not actually stated many necessary details. For example, Dye's paper, which runs into 21 pages, covers many of the points raised by various speakers, such as Giebe's " luminous " quartz, and the effect of air-gaps between 3 and 0.2 mm. Clayton and Hund both discuss the two wavelength/thickness ratios, and Ridley and Goyder give details of their systems of control, which have only been in use at a few stations, so it is yet too early to make valid comparisons.

Several speakers have criticised my reaction coil method. I consider it invaluable in the early stages, as without it you often find you have a transparent object, alleged to be oscillating quartz, which flatly refuses to work. Use reaction, and you can find the correct tuning, and the way to improve results. But a transmitter with a reaction coil I admit to be a very poor affair. For one thing, you get the trouble of several fundamentals, and then the frequency is apt to shift or wander. A crystal that requires reaction is really only fit for a wavelength standard where a small inaccuracy is permissible.

With regard to thin crystals, few people have tried the 33 and 23-metre ones. When further research work has been done, I feel sure that crystals of similar properties will occur, whatever the thickness, and that our present difficulties in finding enough good thin ones will disappear.

One would expect a station to creep a bit owing to temperature effects, but I will ask Mr. Goyder to answer that question.

**Mr. Goyder :** I have had some trouble due to a gradual drift of frequency but I do not think it is due to the valve or the method in use. I have always found it was caused by a poor inductance. If the wire is too small in cross section or if the di-electric on which it is wound is poor, it gradually heats up and so the wire moves due to expansion, or just because the di-electric gets soft. It makes quite a large frequency change on the short waves. I used an inductance wound on a wooden frame, boiled in wax for 90 metres and 45 metres, when I tried it on 32 metres the wood warmed so much that the wax melted ! At present I am using an ebonite frame and I have no trouble. A poor high frequency choke can cause the same trouble.

**Mr. Hinderlich,** continuing, said: All the precepts I have enjoined this evening were more of an indication than positive injunctions. I find my way works, and that a lot of others do not, at first. The reason I suggested using a large condenser with a small coil was partly that when testing you want plenty of room at the bottom, to see when the self-oscillation is going to end, and partly because it does not follow that a large coil is going to give better results. Occasionally it spoils them. Anything that will make the crystal oscillate easier should be used.

I am very interested in Mr. Ward's observation that a fairly critical value of air-gap around 0.003 in. (0.08 mm.) gives the best results in an oscillator. I had not noticed anything of the sort, and it is not easy to try, but I will have a go at it.

As regards tuning-fork versus quartz, I could talk for hours, but it is a case of knowing the accuracy required. If you ask for absolute accuracy, you will never get it, but you can get whatever accuracy you require in practice. I am not aware of any attempt to measure the results obtained with quartz. The inherent accuracy satisfies most people.

I do not see how you can avoid using a micrometer when grinding—it will be wanted to keep the faces nearly parallel. I am surprised at Mr. Goyder's difficulty. I put mine under the warm water tap and dry off with an old handkerchief. If you should have a grain of abrasive, you can hear it being crushed by the micrometer.

I brought my specimen with the 25 per cent. variation in thickness along to demonstrate my point that the state of the surfaces does not make a tremendous amount of difference. The oscillating power must exist in the rough specimen.

At an intermediate stage of the grinding, I much prefer to have the crystal rather wedge-shape Then any supplementary wavelengths are immediately obvious. With a crystal having two wavelengths, you might, with fairly good workmanship, get such values as 39.9 and 40.1, and never spot the trouble for a long while. Excessive reaction promptly brings out any supplementary wavelengths, as noticed by Mr. Simmonds. Curiously enough, I have known beautifully polished specimens that failed to work until one surface was roughened, though usually a good surface improves the results.

It is impossible to give much information about Patents, as those taken out months ago are now being published, but if Mr. Robinson will look up the patents in the names of Eccles, Goyder, Hinderlich, Hoyt Taylor and Standard Telephones, he will find something.

The idea of coating the quartz itself with metal is most attractive, and only the practical difficulties in the way of applying a thin coating have prevented my trying it.

I do not think that quartz suffers from fatigue, which is easily simulated by the sticking electrode trouble.

**Mr. Bevan Swift :** We are deeply indebted to Mr. Hinderlich for coming here and telling us all about crystals ; whether it is the broadcast listeners wanting crystals for reception or of the transmitter wanting to tie his wavelength down, Mr. Hinderlich can advise us. I remember that some time ago he came down to our local Society and told us all about crystals for ordinary receivers, and we thoroughly enjoyed that lecture. Now he comes to us to-night with a more advanced subject and tells us how to tie our wavelengths down to one spot so that they will not jump off it. I do not know anything about crystal-controlled transmitter working myself. I have not used it, but I know I can tell a crystal-controlled station directly I hear it, and it is quite a treat to listen to it. I think that great praise is due to Mr. Hinderlich, Mr. Goyder, and others who have made a feature of crystal control. I am sure it is the coming thing for the amateur transmitter, as well as the commercial station.

# Amateur Long-Distance Work.

## *By Hugh N. Ryan (5BV).*

INTEREST, or at any rate the interest of a large section of the transmitter community, centres at present on the results of the week of low-power tests organised by the R.S.G.B. and, more particularly, on the regular low-power work which many stations are now carrying out, doubtless under the stimulus of the organised tests in November. At the time of writing, the detailed results of these tests are not yet available. It appears that, as so often happens, the participants' enthusiasm for the tests was not equalled by their subsequent zeal in reporting their results. However, one knows the general trend of these results. First and foremost, the tests proved definitely that, given care and organisation, 5 watts is a thoroughly useful power for reliable communication over distances of several thousand miles, but it is doubtful whether this can yet be said of the same power used in the ordinary course of work without special organisation. This desirable result, however, should follow in a very short time now that more stations are devoting themselves to the problems involved in the use of low power. The tests have shown those who are compelled by circumstances to use low power, and who have perhaps not yet met with success, that they are not up against an impossible task.

Before the tests, many Irish Free State stations had been very successful with low power, and the promise thus shown was evidently fulfilled in the tests themselves, as the "GW" stations did very well indeed.

Judging from the general trend of all reports received this month, conditions would appear to have favoured unusually good reception of transatlantic stations in the early evening here (this applies especially to reception in the North) and very frequent and good reception of Japanese stations, especially in Ireland. Most stations in the South of England report a period of poor conditions, while no Welsh station reports anything at all.

Space only permits of a brief reference to the work of individual stations. 6NF has worked 3CYB (Spanish W. Africa) with 5 watts in daylight. It is interesting to note that, for his higher-power work, 6NF is directly crystal-controlling his main power valve, with 1,000 volts on the plate, which voltage he is soon increasing. 6LJ is out of active operation for some time but his extensive work on weather condition effects has reached an advanced stage, and should soon be available.

6UV has been carrying out a detailed investigation of the "skipped distance" question, mostly with the very efficient co-operation of SMWF (Stockholm).

6KO (Scotland) has been working with a hand-generator and a large receiving valve, and besides effecting two-way working with several transatlantic stations has been heard on at least two occasions in Australia.

5NJ remains the leading station in Northern Ireland, and with 75 watts is in constant touch with most of the world. Of the other "GI" stations, 6YW, 6MU, 5WD, and 5MO have all worked the U.S. with 5 watts or less. (The call 5MO, famous as that of a pioneer long range station in the north, is now re-allotted in Ireland.)

The most active stations in Southern Ireland are 11B, 18B, and 19B, all of whom have worked America with 10 watts or less.

[Reports on low-power long-distance work are welcomed.—ED.].

# Some Notes on Design Details of a High-Power Radio Telegraphic Transmitter Using Thermionic Valves.

Paper read by Dr. R. V. HANSFORD, and Mr. H. FAULKNER, B.Sc., before the Wireless Section, I.E.E., on 1st December, 1926.

### Abstract.

THE paper deals with various specific points in the design of a high power transmitter, more especially that at Rugby, being largely supplementary to Mr. E. H. Shaughnessy's paper on the Rugby Station (abstracted in *E.W. & W.E.*, May, 1926).

The paper is divided into six sections :—

I. Consideration of the most suitable type of aerial circuit from the point of view of the elimination of undesirable harmonic emissions.

II. The design of the electrical proportions of the aerial circuit.

III. The inductance coils for the aerial circuit.

IV. Some notes on valve circuit design.

V. Keying and shape of signals.

VI. Recent results at Rugby.

### Part I.

*Type of coupled aerial circuit from point of view of elimination of undesirable harmonics.*

This is discussed by comparisons of the alternative circuits shown in Fig. 1.* As regards coupling to the valve, it is shown (in an appendix) that the use of a condenser rather than an inductance as the "anode tap" (*i.e.*, types *B*, *D*, and *E*) gives a reduction of harmonics in the aerial in the ratio of $m^2$ for the $m^{th}$ harmonic, that is *B* and *D* are $m^2$ better than *A* and *C* respectively. The same applies to coupling to the aerial, *i.e.*, *E* is $m^2$ better than *D* and $m^4$ better than *C*. It is pointed out, however, that when designing a circuit for an aerial not yet erected and of constants not accurately known, it would be expensive to provide a range of condenser values for a type *E* circuit to cover all the variations required in the experimental period of tuning and adjustment.

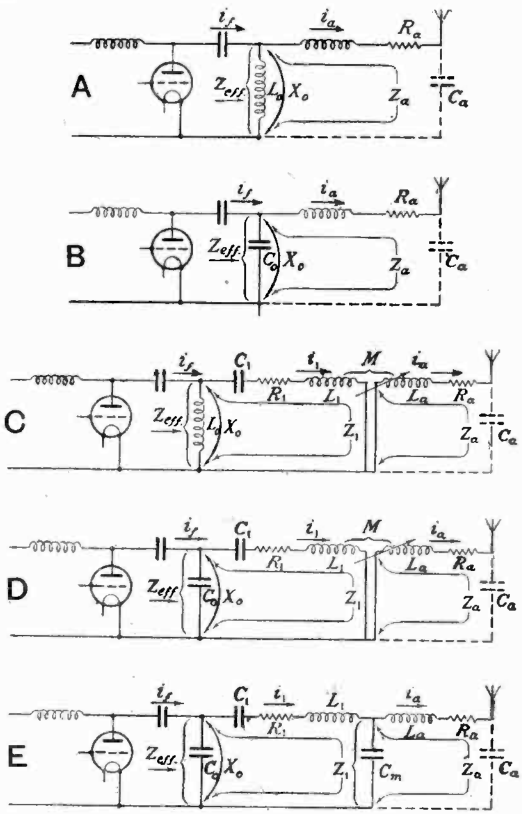


Fig. 1 *Types of output circuit.*

The *D* type circuit has therefore been used, and transition from *D* to *E* can be made comparatively easily and inexpensively should it become necessary.

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

An expression of the "improvement factor" as regards harmonic elimination is given as—

$$\frac{\pi\,\delta_a}{\delta_1\delta_a+\pi^2k^2} \quad \ldots \quad \ldots \quad (2)$$

or

$$\frac{\pi}{\delta_1+(\pi^2k^2)\delta_a} \quad \ldots \quad \ldots \quad (3)$$

Where $\delta_1$ is intermediate circuit decrement, $\delta_a$ is aerial decrement and $k$ the co-efficient of coupling. These expressions must be multiplied by a power of $m$ depending on the nature of the couplings.

of the value of the inductance, and it is desirable for reasons of voltage and cost that the value of inductance chosen should be as low as is consistent with design considerations. The mean value of inductance chosen for the intermediate circuit at Rugby was therefore 500$\mu$H. (See Fig. 3.)

From a curve given showing the relations between efficiency (abscissa) and improvement factor, co-efficient of coupling, and intermediate circuit current and power, it is shown that for an improvement factor of 40 and efficiency of 95 per cent., $k$ would

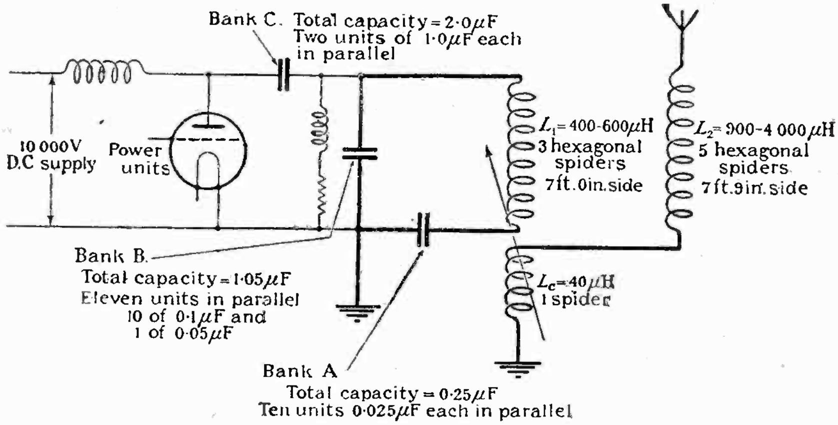


Fig. 3. *Coupled aerial circuit.*

**Part II.**

*Design of the Electrical Proportions of the Coupled Aerial Circuit.*

Taking a $D$ type circuit as a basis, it is shown that the efficiency $n$ of coupled circuits

$$=\frac{\pi^2k^2}{\delta_1\delta_a+\pi^2k^2} \quad \ldots \quad \ldots \quad (8)$$

From (2) and (8) it is seen that the efficiency and improvement factor are both independent of the ratio of inductance to capacity in the intermediate circuit except in so far as this ratio may affect $\delta_1$. Therefore, since with a given value of $k$ both expressions are dependent on $\delta_1$, the problem from both points of view is to design an intermediate circuit of minimum decrement consistent with reasonable cost.

Within the inductance limits imposed by practical considerations the decrement of a well-designed coil for the intermediate circuit can be assumed to be practically independent

require values of from 0.0088 to 0.0107. The range of mutual inductance called for is therefore from 5 to 40$\mu$H, which was provided by the use of a moving coil of 40$\mu$H coupled directly to the intermediate circuit inductance, as in Fig. 3.

It was next necessary to fix the "anode tap" condenser (Bank $B$, Fig. 3). From examination of the probable extreme conditions, it is shown that 0.37 to 1.03$\mu$F would be required. This was provided by 10 banks each of 0.1$\mu$F, and one unit of 0.05$\mu$F. The value of Bank $A$ could then be calculated from the known limits of frequency.

The high frequency condensers were all tested at the manufacturer's works in accordance with a detailed specification.

An inductance coil in series with a resistance so proportioned as to make the circuit non-oscillatory, is connected across the anode tap condenser to ensure that practically the whole of the D.C. voltage is taken by the blocking condenser, Bank $C$.

## Part III.

*Inductance Design for High Power Radio Transmitter.*

The three main points to be decided are (1) size and type of conductor, (2) the method of supporting the conductor, (3) the method of providing the necessary variation of inductance.

The design of the Rugby inductance was based on experience gained at Northolt, which led to the manufacture by the P.O. Engineering Department of its first large

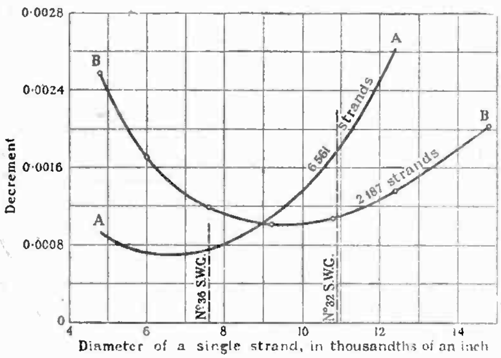


Fig. 6. *Variation of calculated decrement of a large inductance with type of cable used — four spiders, eight turns per spider ; external diameter of outside turn = 15 ft. 9 in.*

stranded-wire inductance. This gave interesting information regarding the necessity for efficient insulation of the stranding. Curves are given showing the effect of stranding, and comparison between measured and calculated results at Northolt, these being in good agreement, having regard to

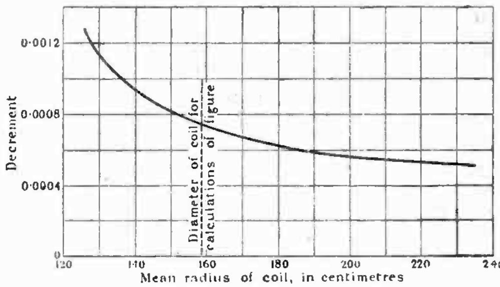


Fig. 7. *Variation of calculated decrement of a large inductance with diameter of inductance—four spiders ; inductance approximately constant at 2,920H.*

dielectric and eddy losses not allowed for in theoretical calculation.

It was decided to base the design of the Rugby inductances on the results of similar calculations. Inquiry elicited the fact that 6,561 strands was probably the limit of the manufacturing plant in this country, while spiders of 16 ft. diameter were as large as could be conveniently handled.

Fig. 6 shows calculated comparisons between 6,561 and 2,187 strands, while Fig. 7 shows the variation in calculated decrement of a cable of 6,561 strands with variation of external diameter.

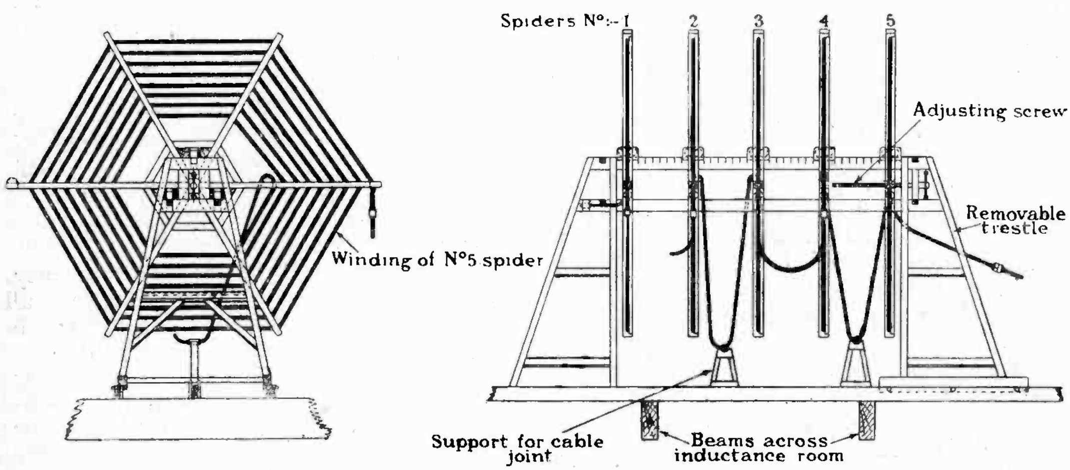


Fig. 9. *General arrangement of aerial tuning inductance.*

Another curve also shows the comparison between calculated and measured decrements for the Rugby coil. Allowing for losses in the framework and surroundings, the agreement is considered satisfactory.

The general arrangement of the aerial tuning inductance is shown in Fig. 9. The spider is of American whitewood, which has proved itself very suitable for the construction of such frameworks.

Considerations of the possibility of voltage breakdown gave a minimum spacing of 10 inches between spiders, which were actually arranged for a minimum of 1 foot.

## Part IV.

*Notes on Valve Circuit Design.*

Experiments were also carried out at Northolt with valves of the type to be used at Rugby, and gave considerable preliminary information about the working conditions. It was found that two different conditions of working could be employed, where the input and output were practically identical although the conditions of operation were widely different. The cases are compared in the table below and in Fig. 11.

TABLE I.

| | Case I. | Case II. |
|---|---|---|
| D.C. voltage ... ... | 10,000V | 10,000V |
| Direct current ... ... | 1.39A | 1.41A |
| Grid A.C. voltage (R.M.S. | 2,000V | 880V |
| Grid bias ... ... ... | 1,330V | 164V |
| Mean grid current ... | 0.19A | 0.082A |
| Oscillating current ... | 28A | 28.1A |
| High-frequency output ($R = 13.3$ ohms) ... | 10.4kW | 10.5kW |
| Efficiency ... ... | 74.8% | 74.5% |

In Case I the anode current has a peaky shape which is assumed in the example considered to be a half sine wave from which a third harmonic of one-third the amplitude is subtracted. In Case II it is of double-lumped shape, assumed to be a half sine wave to which the third harmonic has been added. From analysis on these assumptions it is shown that the efficiencies of the two systems are as shown in the following table.

TABLE II.

| | $V_0 = 10{,}000V$ | $V_0 = 7{,}000V$ |
|---|---|---|
| Case I. ... ... | 66% | 57% |
| Case II. ... | 64% | 61% |

In Case I the peak value of anode current is nearly five times the mean current: in Case II it is only three times. As Case II demands a considerably less maximum from the filament, it is more economical from the point of view of valve life.

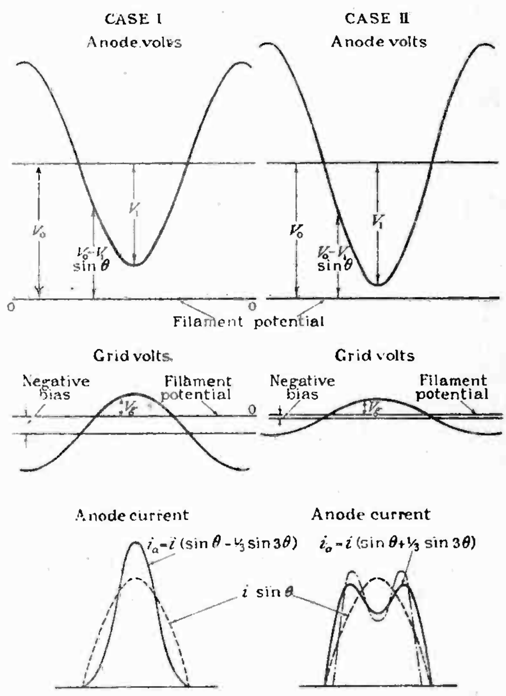


Fig. 11. *Showing alternative methods of operating the valves.*

Another substantial advantage is that greater outputs and higher efficiencies are obtainable when working at the lower anode voltages. It has been experienced that the behaviour of valves when tested in a low-power test set may be very different from that which obtains when used in a high-power transmitter. Current discharges, many times the maximum filament emission, can and do take place through the valve and may leave it quite unaltered as regards hardness and characteristics. In a low-power set the discharge causes an immediate drop in voltage which allows the valve to regain its equilibrium. In a high-power set the voltage drop on overload is not so marked and the valve has not the same opportunity of quick recovery. In these circumstances the discharge often causes the vacuum to be broken down.

The phenomenon may occur with hard valves (previously tested up to 12,000 or 15,000V) in the region of 7,000 volts D.C., and becomes more frequent as the voltage is increased. It is therefore concluded that in the present state of valve development high power sets should be designed to work on comparatively low voltages of the order of 7,000V.

## Part V.

*Keying and Shape of Signals.*

The arrangement of Keying is shown in Fig. 15, reproduced from Mr. Shaughnessy's original paper. It is explained that three keys have been provided at the points marked *a*, *b*, and *c* and that the combination of a grid-leak resistance with a grid bias generator for the final stage of power amplification enables a selective discrimination to be made between the mean grid bias used for signals and that used for "space," the conductivity of the valve increasing the decrement of the coupled aerial circuit during the space, and so improving the shape of the signals. The oscillogram of Fig. 16 shows the shape of the signals at 40 w.p.m., using the three keys and with 800 amperes in the aerial. The difference in decrement

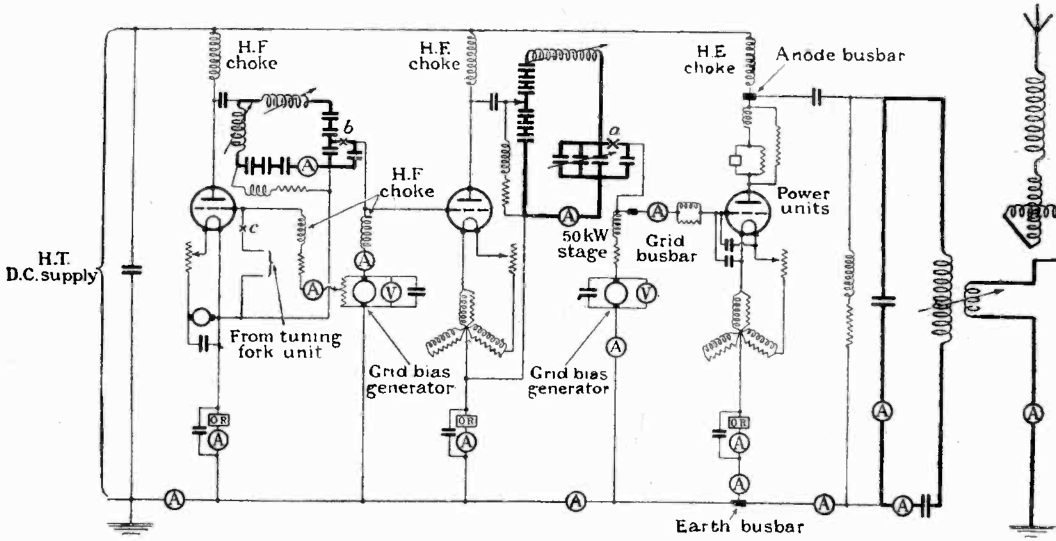


Fig. 15. *Skeleton diagram of transmitting circuits.*

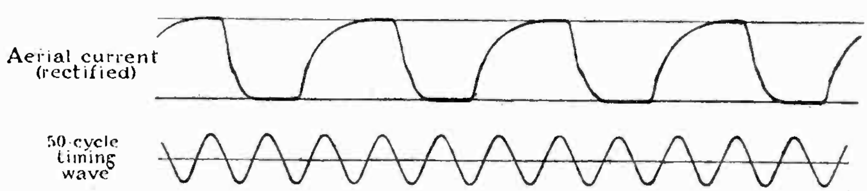


Fig. 16. *Keying* 800*A in aerial at* 40 *words per minute using three keys.*

on rise and fall is very marked, being for rise 0.0057 and for fall 0.011.

The necessity of taking a load through the valves with "key up" is then considered, and illustrated by several oscillograms showing the effect on the shaping of signals under different conditions.

It has been proved to be practicable to key the circuit by the use of one only of the three keys provided, *i.e.*, either at position "*a*" or at position "*c*" of Fig. 15, and oscillograms are also given of the signal shapes under these conditions.

## Part VI.

*Recent Results at Rugby.*

Since Mr. Shaughnessy's paper was read, the complete aerial supported by 12 masts has been brought into use for the telegraph set. The aerials on the north and south sides of the building are led in separately and joined in parallel by means of a stranded wire cable supported by insulators from the roof inside the building. At 16,000 cycles the aerial has effective capacity $45{,}000\mu\mu F$ and effective inductance $358\mu H$. The use of the combined aerial has enabled the normal working current to be increased from 550 to 740 amperes, the following table showing a schedule of readings for normal working conditions.

TABLE III.

*Schedule of Readings for Normal Running Conditions.*

| | | |
|---|---|---|
| Type of valve in use ... | VT26 | VT30 |
| Number of power units in use ... | 3 | 2 |
| Total number of valves in power units ... | 54 | 30 |
| Aerial current (A) ... | 740 | 700 |
| Aerial power(A) at 0.61 ohm (kW) | 335 | 300 |
| Total D.C. input to transmitter :— | | |
| Voltage (V) ... | 6,300 | 6,500 |
| Current (A) ... | 73 | 70.5 |
| Power (kW) ... | 4,608 | 4,608 |
| Filament power (kW) ... | 48 | 41 |
| Efficiency of transmitter % :— | | |
| Excluding filaments ... | 72.5 | 65 |
| Including filaments ... | 66 | 60 |
| Voltage on antenna (V) ... | 166,000 | 157,000 |

Valve type VT26 is rated at 10 and type VT30 at 20kW respectively.

The aerial resistance with masts insulated and earthed is shown in Fig. 25.

Tests were carried out with masts insulated and earthed on alternate days, the results of measurements made in America being shown below.

| Measurement at | Masts Insulated | Masts Earthed |
|---|---|---|
| Houlton-Maine | 578 $\mu V/m$ | 541 $\mu V/m$ |
| Washington ... | 131 $\mu V/m$ | 120 $\mu V/m$ |

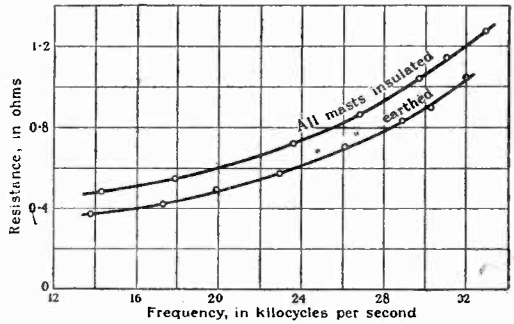


Fig. 25. *Aerial resistance curves for complete aerial using 12 masts.*

## APPENDIX.

An appendix shows the detailed development of certain of the mathematical expressions used in Part I.

## DISCUSSION.

The discussion was opened by **Mr. L. B. Turner,** who recorded his admiration of the great work which the Post Office had done and to the author's large share of responsibility in the work. He then discussed the oscillograms of signal shaping, referring to similar work of his own on the shaping of signals at the receiver. As regards the coupling circuit for minimising harmonics, the comparison of capacitative and inductive coupling was of great importance. He suggested the Post Office should proceed with the further condenser coupling to the aerial. This would permit greater coupling to the aerial and improvement in the delay action on signals.

**Mr. G. Shearing** also expressed great admiration of the work described. The addition of a rejector circuit with the Type A coupling gave good freedom from harmonics. He asked for information as to the relative cost of 6561/36 and 2187/32 stranded wires for comparison of economy and technical advantages; also as to the behaviour of the white-wood frameworks under damp conditions from fresh and salt water.

**Mr. B. S. Gossling** said the design of valves was now a matter of economics. A valuable contribution was given in the paper in the alternative conditions of operating giving the same efficiency. As regards the running cost and valve life, he agreed that reduction of emission was very important. He also discussed at some length the discharge effect mentioned in Part IV of the paper.

**Mr. A. C. Warren** also discussed this discharge, which he said had been attributed to a Schottky effect, although he expressed doubts of this. Possibly it was an effect of gas, perhaps from the copper anode. The problem was to prevent gas. If the effect was due to this it would occur at very definite voltages which depended on the geometry of the valve.

**Col. A. G. Lee** discussed the effect of coupled circuits and their phase relationships on the shape of signals, illustrating his remarks by the use of the familiar two-pendulum model.

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**Mr. Faulkner** briefly replied to several of the points raised in the discussion ; and on the motion of the Chairman (**Prof. C. L. Fortescue**) a cordial vote of thanks was accorded to the authors.

# Abstracts and References.

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## PROPAGATION OF WAVES.

Magnetic Storms and Wireless Communication. —(*Nature*, 118, 6th November, 1926, p. 662.)

A letter from Sir Joseph Larmor referring to the report recently that communication with Canada, by the new beam system of rays of short wavelength, had been completely blocked by a magnetic storm. He questions this, since the fluctuations of magnetic force are but slight, and the rays might be expected to arrive by an altered path. He suggests a deeper and more fundamental cause, namely, that the magnetic storm itself is due to an incursion of free electrons into the upper atmosphere, in such numbers as to upset all the ray-paths and twist them out of regularity. The only alternative, he says, seems to be oscillation of the magnetic field so rapid as to be comparable with the time of transit of the ray, which is very unlikely.

Zur Berechnung des Rotationssymmetrischen Strahlungsfeldes (Calculation of the radiation field of rotational symmetry).—F. Kiebitz. (*Annalen der Physik*, 80, 7, pp. 728-740.)

An integration of Maxwell's equations for the case of a radiating field, free from loss, of rotational symmetry, which leads to the following results :—

1. In every radiating field of rotational symmetry, that is free from loss, the direction of the field at any point in space can be calculated algebraically.
2. The electric field is propagated along the rays with the velocity of light.
3. The field strength in each ray is inversely proportional to the distance from the axis of symmetry.
4. If there is a large conducting sphere, with the source of radiation on its surface, the rays run in circular form from the transmitter as pole to the opposite pole.
5. The field lines in this case are circles, standing upright on the sphere's surface, with their centres lying on the axis of symmetry.

Die Ausbreitung der Elektrischen Wellen, insbesondere die Gerichtete Ausbreitung (The propagation of electrical waves, particularly directional propagation.) — F. Kiebitz. (*Elektrische Nachrichten-Technik*, 3, 10, pp. 376-382, October, 1926.)

An address to a Wiesbaden electrical meeting last June, when the author dealt with two of his contributions to our knowledge of wave propagation, namely, his mathematical description of the propagation of waves around the globe, which is summarised in the preceding abstract, and his morse sign method of directional transmission (*Jahrb. drahtl. Tel.*, 15, p. 299, 1920), which he believes could yield valuable information on directional telegraphy with the co-operation of broadcast listeners.

Ionization in the Upper Atmosphere.—S. Chapman. (*Royal Meteorological Society Journal*, 52, 219, pp. 225-236.)

A lecture delivered before the Royal Meteorological Society. The paper is divided into six sections dealing with the subject from the following aspects : Reflection of wireless waves ; comparison of wireless and magnetic results ; the cause of the general ionisation of the upper atmosphere ; the mode of ionisation of the air ; ionisation associated with auroræ, in high latitudes ; the auroral ionisation and spectrum.

A bibliography of the subject is appended.

General Electric Short Wave Test Results. —M. Prescott. (*Q.S.T.*, 10, 11, November, 1926, pp. 9-13.)

The results are given of a series of investigations on radio wave propagation conducted by the General Electric Company with the co-operation of about 500 amateurs. The tests were carried out on transmissions varying from 20,000 to 2,750 kC. The observations included day and night audibility, antenna comparison and fading. The results for audibility and antenna comparison are shown by means of curves. With regard to fading, this was recorded during both day and night transmissions on each of the frequencies under observation. Its occurrence was found to be a function of the frequency, becoming more troublesome as the frequency increased. The observers all found fading more pronounced at night than by day and that for both day and night an increase in the distance from the transmitter showed a lessening of the fading effect.

Short Wave Tests.—(*Scientific American*, November, 1926, p. 385.)

The Naval Radio Research Laboratory at Anacostia, D.C., is co-operating with 40 stations scattered over a territory of 7,000 miles in making tests on the 25.6-metre wavelength. So far it has been found that these signals are not audible in daylight within a 500-mile radius of the transmitter, but that the intensity is good in the zone between 700 and 1,200 miles, and that from 2,000 to 3,000 miles the waves seemed more uncertain than within the 2,000-mile region.

HORIZONTAL WAVE EXPERIMENTS AT 2AER.—J. Hollywood. (*Q.S.T.*, 10, 11, pp. 32-33, November, 1926.)

The general problem of wave propagation is briefly examined, illustrations being shown of the "pebble in the pond" theory, the radiant ray theory, and the "line of force" theory.

The tentative conclusion is drawn that radio energy is transmitted in the form of lines of force which are reflected from the ionised layer of the atmosphere in straight lines.

The experiments show that for local and long distance work, the transmitting and receiving stations should both use the same type of transmission and reception, either vertical or horizontal; while for semi-local and medium distance work, the signals should be transmitted vertically and received horizontally—this method being also best for ultra short-wave work.

## ATMOSPHERICS.

LES PERTURBATIONS ORAGEUSES DU CHAMP ELECTRIQUE ET LEUR PROPAGATION À GRANDE DISTANCE.—P. Lejay. (*L'Onde Electrique*, 5, 58, pp. 493-499, October, 1926.)

The introduction and first two of five chapters of a communication delivered before the S.A.T.S.F., 14th April, 1926 (thesis for the doctorate). The paper is summarised as follows:—

Introduction: Brief outline of what we know about storms; general character of the earth's electric field at the Pic du Midi Observatory; conditions under which the experiments described were made; relative constancy of the field on a mountain.

Chap. I.: Recall of the mathematical expression for the field produced by a rectilinear discharge compared to a doublet. Applications to the discharge of clouds: the variation of the static field should be felt at a great distance; the effects produced on an antenna and a frame can be very different; the radiogoniometry of atmospherics is only possible at a great distance.

Chap. II.: The variations of the static field during storms have been measured with a radium potential collector joined up either to an electrostatic voltmeter, or in the case of distant storms, to a new amplifying electrometer, the principle and method of employment of which are described in detail.

Chap. III.: Analysis of some ten storms, varying in distance from 1 to 100 kilometres, shows that the variations of the static field reach 300 volts per metre at 30 km. from the lightning and some tenths of a volt at 100 km. It is proved, on the one hand, that the flashes coincide with the occurrence of atmospherics in the receiver, but on the other hand, there are numerous sudden and violent variations of the field without any luminous manifestation.

Chap. IV.: The circuit arrangement ordinarily employed to analyse atmospherics by the cathode oscillograph deforms the disturbances: these last a very short time and assume very complex forms.

Chap. V.: Meteorological data do not conflict with the preceding results, but to a certain extent confirm them. It is not right to assert in general that atmospherics have no range—this depends on the violence of the discharge that has given rise to the disturbance and can be considerable.

ABSTRACTS OF PAPERS ON THE METEOROLOGICAL RELATIONS OF ATMOSPHERICS.—R. A. Watson Watt. (*Journal of the Meteorological Society*, 52, 218, pp. 199-208.)

A bibliography of the relations between meteorological phenomena and the intensity of atmospherics compiled for a committee appointed to consider whether observations on atmospherics might be of service in weather forecasting. From the summary of conclusions by different observers it is seen that, apart from overwhelming unanimity in favour of the correlation between the occurrence of actual thunder or lightning and atmospherics, and moderate agreement in the correlation with convective processes in the absence of reported thunder, the evidence is contradictory. Reasons assigned for this are:—

1. The range of reception for atmospherics reaching probably the length of the earth's semi-circumference, comparison between received atmospherics and local weather is to a certain extent like comparing the weather of a parish with the electrical phenomena of a hemisphere.

2. It is still impossible to find a scale and a classification for the intensity and character of atmospherics which shall be generally acceptable, unambiguous, and capable of assessment by the average observer.

Mr. Watson Watt writes in conclusion, however, that the evidence that the atmospheric was well, if rashly, named is accumulating rapidly, and the summaries of the most recent work show that the location of "cold fronts" by radio telegraphic observations on atmospherics is an established possibility.

PROGRESSIVE LIGHTNING.—C. V. Boys. (*Nature*, 20th November, 1926, pp. 749-750.)

An article referring to the papers recently published by Dr. Simpson and Dr. Dorsey on the start and progress of a lightning flash. Mention is made of a paper by Dr. Hoffert that it is thought these authors have overlooked. This paper shows that a lightning flash is very often multiple: two, three, or many more flashes succeeding one another very rapidly along exactly the same path. It also shows, with the help of photographs, that a flash within a cloud, terminating (or starting?) at a point from which the main flash started, preceded this by a very evident interval, and that this region remained luminous until the third main flash had occurred. Prof. Boys further relates an observation of his that may also have some bearing on the conclusions of the two authors. On one occasion when watching a storm he noticed that for every flash seen in the rain cloud and below, there were simultaneously one or more very slender flashes from the cloud upwards, many times as long as the lightning below, reaching perhaps halfway towards the stars of the Great Bear (which were in their lowest position)—at one moment there were seven of these flashes going into the clear sky.

Prof. Boys also describes apparatus he has made for obtaining experimental evidence of the progress of the lightning flash.

LIGHTNING DISCHARGES.—T. Gilbert. (*Electrical Review*, 26th November, 1926, pp. 870-871.)

The phenomenon of the lightning discharge is explained with particular reference to the protection of radio aerials and apparatus.

DIE GRÖSSE DES LUFTELEKTRISCHEN KONVEKTIONSSTROMES (The value of the atmospheric electric convection current).—W. Schmidt. (*Physik Zeitschr.*, 27, 14, pp. 472-473.)

A new calculation of the atmospheric electric convection current showing that the density of the upwards directed current is less than $\cdot 87.10^{-9}$ stat. units/cm² sec. and therefore not greater than the eight-hundredth part of the supposed mean conduction current (about $7.10^{-7}$).

## PROPERTIES OF CIRCUITS.

ÜBER KIPPSCHWINGUNGEN, INBESONDERE BEI ELEKTRONENRÖHREN (Concerning "tilting" oscillations, particularly with valves).—E. Friedländer. (*Archiv. für Elektrotechnik*, 16, 4, pp. 273-279, July, 1926; 17, 1, pp. 1-16, September, 1926; 17, 2, pp.103-142, October, 1926.)

The production of "tilting" (*i.e.*, in unstable equilibrium) oscillations, periodic changes of charge of a single store of energy, is shown to occur in a series of systems containing no actual oscillatory circuit. These oscillations are characterised by the cyclic sudden changing of an unstable position of equilibrium. The frequency is essentially determined by the time constants and applied tension and not by the natural frequency of any part of the system. This in general only comes into evidence when with the tilting of the charged store of energy there is no discharge path available. Of the known means for generating undamped oscillations the valve has not yet been remarked as a producer of tilting oscillations, and in this article a simple valve oscillator, with transformer grid and anode circuit coupling, is investigated for the tilting phenomena. The oscillograms obtained are in agreement with the forms of oscillation found theoretically. It is also shown that every amplifier is in a position to execute tilting oscillations and that only the fact that involuntary back-couplings occur to disturb their development can explain the exclusion of undesired oscillation phenomena in many cases.

ON "RELAXATION-OSCILLATIONS."—B. van der Pol, Jun. (*Philosophical Magazine*, 2, 11, pp. 978-992, November, 1926.)

A consideration of the equation

$$\ddot{v}-\epsilon(1-v^2)\dot{v}+v=0$$

with the supplementary condition $\epsilon \ll 1$, and an investigation of the sequence of events when $\epsilon \gg 1$. No approximate analytical solution could be obtained with this latter condition, but it is shown how a graphical solution may be easily found. The equation for the quasi-aperiodic case, which differs considerably from the normal approximately sinusoidal solution, is shown to have again a purely periodic solution, the time period of which is expressed by the time of relaxation of the system—hence the suggestion of the term "relaxation-oscillation" for this phenomenon.

ERZWUNGENE SCHWINGUNGEN IN ANGEFACHTEN SYSTEMEN (Forced oscillations in excited systems).—F. Ollendorff. (*Archiv für Elektrotechnik*, 16, 4, pp. 280-288.)

An investigation of the properties of forced oscillations in coupled systems for the particular case of the oscillating audion and a method of integrating the fundamental equation is outlined that is applicable to all coupled systems.

LOAD CARRYING CAPACITY OF AMPLIFIERS.—F. Willis and L. Melhuish. (*Bell System Technical Journal*, 5, 4, October, 1926, pp. 573-592.)

A paper describing the adaptation of the cathode ray oscillograph to the determination of the overload point of vacuum tube amplifiers. Using the input voltage to produce a horizontal deflection, and the output voltage or current to produce a vertical deflection, the amplifier performance is readily determined by noting the resulting figure on the fluorescent screen. So long as the figure is virtually a straight line or an obviously undistorted ellipse, the amplifier output is free from harmonics, but as soon as overloading begins, the oscillogram shows either a sharp bend at either or both extremities of the line or apparent distortion of the ellipse. The method has the advantage of being quick.

GIBT ES EINEN UNTERSCHIED ZWISCHEN STOSSERREGUNG UND AUSSIEBUNG VON OBERSCHWINGUNGEN BEIM RUHENDEN FREQUENZWANDLER? (Is there any difference between impact-excitation and the filtering out of harmonics with the static frequency changer?) —R. Kümmich. (*Zeitschr. für Tech. Physik*, 17, 7, pp. 337-345.)

The principal phenomena in frequency multiplication by static transformers can be regarded from two points of view: one that it is a case of the filtering out of harmonics (also selection of the higher harmonic named), the other that it is a question of impact excitation. It is shown here that the physical phenomenon is capable of only one interpretation and can be looked at from either aspect, which only appear to be contradictory.

SUPERSONIC TRANSFORMERS. — N. McLachlan. (*Wireless World*, 10th November, 1926, pp. 631-634; 17th November, 1926, pp. 680-684; 24th November, 1926, pp. 715-718.)

A paper in four parts dealing respectively with the design and performance of iron-cored types, the measurement of transformer magnification curves and valve coefficients, the measurement of primary inductance, effective primary capacity and optimum wavelength, and the application of these transformers to superheterodyne circuits.

GENERAL FORMULÆ FOR TWO SYNTONISED COUPLED CIRCUITS.—R. Wilmotte. (*Philosophical Magazine*, November, 1926, 2, 11, pp. 1,098-1,108.)

## TRANSMISSION.

MODULATION UND ÜBERTRAGUNGSGÜTE IN DER HOCHFREQUENZTECHNIK (Modulation and quality of the transmission in high-frequency technics).—F. Trautwein. (*Zeitschr. für Techn. Physik*, 17, 7, pp. 345-352.)

Discussion of the correctness of the frequency and amplitudes in broadcast transmission—which it is for the most part possible to obtain with present day technique. All that seems to be lacking is a technically useful method of modulating one side band, which the author suggests supplying by combining two oscillations, modulated after the two-side band, whose high and low frequency parts are 90° out of phase.

L'EMISSION À FAIBLE PUISSANCE.—R. Desgrouas. (*L'Onde Electrique*, September, 1926, 5, 57, pp. 489-490.)

A brief note enumerating the merits of the "symmetrical circuit arrangement" for short-wave communication.

A SHIELDED CRYSTAL-CONTROLLED UNIT.—J. Clayton. (*Q.S.T.*, November, 1926, 10, 11, pp. 22-25.)

Detailed description of a compact completely shielded unit which may be used either as a good low power outfit or as a "feeder" for a larger, and unshielded, amplifier.

## RECEPTION.

WAVE PROPAGATION IN OVERHEAD WIRES WITH GROUND RETURN.—J. Carson. (*Bell System Technical Journal*, 5, 4, October, 1926, pp. 539-554.)

A solution of the problem, required for the theory and design of the wave antenna, is given here for the case where the actual earth is replaced by a plane homogeneous semi-infinite solid, the complete solution not being possible, owing to the inequalities in the earth's surface and its lack of conductive homogeneity.

NOTES ON WIRELESS MATTERS.—L. B. Turner. (*Electrician*, 8th October, 1926, pp. 412-420; 12th November, 1926, pp. 556-557.)

Continuation of the discussion of the detector problem begun in the *Electrician* of 10th September. A letter from "R.L.H.," in the issue of 12th November, p. 564, questions Mr. Turner's assumption that the form of the signal is sinusoidal.

NOTE SUR UN NOUVEAU MONTAGE NEUTRODYNE. —F. Dufrenoy. (*L'Onde Electrique*, 5, 57, September, 1926, pp. 487-489.)

Diagrams of two new neutrodyne circuit arrangements are shown utilising to the full the difference of potential in the oscillating circuit.

RADIO INTERFERENCE.—R. Ashbrook and R. Wight. (*Electrical World*, 23rd October, 1926, pp. 851-853.)

An article dealing with "man-made" interference as distinct from atmospherics. The causes of such interference are discussed and experiments in locating it described.

## STATIONS: DESIGN AND OPERATION.

BROADCASTING IN SWEDEN.—(*Electrician*, 12th November, 1926, p. 560.)

Details are given of the new 30-45kW station that is being erected at Motala, on Lake Vättern, about 200 km. south-west of Stockholm. The rectifying system consists of 8 water-cooled tubes each rated at 10kW at 10,000V anode potential. The drive oscillator has 1 water-cooled tube with 10,000V on the anode, derived from 2 air-cooled rectifier tubes, while the amplifier system comprises 4 water-cooled tubes in parallel, of the same rating as the rectifier tubes. The filament takes 50 amps at 20V. The wavelength, which it is hoped will be definitely allocated for this station, is 1,350 metres. It is expected that relay stations will be set up at Boras, Halmstadt, Uddevalle, and Upsala.

CANADA — TRANSMITTING STATIONS. — (*Electrical Review*, 12th November, 1926, p. 798.)

A short paragraph under "Radio Notes," stating that there are now 543 transmitting stations in Canada, of which 67 are broadcasting stations, 356 are amateur and experimental, 67 are code stations, and 46 are operated on the coasts and great lakes for the benefit of shipping. All broadcasting and other wireless in the Dominion is under the direction of the Dominion Government Department of Marine and Fisheries.

RADIO SIGNALLING SYSTEM FOR THE NEW YORK POLICE DEPARTMENT.—S. Anderson. (*Bell System Technical Journal*, 5, 4, October, 1926, pp. 529-538.)

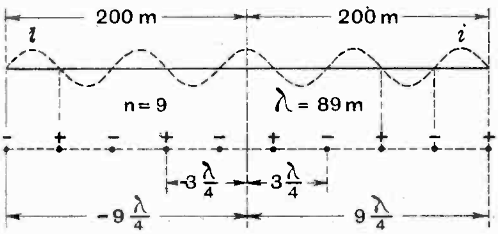
By means of the system described it is possible, through the addition of a comparatively simple attachment to a standard radio telephone transmitter, to modulate the carrier with an audio-frequency tone in such a manner as to provide for calling individually, simultaneously, or in a number of designated groups, any one of several hundred radio receiving stations. At the receiving stations apparatus is provided giving a visible or audible signal to the operator that a message is about to be broadcast to which he should listen.

## DIRECTIONAL WIRELESS.

STRAHLUNGSUNTERSUCHUNGEN AN HORIZONTALEN SENDEDRÄHTEN, DIE IN EINER HÖHEREN HARMONISCHEN ERREGT SIND (Investigation of radiation from horizontal transmitting wires excited in a high harmonic).—G. Grimsen. (*Elektrische Nachrichten-Technik*, 10, 3, pp. 361-376.)

Exciting a horizontal conductor, placed close to the earth's surface, in its ninth harmonic, produces marked directivity in the radiation from it. To calculate the distant effect characteristic of this horizontal arrangement, its total radiation is replaced by the sum of the radiations from a row of perpendicular dipoles, oscillating with the same frequency and amplitude and alternately of opposite phase, as represented in the figure below.

This substitution is permissible when the distribution of the field lines radiating from these vertical dipoles is the same at the earth's surface as that due to the horizontal antenna. This is the case if the conductivity of the ground plays the same part in the range of these short waves as with long waves, *i.e.*, the lines of electric force close to the transmitter are perpendicular to the earth's surface and horizontal components are absent. On this assumption, the radiation diagram calculated for the ninth harmonic of a conductor 380 m. long ($\lambda = 85$ m.) shows marked directivity in the direction of the axis, and places where the radiation is nil on either side of it.




This calculated radiation diagram was tested experimentally by taking field measurements with a movable receiver (thermo-element and galvanometer) in different directions around the transmitter, when the results were found to be in good agreement with the theoretical figure. Confirmation of the theoretical propagation diagram was also obtained by means of Kiebitz' inverse morse sign method (*Jahrb. drahtl. Tel.* 15, p. 299, 1920), divergences between calculated and observed values being only remarked at places where disturbance of the propagating medium was likely owing to the presence of transmission lines or antenna structures.

Imperial Wireless "Beam" Communication. (*Electrical Review*, 29th October, 1926, pp. 709-712; 5th November, 1926, pp. 749-751.)

The first public telegraph service operated on the short-wave beam system was opened on 21st October. An account is given here of the English stations concerned, at Bodmin and Bridgwater, for transmitting and receiving respectively, the corresponding stations in Canada being at Drummondville and Yamachiche.

The inauguration of the Canadian beam service is also discussed in *E.W.& W.E.* for December, pp. 715-716, and the Bodmin and Bridgwater stations are described in the *Wireless World* of 3rd and 24th November respectively.

The Flying Loop.—O. Wright. (*Q.S.T.*, 10, 11, November, 1926, pp. 36-40.)

The results are given of tests with a frame aerial installed on a De Haviland airplane.

## VALVE DESIGN AND THERMIONICS.

Reactivating Vacuum Tubes. (*Scientific American*, September, 1926, p. 224.)

A short paragraph quoting from a Technical News Bulletin of the National Bureau of Standards. The method given for restoring filaments to full activity is to disconnect the "B" batteries from the receiver and burn the filaments above normal brilliancy for half an hour.

Thermionic Emission of the Metals Tungsten, Molybdenum, Thorium, Zircon and Hafnium. C. Zwikker. (*Proc. Royal Acad. Amsterdam*, 29, 6, pp. 792-802.)

Discussion concerning the value of $A$ in the emission formula

$$i = AT^2\, 10^{-\frac{\ }{T}}\ Amp./cm.^2$$

It is shown that for every pure metal surface examined $A$ could be represented by 60.2. Discrepancies found in the case of zircon and hafnium are attributed to their being covered with an oxide layer up to the melting point.

The Effect of a Hydrogen Atmosphere on the Velocity Distribution among Thermionic Electrons.—C. del Rosario. (*Physical Review*, 28, 4, October, 1926, pp. 769-780.)

The thermionic current from a tungsten or platinum filament to a coaxial cylindrical electrode was measured for different retarding potentials, first in vacuum and then in hydrogen, keeping the temperature of the filament constant. The distribution of velocities among the electrons in vacuum and in hydrogen was found to follow Maxwell's law and, contrary to the experience of former observers, the temperature calculated from the Maxwellian distribution was found to be the same for the case of a vacuum as for that where hydrogen was present. The maintenance of thermal equilibrium between the electrons and the filament in hydrogen suggests the elastic nature of the collisions between the electrons and the hydrogen molecules.

## MEASUREMENTS AND STANDARDS.

Establishment of Radio Standards of Frequency by the Use of a Harmonic Amplifier.—C. Jolliffe and G. Hazen. (*Scientific Paper No.* 530 *of the Bureau of Standards.*)

The method consists essentially of the production of harmonics of the fundamental frequency of an alternating current by means of the non-linear characteristics of valves, the selection of any desired harmonic by means of tuned circuits, and its amplification to sufficient power to operate a standard frequency meter (wavemeter). Any harmonic of the source may be selected, and thus from a known audio-frequency source a frequency meter may be standardised throughout its entire range.

Die Graphische Dimensionierung von Elektrischen Schwingungskreisen (Finding the dimensions of electrical oscillatory circuits graphically).—E. Asch. (*Zeitschr. für Techn. Physik*, 17, 7, pp. 330-332.)

A graphical method is described of finding the natural frequency of capacities and inductances joined together in parallel.

Discussion on Portable Receiving Sets for Measuring Field Strengths at Broadcasting Frequencies, by A. Jensen.—G. Gillett. (*Proc. Inst. Radio Engineers*, 14, 5, October, 1926, pp. 699-705.)

A paper showing how these sets are being used in the field in actual field strength measuring work and their great value for research work.

A New Method of Obtaining Frequency Stabilisation of a Transmitter by means of an Oscillating Quartz Crystal.—C. Goyder. (*E.W. & W.E.*, 3, 39, December, 1926, pp. 717-724.)

Description of a method of employing the oscillating quartz crystal to obtain a constant frequency at a transmitter, which is said to have decided advantages from the point of view of simplicity, flexibility, efficiency and reliability, over the method of pure high-frequency amplification at present in general use.

The Absolute Measurement of Resistance at Radio Frequencies. R. Wilmotte. (*E.W. & W.E.*, 3, 39, December, 1926, pp. 725-729.)

## SUBSIDIARY EQUIPMENT AND MATERIALS.

Magnetic Permeability of Iron in High Frequency Alternating Fields.—G. Wait. (*Physical Review*, 28, 4, October, 1926, p. 848.)

Abstract of paper presented at the Oakland meeting of the American Physical Society last June. Wwedensky and Theodortschik have found the magnetic permeability of iron in alternating fields to be abnormally large in certain frequency bands, and nearly normal in other regions. The wavelengths corresponding to these bands were approximately 88 metres and 100 metres. The general appearance of the phenomena suggested the existence of resonators corresponding to these frequencies. The effect has also been observed by Kralovec. The writer has repeated the experiments and finds the permeability of the samples used much more constant than would appear from the measurements of these investigators. Two experimental methods were used: one consisted in the measurement of the inductance of a coil by a resonance method, the inductance being measured with the sample inside the coil and with it out; and the second method employed a heterodyne arrangement of two high-frequency valve circuits and one of audio frequency

Le Fonctionnement des Ampèremètres Thermiques en Haute Frequence.—J. Granier. (*Q.S.T. Français et Radio Electricité Réunis*, 7, 32, pp. 45-48.)

Les Transformateurs. — J. Vivie. (*Q.S.T. Français et Radio Electricité Réunis*, 7, 32, pp. 11-23.)

An article dealing principally with the mathematics of the transformer.

A Sensitive Vacuum Tube Relay.—W. Hoffman and F. Schnell. (*Q.S.T.*, 10, 11, November, 1926, pp. 20-21.)

Description of a relay developed from a circuit appearing in a recent issue of the *Wireless World*. A diagram is given of the modified circuit and a photograph showing the arrangement of the apparatus.

Further Notes on the Laws of Variable Air Condensers.—W. Griffiths. (*E.W. & W.E.*, 3, 39, December, 1926, pp. 743-755.)

## GENERAL PHYSICAL ARTICLES.

Methoden und Ergebnisse der Klangforschung (Methods and results of sound research).—F. Trendelenburg. (*Zeitschr. für Hochfrequenz*, 28, 2, pp. 54-64; 28, 3, pp. 84-91.)

After considering the theoretical bases for the investigation of sound and examining the different methods, the results are discussed in so far as they affect the questions of sound transference and reproduction.

A Simple Exposition of Electro-magnetic Relations. — H. Biggs. (*Philosophical Magazine*, 2, 11, November, 1926, pp. 1052-1056.)

The Scattering of Cathode Rays.—B. Schonland. (*Proc. Roy. Soc.*, 113, A763, November, 1926, pp. 87-106.)

## MISCELLANEOUS.

Über die Rückwirkung des Menschlichen Körpers auf Sender und Empfänger bei kurzen Wellen (The reaction of the human body on transmitter and receiver with short waves).—N. Skritzky and W. Lermontoff. (*Zeitschrift für Hochfrequenz.*, 28, 3, pp. 82-83, September, 1926.)

During the authors' work at the Leningrad experimental electro-technical laboratory where various transmitters and receivers for wavelengths of 1-4 metres were set up and tested, observations

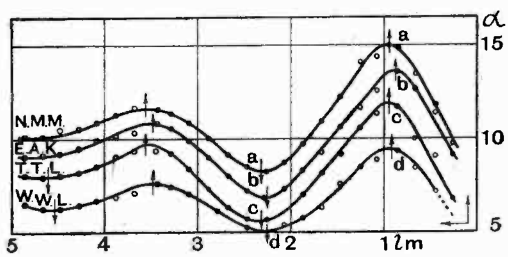



Fig. 3

were made throwing light on the question of the effect of a person's presence near the apparatus, a description of which is given here.

Two series of observations were made:—

In the first series a person moved perpendicularly to the line joining receiver and transmitter along a straight line passing through the centre of the receiving frame. The readings on a galvanometer in the receiving circuit corresponding to his different distances from the receiver are shown in curve *a* below (where the abscissæ are distances and the ordinates the readings) characterised by a succession of maxima and minima.

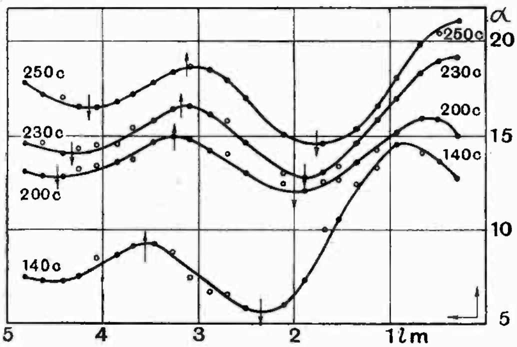



Fig. 4.

The curves *b*, *c*, *d*, with their ordinates displaced for the sake of clearness, represent the phenomena for three other people. All the curves show the same character—only the position of the maxima and minima varying slightly in each case.

In the second series of observations, instead of a person, a wooden stick carrying a copper wire was moved along the same path. The stick alone did not affect the galvanometer, but with wires of different lengths the following curves were obtained.

The series of maxima and minima obtained in the two sets of observations are seen to be very similar. Now a copper rod in the electro-magnetic field of a progressing wave absorbs a part of its energy and radiates it again in the form of forced oscillations of the transmitter frequency, the interference curves (Fig. 4) thus representing the resultant effect of two electro-magnetic fields acting simultaneously on the receiver, and the great similarity between the two series of curves permits the conclusion to be drawn that the effect of electro-magnetic fields in the human body is similar to that in a straight oscillator, *i.e.*, the body absorbs radiation energy and sends it out again in forced oscillations of the transmitter frequency.

The effect of different persons is somewhat different, but the question whether the method can be used conversely for giving information on the living organism must to-day be left undecided the authors say.

La Determination des Differences de Longitude par Télégraphie sans Fil.—L. de la Forge. (*Q.S.T. Français et Radio Electricité Réunis*, 7, 32, pp. 38-44.)

La Téléphonie sans Fil par Ondes Lumineuses.—M. Chauvierre. (*Q.S.T. Français et Radio Electricité Réunis*, 7, 32, pp. 24-28.)

First part of a general description of the transmission of speech by light waves, dealing with early experiments on the subject.

Bildübertragung und Schnelltelegraphie (Picture transmission and high-speed telegraphy).—F. Schröter. (*Zeitschr. für techn. Physik*, 17, 9, pp. 417-428.)

Description of experiments on photo-telegraphy carried out by the Telefunken Company in conjunction with Professor Carolus. Illustrations of apparatus are shown, also samples of photographs and text telegraphed.

Television.—J. L. Baird. (*E.W. & W.E.*, 3, 39, December, 1926, pp. 730-739.)

A paper read before the Radio Society of Great Britain on 26th October, 1926.

Wireless Progress.—C. L. Fortescue. (*Electrician*, 12th November, 1926, pp. 563-564; *E.W. & W.E.*, December, 1926, pp. 740-742.)

Abstracts of the Chairman's address at the opening meeting of the Wireless Section of the Institution of Electrical Engineers on 3rd November.

The B.E.S.A. Glossary.—G. W. O. Howe. (*Electrical Review*, 5th November, 1926, p. 778.)

A letter in reply to that of Prof. Fortescue in the *Review* of 24th September, p. 523. Prof. Howe explains that his criticism was directed less to the system of units employed than to confusion in its use, particularly to the failure to distinguish clearly between electric force and flux density. This latter is criticised in the *Review* of 12th November, p. 818, by Mr. F. T. Fawcett, who points out that in it Prof. Howe makes "force" mean "work"; and again in the *Review* of 19th November, p. 831, Prof. Fortescue asks for the *physical* difference between field strength and flux density.

# Esperanto Section.

## Abstracts of the Technical Articles in our last Issue.

# Esperanto-Sekcio.

## Resumoj de la Teknikaj Artikoloj en nia lasta Numero.

### R000. SENFADENO ĜENERALE.

R050.—RESUMOJ KAJ ALUDOJ.

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

R060.—MALFERMO DE LA SEZONO DE LA INSTITUCIO DE ELEKTRAJ INĜENIEROJ.

Mallonga raporto estas presita pri la malferma kunveno de la 1926-7a Sezono de la I.E.I. (Londono), kiam la nova Prezidanto, Dro. W. H. Eccles faris sian prezidantan paroladon. La parolado temis la esploron kaj komparon de la ĉefaj kampoj de moderna elektra disvolviĝado.

### R200.—MEZUROJ KAJ NORMOJ.

R240.—LA ABSOLUTA MEZURADO DE REZISTECO JE RADIO-FREKVENCOJ.—R. M. Wilmotte.

La aŭtoro unue diskutas la malfacilaĵojn de altfrekvencaj rezistecaj mezuroj, kaj montras ke, se kurento estas pasigita tra bobenon posedantan rezistecon, la tuto de la energio dispelita estos liberigita kiel varmo, tiel ke la rezisteco estas mezurebla per mezurado de la kurento kaj la varmo kreita. Diversaj metodoj uzitaj por fari ĉi tiun mezuradon estas diskutitaj, kaj la aŭtoro priskribas metodon utiligi bobenojn laŭ formo de bobeno de vitra tubo plenigita je hidrargo. Unu ekstremaĵo estas fermita, kaj la alia finiĝas per kapilara tubeto, sur kio estas du markoj, kelkajn centimetrojn apartaj unu de alia, tiel ke la bobeno fariĝas ĝia propra termometro. Du tiaj bobenoj estas faritaj, kaj oni donas grafikaĵojn por la K.K. kaj A.F. normigoj por ĉiu. La rezistecoj tiel kalkulitaj estis uzitaj por kontroli la ordinarajn rezistec-variadajn metodojn de mezurado, kun tabelo de komparaj rezultoj, dum la bezono por zorgeco je tiaj mezuroj estas emfazigita. Vario de la terma metodo por la mezurado de kurento je tre altaj radio-frekvencoj estas ankaŭ sugestita.

### R300.—APARATO KAJ EKIPAĴO.

R351.—NOVA METODO POR OBTENI FREKVENCAN STABILIGON DE SENDILO PERE DE OSCILA KVARCA KRISTALO.—C. W. Goyder.

Post enkonduka diskutado pri la fenomeno de sinkronizado, oni rimarkas, ke je agordita-anoda agordita-krada tipo de oscilatoro sub 200 metroj, ne estas necese kupli la bobenojn senpere, la valva kaj hazarda kuplo sufiĉanta. Cirkvito tiuspeca estas uzebla kune kun kvarc-kristala kontrola oscilatoro, la cirkvito estante permesita oscili propravole je proksimume la kristala frekvenco, dum sinkronizo kun la kvarca oscilatoro konservas stabilecon de frekvenco. La apliko de ĉi tiu principo al amplifikatoro funkcianta je malgrand-potenca (ekz., ¼ ĝis ½ k.v.) sendilo, estas montrita kaj diskutita. Oni pretendas, ke la aranĝo donas pligrandan efikecon al la ne-oscila tipo de amplifikatoro. Ĉiuj sendilaj cirkvitoj havas krad-cirkviton, al kiu la kristale kontrolita aparatero estas kuplebla ; tial la metodo estas nur aldona kaj neniaj ŝanĝoj estas necesaj ĉe la ekzistanta sendilo. Por plimallongaj ondolongoj, harmoniko de la kristala frekvenco povas esti simile uzita, tiu ĉi aranĝo ankaŭ estante ilustrita kaj diskutita. Oni faras ĝeneralajn rimarkigojn pri la alĝustigo de sendila amplifikatoro ĉi tia, kaj pri la ĝenerala funkciado de kvarckristala kontrolado.

R381.4.—PLUAJ NOTOJ PRI LA LEĜOJ DE VARIEBLAJ AERAJ KONDENSATOROJ.—W. H. F. Griffiths.

La artikolo estas daŭrigo de antaŭa kontribuaĵo de la sama aŭtoro (*E.W & W.E.*, Januaro 1926a), en kiu oni kunmetis formularon por la platformoj necesaj por doni definitivajn leĝojn kunrilatigantajn Ondolongan (aŭ Frekvencan) kaj Angulan Movadon.

La nuna artikolo diskutas la okazojn kiam simila rilatigo estas dezirita, je kiu la kondensatoro estas uzita kun multa ekzistanta kapacito paralele aŭ serie je ĝi.

Koncerne paralelan kapaciton, oni diskutas la okazojn pri variebla kondensatoro de 16 $\mu\mu$F minimume, kaj 480 $\mu\mu$F maksimume, kiam ĝi estas kunligita paralele kun "pliigantaj" kapacitoj de 20, 84, kaj 284 $\mu\mu$F respektive. La formo de la platoj por doni linian ondolongan leĝon en ĉiu okazo estas montrita.

La okazo pri seria kapacito estas tiam diskutita sub la rubrikoj : (1) Platformo por Rektlinia Leĝo de Kapacito, (2) Platformo por Korektita Kvadrata Leĝo de Kapacito, t.e., Rektlinia Ondolongo, (3) Platformo por Inversa Kvadratleĝo de Kapacito t.e., Rektlinia Frekvenco, (4) Platformo por Konstanta Procenta Ŝanĝo de Ondolongo kaj Kapacito. Oni kunmetas esprimojn por la platformo en ĉiu okazo, kaj la diversaj formoj ilustritaj. Fina tabelo tre nete resumas la kvar okazojn.

### R500.—APLIKOJ KAJ UZOJ.

R586.04.—TELEVIDADO.—Prelego de S-ro. J. L. Baird, legita de Leŭt.-Kol. J. R. Yelf, antaŭ la Radio-Societo de Granda Britujo, je 26a Oktobro, 1926a.

Kiel enkonduko, la aŭtoro unue diskutas la lumrespondon de selenio kaj foto-elektraj ĉeloj, kaj la optika ago de la homa okulo. Sekvas mallongaj raportoj pri la plifruaj eksperimentoj pri Televidado, t.e., tiuj de Rignoux kaj Fournier, Rhumer, Rosing, Campbell Swinton, k.t.p., kaj la plimalfrua laborado de Belin kaj Holweck, Jenkins, Moore, k.c. Skizo pri la sistemo de l'aŭtoro tiam sekvis, kaj oni diris, ke de la unuaj sendoj de lumo kaj ombroj, figuroj de diversaj objektoj, inkluzive de la vivanta homa vizaĝo, estis senditaj kun duontonoj kaj detaloj. Fotografaĵo de unu el la figuroj estis donita, kaj oni diris, ke la difektoj estas grade forigitaj.

Diskuto kiu sekvis la legadon de l'prelego estas ankaŭ presita.

R599.—SENFADENA DISVOLVIĜADO DEPOST LA MILITO.—Resumo de la malferma parolado de Prof. C. L. Fortescue, Prezidanto de la Senfadena Sekcio, Inst. de Elek. Inĝ. farita ĉe la malferma kunsido de la Sekcio je 3a Nov. 1926a.

La lekcio estis dediĉita al kritikema revuo pri la disvolviĝo de la senfadeno dum la pasintaj sep jaroj, la progresado pri Sendiloj, la Senda Medio, kaj Riceviloj, estante diskutita.

Rilate al Sendiloj, oni diskutis la progresadon de la Arko, A. F. Alternatoro, kaj, la Grandpotenca Valvo. Koncerne la Sendan Medion, la agoj de la reflekta tavolo ĉe longaj kaj mallongaj ondoj estis komparitaj.

Pri Riceviloj, oni unue diskutis la Antenon "Beverage"; poste ricevilan selektivecon, atmosferaĵojn, k.t.p. La stato de brodkastado estis fine revuita, kun aludo al interfero de la komerca ŝipa trafiko.

## R800.—NE-RADIAJ TEMOJ.

510.—MATEMATIKOJ POR SENFADENAJ AMATOROJ.—F. M. Colebrook.

Daŭrigita el la antaŭaj numeroj. La nuna parto daŭrigas pri la Ĝenerala Ekvacio de la *n* Grado, kaj poste traktas Samtempajn Ekvaciojn por du Nekonitaj Numeroj, de la unua kaj dua gradoj, k.t.p.

535.—LA ENKONDUKO DE NATRIO KAJ KALIO EN DISŜARGAJN TUBOJN.—Dro. J. Taylor.

Oni donas priskribon pri metodo enkonduki puran natrion aŭ kalion en vakuigitan disŝargan tubon per speco de elektrolizo tra la vitraj muroj. La bulbo estas trempita en fanditan natrian (aŭ kalian) nitraton varmigitan en metala (ekz., aluminia) ujo, kiu estas igita la anodo de disŝarga sistemo kun la filamento kiel katodo. La pura metalo estas tiam aŭ demetita sur la internan muron de la vitraĵo aŭ vaporigita en la bulbon. Oni sugestas la eblecon ke, per variigo de la speco kaj konsistaĵo de la muroj, aliaj elementoj povus esti enkondukita je stato de granda pureco en tiajn vakuigitajn specojn. La metodo estas ankaŭ uzita per neona disŝarga lampo kun multa sukceso pliiganta ĝian stabilecon de funkcio.

# Correspondence.

*Letters of interest to experimenters are always welcome. In publishing such communications the Editors do not necessarily endorse any technical or general statements which they may contain.*

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

**Plate-current, Plate-voltage Characteristics.**

SIR,—Permit me to attempt to reconcile the views of Messrs. E. Fowler Clark and I. A. J. Duff on the above question.

To take the simple case where a low frequency transformer may be represented as a simple inductance and resistance in series, with no load on the secondary the magnification of valve plus

$$\text{transformer} = \mu . \frac{n_2}{n_1} \sqrt{\frac{X^2}{X^2+(R+\rho)^2}}$$

where $\mu$ = amplification factor of valve.
$n_1$ = primary turns on transformer.
$n_2$ = secondary turns.
$X$ = primary reactance.
$R$ = effective resistance of primary
and $\rho$ = A.C. resistance of valve.

If we assume with Mr. Fowler Clark that reactance and resistance are both proportional to the square of the primary turns and write

$$X = an_1^2; \; R = bn_1^2$$

then (magnification)$^2$

$$= \mu^2 \frac{n_2^2}{n_1^2} \cdot \frac{a^2n_1^4}{a^2n_1^4+(\rho+bn_1^2)^2}$$

From which it can easily be shown that :—

1. If the transformer ratio $\frac{n_2}{n_1}$ is constant then maximum amplification occurs when $n$ is infinite, *i.e.*, infinite primary impedance.

2. If the transformer secondary turns $n_2$ is constant, maximum amplification occurs when the transformer impedance equals the resistance of the valve.

If we consider the more practical case where the transformer is shunted by a condenser, either external or in the form of its own self-capacity, then two values are again found for the primary impedance of transformer combined with condenser, according as $\frac{n_2}{n_1}$ or $n_1$ is regarded as constant. The first relationship still gives us infinite impedance for maximum amplification. The second case, however, does not give us maximum amplification when the impedance of transformer, or transformer and condenser, equals the resistance of the valve. As evidence of this, consider the case where the transformer plus condenser show a capacity reaction and the impedance of the two, or transformer alone, equals the resistance of valve. By reducing the primary turns we will increase the impedance of the circuit, hence increase the voltage across the transformer primary and increase also the transformer ratio, thus giving an increased total amplification. This is obviously at variance with Mr. Fowler Clark's rule.

A statement by Mr. E. Green on page 470 of the August issue of *E.W. & W.E.* must be similarly qualified. The statement, "For amplifiers using tuned circuits maximum amplification occurs when the output power is a maximum for a given amplitude of grid voltage," requires some qualification.

If we consider a tuned anode circuit consisting of an inductance $L$ in series with a resistance $R$, the whole shunted by a condenser $C$, then if $R$ and $L$ are regarded as fixed, and $C$ is varied, the rule holds good. If, however, $C$ is fixed so that $\omega^2LC = 1$, and $R$ is varied then maximum amplification obviously occurs with minimum power output, when $R = 0$.

We must conclude therefore that the laws laid down by Messrs. Green and Fowler Clark are by no means generalities, and should indeed be accepted with a very liberal pinch of salt.

S. Farnborough. C. HOLT SMITH, B.Sc.

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

SIR,—I am surprised to read a letter in your November number from Mr. E. Fowler Clark, B.Sc., B.A., A.M.I.E.E., attempting to correct a letter by Mr. I. A. Duff, in which he still maintains that a transformer primary impedance should be equal to that of a valve in whose plate circuit it is connected.

The elementary theory of intervalve coupling is very simple to follow, and even in the more advanced form in which all the various factors entering, are taken into account, it should not be beyond the understanding of a technically trained man, and yet the above idea seems to persist.

The function of any method of intervalve coupling is to pass on the voltage applied to the grid of the first valve through the coupling, to the grid of the following valve, magnified and, as far as possible, a true copy. It is only voltage that is passed on and amplified. If the valves are being correctly used, there should be no current flowing in the grid circuit except that caused by the grid capacity to the filament or the self-capacity of the grid circuit. Any such current is a loss. When we come to the last valve, the state of affairs is somewhat different. The magnified voltage which reaches the grid circuit of this valve has to produce power in the plate circuit of the same valve, this power being necessary to work a loud-speaker to produce sound energy. The magnified voltage which we have obtained and applied to the grid of this valve acts purely as a relay, the energy being drawn from the battery feeding the plate circuit of this valve. This seems to me a clear statement of the case and Mr. Clark, to some extent, admits this, but then enters into a complicated and almost unintelligible argument about maximum activity in the primary, and so on.

But there is another way of settling this matter apart from any question of theory or calculation. It is quite easy, as far as concerns the audio frequency stages, to measure the actual voltages obtained across the grid of each valve, and it is also comparatively easy to measure the impedance of the primary winding of the intervalve coupling, for example, an intervalve transformer for audio frequencies. If this is done it will be found that the impedance of the primary winding is smallest for the lowest frequencies. increases to a maximum at some intermediate frequency, say 1,000 cycles for a very good transformer, or up to 2,000 cycles for a poor one, and then fails off again as the frequency is increased beyond this point. If Mr. Clark will turn back to the October and November numbers of your paper for the year 1924, he will see a number of measurements made by Mr. Dye at the National Physical Laboratory.

Now a transformer I am interested in has, under the working conditions in a wireless set, an inductance of somewhere about 90 henries, which gives an impedance at 25 cycles (a very low frequency) of about 14,000 ohms. This, by measurement in the plate circuit of a valve whose impedance was 10,500 ohms, and whose amplification factor was slightly above 9, gave for the 25-cycle signal an amplification of **22**. Now, at about 1,000 cycles, the impedance of the primary winding of this transformer has increased to something of the order of 800,000 ohms, and the amplification of the valve and transformer then measured was **31·6.** Here Mr. Clark will see that when the impedance of the transformer primary was somewhere near equal to that of the valve (that is, 14,000 ohms against 10,000 ohms for the valve) the voltage amplification obtained of the valve and transformer is only 22, but when the impedance of the transformer (namely, 800,000 ohms) is enormous compared with that of the valve, the amplification is then at its greatest, namely, 31·6. I may say these sort of figures have been measured by myself on hundreds of occasions and have been measured by the same and by other methods by other experimenters who, as far as reputation is concerned, would be considered more important than myself. Hence, Mr. Clark has to solve this problem : When the impedance of the transformer primary matches that of the valve, the amplification obtained is quite low. This is not a question just of frequency; it is merely a question of the impedance of the winding against that of the valve at whatever frequency that may, in a particular transformer, be obtained. On the other hand, when the impedance of the primary is exceedingly high, the amplification you get is just that which you expect to obtain from the $\mu$ of the valve and the ratio of the transformer and is much greater than in the first case. The statement apparently made by Mr. Duff that the *transformer primary should be of the utmost possible impedance and not of equal impedance to the valve, is absolutely true.* I have made for experimental purposes a transformer whose primary winding had an inductance of over 200 henries and a ratio of $3\frac{1}{2}$. At 25 cycles, the impedance, as Mr. Clark will be able to calculate, is of the order of 31,000 ohms, and so very much greater than the above mentioned valve, and the amplification obtained then was about 28 (I have not the exact figure by me as I made the measurements in Canada). Here we have a transformer with a primary impedance, at whatever frequency you care to take, much greater than anything which can be obtained commercially, giving a better amplification with a given valve than any commercial article would give.

Of course, we cannot go on indefinitely increasing the impedance of the primary of a transformer, because self-capacity is introduced, which will actually, at high frequencies, reduce the impedance and give for notes, say of 4,000 to 8,000 cycles, a lower amplification than is desirable. This, and the question of price and weight, sets the limit to the inductance which one can incorporate in the primary of a low frequency transformer.

I have written at some length hoping to have made the matter clear enough to convince those who still hold *the erroneous idea* that impedance of the primary of a transformer should equal that of the valve. At the best this seems a curious phrase because, as explained, the impedance of the primary of a transformer may vary from a very low figure up to three-quarters of a million ohms.

Stockport. ALBERT HALL, A.R.C.Sc.

## Signal Fading.

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

SIR,—Having been an observer of the variations of radio signal intensity with weather conditions for several years, I have been very much interested in the articles on signal fading and related subjects published in your journal in recent months.

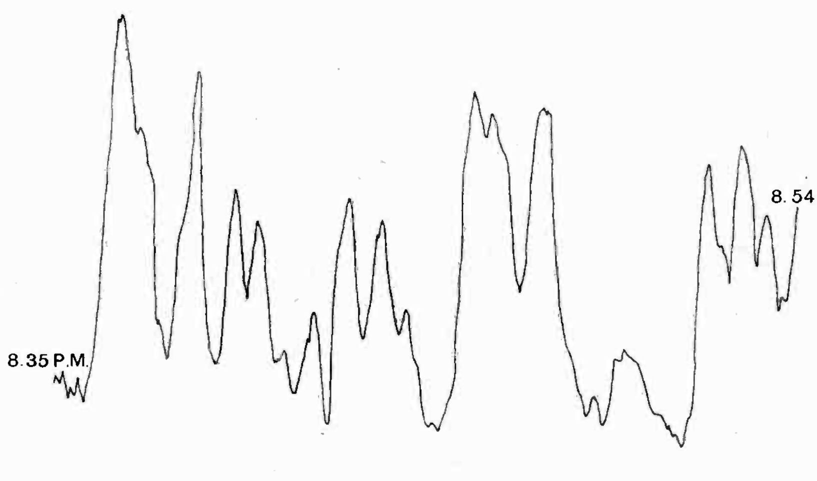
Our laboratory is located almost in the geographical centre of the United States so that we are surrounded by rolling plains for at least 300 miles in every direction and are near no large body of water. Furthermore, stations at Denver, Dallas, New Orleans, Atlanta, Pittsburg, Cincinnati, Chicago and Minneapolis can be logged on almost any winter evening, and often we get Los Angelos on the west and New York on the east. For a number of months we have had in operation a signal-fading recorder which consists of a six-valve superheterodyne, in the last stage of which is a rectifying valve in series with a sensitive galvanometer. The galvanometer throws a beam of light through a right-angled prism on a rotating drum 30 cm. long and 8 cm. in diameter. The enclosed sample records show the general form of the curves obtained, the ordinates being proportional to the square of the received current and the abscissæ the time coordinates. These curves are also typical of the types of fading observed. The first from WHT shows unusually steady reception, the second from WCCO is long-period fading with 6 to 8 minutes between maxima, and the third from WOAI shows violent short period fading.

It is possible here to give only a few of the outstanding features of our experiments to date, one report on the earlier observations having already been published. (See *Radio Broadcast*, March, 1926.) We have found that on a night when fading is severe in one direction it also interferes with signals from other directions but usually to a lesser extent. Fading may be most troublesome in one direction on one night and in quite another direction on the next night. It also is independent of the sending station. Contrary to Mr. Chapman's statement in his excellent article in the issue for September, 1925, we have on record some good coincidences in both magnitude and period of fading on WSMB recorded by our own apparatus and another stationed four miles west of us. The best conditions for radio reception as respects signal intensity, absence of static, and fading, occurs when transmission takes place along the ridge of an extended high-pressure area. With transmission at right angles to the isobars signal strength is also good but the signal-to-static ratio may be high.

So far as the influence of the moon is concerned we have collected no definite data, but it probably is of a second-order magnitude. Doubtless sunspot activity and penetrating radiations play an important part in determining the height and conductivity of the Heaviside Layer whose presence seems now to be proved by the experiments of Breit and others. The Heaviside Layer is above the isothermal region and much farther above the surface strata where storm phenomena and convection currents exist that the convolutions in this layer which are needed to explain fading on the Heaviside theory, or the variations in its density which are demanded by the Larmor hypothesis, must result primarily from causes outside the earth, or from variations in the earth's magnetic field. The latter view I have not seen previously suggested and I have not had available the necessary magnetic data to prove it, but it would at least help to explain the polarisation experiments of Dr. Pickard and the direction shifts recently observed by Professor Bidwell. Perhaps some of your English investigators have available the necessary magnetographic apparatus to check it up.


WHT 11TH SEPT 1925


WCCO 21ST. DEC. 1925.




WOAI 3RD NOV. 1925.

J. C. JENSEN.
Nebraska Wesleyan University, University Place, Nebraska, U.S.A.

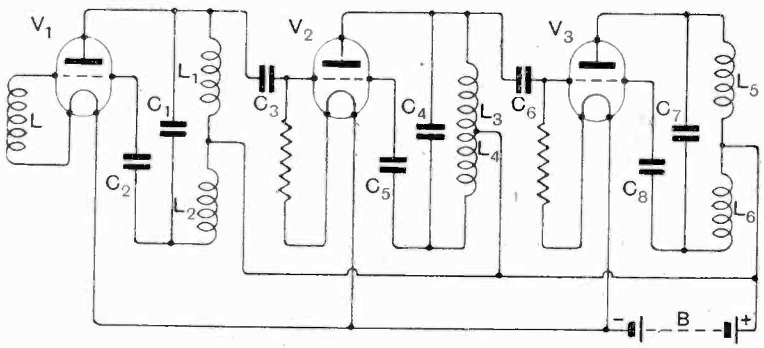
# Some Recent Patents.

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

## A NEUTRALISED AMPLIFIER.

(*Application date, 20th July,* 1925. *No.* 260,036.)

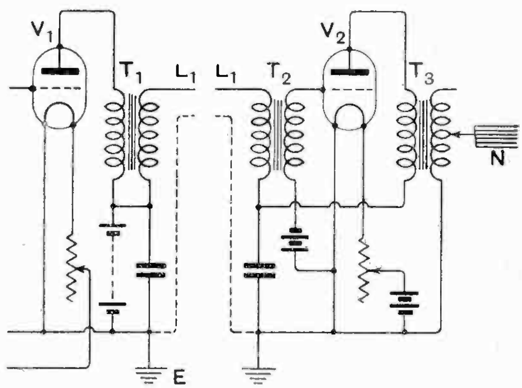
Those who are familiar with multi-valve amplifiers, employing several stages of neutralised intervalve coupling, will, no doubt, have experienced considerable difficulty in stabilising the arrangement, although each particular stage appears to be perfectly neutralised. A circuit which overcomes this difficulty is described in the above British Patent, No. 260,036 by H. J. Round, and consists essentially of a series of high frequency circuits, the inductances of which are alternately astatic and non-astatic. The arrangement of the three valves, $V_1$, $V_2$ and $V_3$, is shown in the accompanying illustration. The input of the first valve comprises an inductance $L$, while the anode circuit contains an astatic inductance comprising two portions, $L_1$ and $L_2$, that is, one inductance wound on a common former, the two portions being in opposition. The centre tap is taken to the high tension supply $B$, and the whole inductance is tuned by a variable capacity $C_1$. The anode end of the inductance $L_1$ is coupled to the grid of the next valve $V_2$ by means of a condenser $C_3$, while the other end of the inductance is connected through a neutralising capacity $C_2$, to the grid of the first valve. The anode circuit of the second valve $V_2$ includes an inductance $L_3$ $L_4$, which is non-astatic, that is, an ordinary centre tap coil which is coupled to the next valve $V_3$ through a condenser $C_6$, while the free end is taken through a neutralising capacity $C_5$ back to the grid of the second valve. The anode circuit of the next valve $V_3$ contains another astatic arrangement $L_5$ $L_6$, the arrangement being continued for other valves if desired. The oscillatory circuits associated with each valve are, of course, balanced, but since the inductances in the input and output circuits of each valve are different, there is no tendency for the generation of oscillations by the system as a whole, which frequently arises when the ordinary centre tap method is employed.




## INDUCTIVE REPRODUCTION.

(*Application date, 6th August,* 1925. *No.* 260,061.)

Readers will, no doubt, remember that details were given in these pages in a past issue of *E.W. & W.E.* of a system of inductive reproduction described in a specification by G. W. Hale and R. Lyle. The above British Patent specification gives further details of a modification of the invention. The arrangement consists in using a powerful low frequency amplifier, the output of which is connected to earth, and a system of insulated overhead wires, a fairly strong low frequency alternating current field existing between the two. In order to receive the music it is only necessary to wear a pair of head telephones, the leads of which are of sufficient area or occupy sufficient space to cut

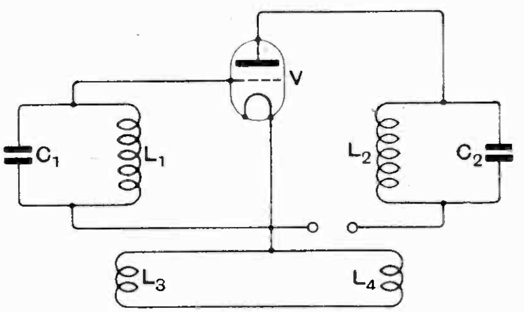



the field, and have produced in them low-frequency currents of appreciable magnitude. The present invention gives details of a convenient method for extending the system. For example, it may be necessary to have a distributing network in more than one room. It is not found convenient to energise all the networks from one amplifier, and accordingly one network is electrically connected with another amplifying valve, and is used at the same time for supplying the high tension current. Thus, in the accompanying illustration the valve $V_1$ represents the last valve of the main amplifier, the anode circuit containing a transformer $T_1$ which is connected to a line $L_1$ and earth $E$. The line $L_1$ may also be connected to one of the distributing networks in some particular room. The continuation of this line $L_1$ is connected to an input transformer $T_2$, which is between the grid and filament of a valve $V_2$. The anode circuit of the valve $V_2$ deriving its power from the line contains an output transformer $T_3$, which, in turn, energises another frame or network $N$, located in another portion of the building. The usual batteries and other components of the valve circuits are quite normal, and are, therefore, not mentioned in detail.

## NEUTRALISING MAGNETIC COUPLING.

(*Application date, 2nd July*, 1925. *No.* 260,324.)

A method of neutralising magnetic coupling existing between the input and output circuits of a valve is described in the above British Patent by Igranic Electric Company, Limited, and P. W. Willans. The invention should be clearly understood by reference to the accompanying illustration, which shows a valve $V$ provided with an input oscillatory circuit $L_1$ $C_1$, and an output oscillatory circuit $L_2$ $C_2$, the two being substantially equivalent. Owing to the disposition of the two induct-

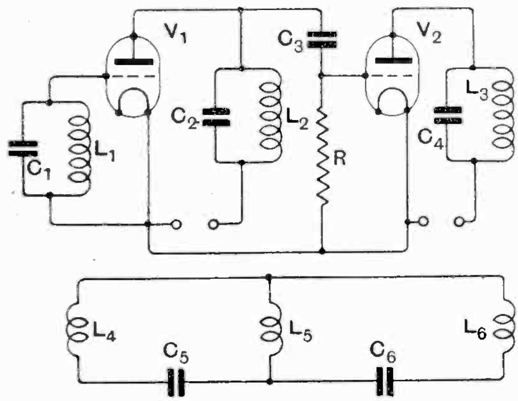



ances $L_1$ and $L_2$, it usually happens that there is an appreciable magnetic coupling between the two, and the mutual induction is frequently sufficient to sustain the generation of continuous oscillations by the valve at the frequency of the tuned circuits. The effect of this coupling is neutralised or overcome by the inclusion of two other auxiliary inductances $L_3$ and $L_4$, consisting of a considerably smaller number of turns than those used in the main inductances $L_1$ and $L_2$. The inductance $L_3$ is tightly coupled to the inductance $L_1$, and the inductance $L_4$ is similarly coupled to the inductance $L_2$. The two inductances $L_3$ and $L_4$ are then connected together so as to form a closed circuit, and they are so arranged that potentials transferred from the output circuit to the input circuit are such that they tend to oppose any regenerative effect between the input and output circuits. Another point to notice in the circuit is that the two inductances $L_3$ and $L_4$ are connected to the filament of the valve, thereby fixing their potentials in space with respect to earth, further tending to stabilise the arrangement as a whole.

## NEUTRALISING CAPACITATIVE COUPLING.

(*Application date, 2nd July*, 1925. *No.* 260,325.)

The above specification, also granted to Igranic Electric Company, Limited, and P. W. Willans, is very similar to British Patent No. 260,324. In the former specification details were given of a system of neutralising inductive coupling, while in the present specification a somewhat similar system is

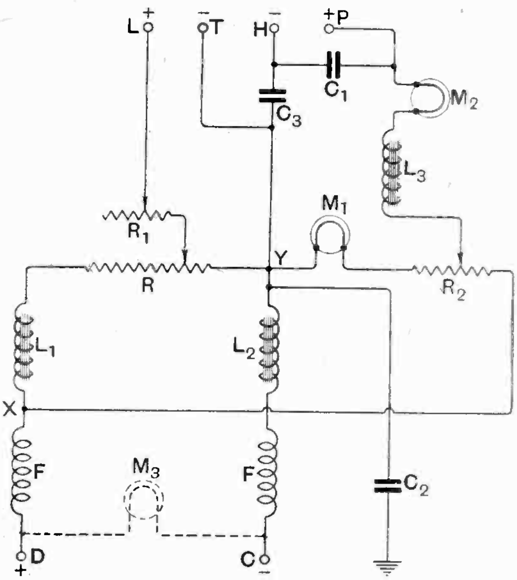



used, only in this case it is the capacitative coupling which is neutralised. Previous methods of neutralising capacity have consisted in connecting, perhaps, one end of an anode inductance through a capacity to the grid of the valve, or, alternatively, connecting the grid of the valve through a small capacity to another inductance coupled to the anode inductance. The specification states that the disadvantage of this arrangement is that unless this capacity is very small it adds very considerably to the capacity either of the anode or grid circuit. The system employed according to the present invention is shown applied to a two-valve circuit in the accompanying illustration. Two valves $V_1$ and $V_2$ are shown connected together through the usual system of oscillatory circuits, where the input to the first comprises an inductance $L_1$ tuned by a capacity $C_1$. The anode circuit of this valve contains another inductance $L_2$ tuned by a capacity $C_2$. The anode end of this inductance is coupled through a capacity $C_3$ and a grid-leak $R$ to the grid-filament system of the valve $V_2$. The anode circuit of the valve $V_2$ contains an inductance $L_3$ and a condenser $C_4$, the three oscillatory circuits being tuned to substantially the same frequency. The usual anode and filament batteries are omitted for the sake of clearness. Normally a system such as this would generate continuous oscillations owing to the inherent stray capacities existing between the input and output circuits of the valves. The stabilisation system consists of three inductances $L_4$, $L_5$ and $L_6$, which are respectively coupled to the inductances $L_1$, $L_2$ and $L_3$. One side of the three inductances $L_4$, $L_5$ and $L_6$ is common, while the free ends of $L_4$ and $L_5$ are joined through a capacity $C_5$, and the free ends of $L_5$ and $L_6$ are joined through another capacity $C_6$. The direction of the windings of $L_4$, $L_5$ and $L_6$ in relation to the inductances $L_1$, $L_2$ and $L_3$ respectively is so arranged that the induced currents tend to oppose regeneration between the circuits. In another modification of the invention instead of connecting the three inductances $L_4$, $L_5$ and $L_6$ directly together connection may be made through condensers.

## MAINS SUPPLY.

(*No.* 259,260. *Application date*, 30*th April*, 1925, *and No.* 259,262, *Application date*, 8*th May*, 1925.)

G. G. Blake and L. Russell-Wood claim various circuital arrangements for mains supply to broadcast receivers in the above two specifications.

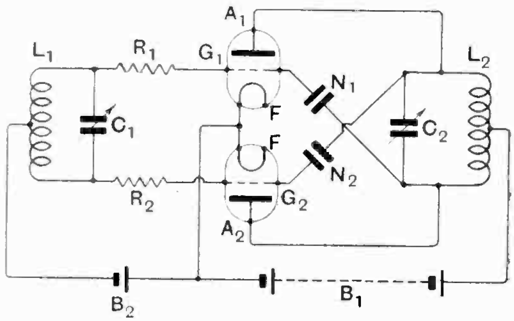


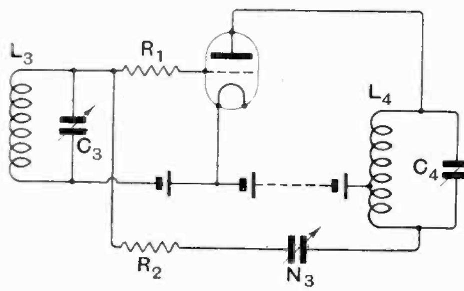

Perhaps the most important feature of the invention is the inclusion of radio-frequency chokes, and the accompanying illustration is taken from one of the specifications, which should indicate most of the chief features of the invention. The mains supply is shown at *D C*, which may be either the leads from a direct current supply, or from a rectified alternating supply. These are taken through high frequency chokes *F*. The filament supply is then taken through two iron-cored chokes $L_1$ and $L_2$, across which is a resistance *R*. The filament current is then drawn from *L T* through another variable resistance $R_1$, which is used for finer regulation. The high tension supply is actually taken across the points *X* and *Y*, *i.e.*,, through both radio-frequency chokes, and the low frequency choke $L_2$. The resistance across the high tension supply comprises a lamp $M_1$ and a resistance $R_2$, the H.T. supply being drawn through the choke $L_3$ and another lamp $M_2$, the whole being shunted by a large condenser $C_1$. A protecting condenser $C_2$ is included in the earth lead, which, of course, is usual practice. A similar safety condenser in the H.T. circuit is shown at $C_3$. Another feature of the two inventions which is dealt with in the former specification lies in the use of series resistances in the main positive high tension lead *P* for the purpose of obtaining varying voltages for separate valves in the receiving system. Another rather interesting feature of the invention is the use of a third lamp $M_3$, which, of course, glows brightly since it is directly across the mains, so as to indicate when the system is live.

## STABILISING RADIO-FREQUENCY AMPLIFIERS.

(*Application date*, 29*th June*, 1925. *No.* 260,321.)

One of the greatest problems in radio-frequency amplifier design is that of stabilisation. Some of the earliest attempts at stabilising amplifiers consisted in increasing the damping of one or more of the circuits which, although preventing the generation of oscillations, was most inefficient, since it lowered the overall amplification, and also materially affected the selectivity. Balanced or neutralised circuits are preferable, since neither of these defects is present. Even with a carefully balanced circuit stabilisation is not always secured.



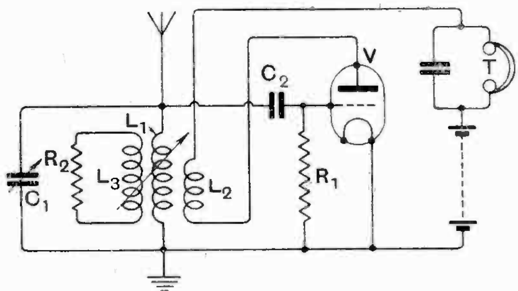




Why this is so, and how it may be prevented, is disclosed in the above British Patent, which is granted to G. M. Wright and S. B. Smith. It is pointed out in the specification that although a circuit may be electrically balanced when considered as a Wheatstone Bridge, and it would appear that there could be no transference of potentials between input and output circuits of a valve, oscillations are even maintained under these conditions, and this, it is stated, is due to the fact that secondary oscillations are existent. These may pass from one tuned circuit through one valve, the second tuned circuit, the second valve, and back to the first circuit, and the balancing condensers do not prevent these oscillations taking place. The accompanying illustrations show how the secondary oscillations may be prevented by the inclusion of series resistances. One circuit is actually a two-valve push-pull arrangement. The input circuit comprises a centre tapped inductance $L_1$ tuned by a capacity $C_1$, while the output circuit is an inductance $L_2$ tuned by a capacity $C_2$, the inductance $L_2$ again being centre tapped, the anode potential being introduced at this point, while the grid potential is introduced at the centre tap of the inductance $L_1$, the two batteries being $B_1$ and $B_2$ respectively. The filaments $F$ of the two valves are connected, of course, to the centre tap and common battery junction. The ends of the oscillatory circuit $L_2$ $C_2$ are connected to the two anodes $A_1$ and $A_2$. Neutralising condensers $N_1$ $N_2$ are included between the anode of one valve and the grid of the other. The secondary oscillations are prevented from occurring in the system by the inclusion in the two grid leads of resistances $R_1$ and $R_2$ respectively. The illustration also shows a single valve arrangement, which is, no doubt, more familiar. Here the input comprises an inductance $L_3$ tuned by a capacity $C_3$, while the anode circuit contains an inductance $L_4$, tuned by a capacity $C_4$. The anode battery is connected to a tapping of the inductance $L_4$, while the remote end is taken through a neutralising condenser $N_3$ to the grid of the valve. Stabilising resistances $R_1$ and $R_2$ are again inserted. The specification states that it is necessary in order that stabilisation may occur for the ratio of the inter-electrode capacity to the neutralising capacity and the resistances to be given by the product of $R_1$ and the valve capacity to equal the product of $R_2$ and the neutralising capacity.

## CONTROLLING REACTION.

(*Application date, 31st July*, 1925. *No.* 260,359.)

A resistance method of controlling reaction where a special controlling circuit is introduced is described by N. H. Clough in the above British Patent. Only the theoretical circuit is shown in the accompanying illustration, but the specification gives details of certain constructional methods which are found preferable. Essentially, the invention consists in coupling a resistive circuit through a system which is generating oscillations, the coupling being increased until a sufficient amount of the resistance of the circuit is thrown back into the oscillatory circuit, thereby causing a cessation of the generation of oscillations. A very simple circuit is shown in the accompanying illustration, which should make the invention quite clear. Here the grid circuit of the valve $V$ comprises an inductance $L_1$ tuned by a capacity $C_1$. The grid circuit also contains a grid condenser $C_2$ and grid-leak $R_1$. The anode circuit of the valve includes a reaction coil $L_2$ and the telephones $T$. The reaction coil is tightly coupled to the aerial coil $L_1$, the direction of the windings being such that the valve will continue to generate oscillations. The resistive control circuit which is shown as an inductance $L_3$ shunted by a resistance $R_2$, is capable of being variably coupled to the inductance $L_1$. The resistive control circuit may comprise one or more turns of resistance wire, or may comprise simply one or more turns of ordinary copper wire shunted by

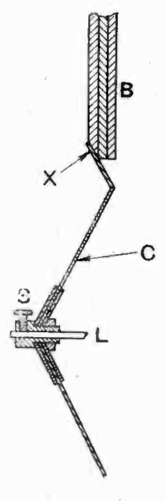



an ordinary resistance element. The specification also indicates other suitable forms of construction such as a number of closed circuits comprising one or more short-circuited turns of resistance wire. Another point which is mentioned in the specification is that when the invention is applied to a variometer the resistive circuit may be variably coupled to an inductance which is in series with one of the windings of the variometer.

## A LOUD-SPEAKER DIAPHRAGM.

(*Convention date* (*U.S.A.*), *5th January*, 1926. *No.* 258,502.)

The construction of a loud-speaker diaphragm is claimed in the above British Patent by Hopkins Corporation. The diaphragm itself consists of a cone $C$ made of paper, provided with the usual form of collar and set screw $S$, by means of which it is connected to a driving link $L$, operated by the usual form of telephone receiver. The periphery of the conical diaphragm is bent back as shown at $X$, where it is united to the edge of a three-ply sound board $B$. The sound board has considerably greater area and mass than the conical diaphragm itself. A particular feature of the invention is the use of Balsa wood, which is exceedingly light and thin, and which is stated to improve very considerably the quality of the reproduction, particularly that of the lower frequencies. It is also mentioned in the specification that no explanation of this particular fact is suggested.



# BUYERS' GUIDE.

**ACCUMULATORS.**—C. A. Vandervell & Co., Ltd., Acton, London, W.3.

**AMMETERS.**—Burndept Wireless, Ltd., Aldine House, Bedford Street, Strand, W.C.2.

**COILS.**—Igranic Electric Co., Ltd., 149, Queen Victoria Street, E.C; Pettygrew & Merriman (1925), Ltd., 2 & 4, Bucknall Street, New Oxford Street, W.C.1.

**COIL HOLDERS.**—Igranic Electric Co., Ltd., 149, Queen Victoria Street, E.C. Pettygrew & Merriman, (1925), Ltd., 2 & 4, Bucknall Street, New Oxford Street, W.C.1.

**CHOKE (L.F.).**—Lissen Ltd., Friars Lane, Richmond, Surrey.

**CONDENSERS (GENERAL).**—Autoveyors, Ltd., 84, Victoria Street, S.W.1. Bowyer-Lowe Co., Ltd., Letchworth. Dubilier Condenser Co. (1925), Ltd., Goldhawk Road, W.12. Igranic Electric Co., Ltd., 149, Queen Victoria Street, E.C. Lissen Ltd., Friars Lane, Richmond, Surrey. Marconiphone Co., Ltd., 210, Tottenham Court Road, W.1. Pettygrew & Merriman (1925), Ltd., 2 & 4, Bucknall Street, New Oxford Street, W.C.1. W. G. Pye & Co., "Granta Works," Montague Road, Cambridge. Wilkins & Wright, Ltd., Utility Works, Kenyon Street, Birmingham.

**GALVANOMETERS (CAMBRIDGE UNIPIVOT).**—Cambridge Instrument Co., Ltd., 45, Grosvenor Place, S.W.1.

**GRID LEAKS.**—Igranic Electric Co., Ltd., 149, Queen Victoria Street, E.C. Lissen Ltd., Friars Lane, Richmond, Surrey. Watmel Wireless Co., 332a, Goswell Road, E.C.4.

**KNOBS (SPECIAL TYPE).**—Igranic Electric Co., Ltd., 149, Queen Victoria Street, E.C.

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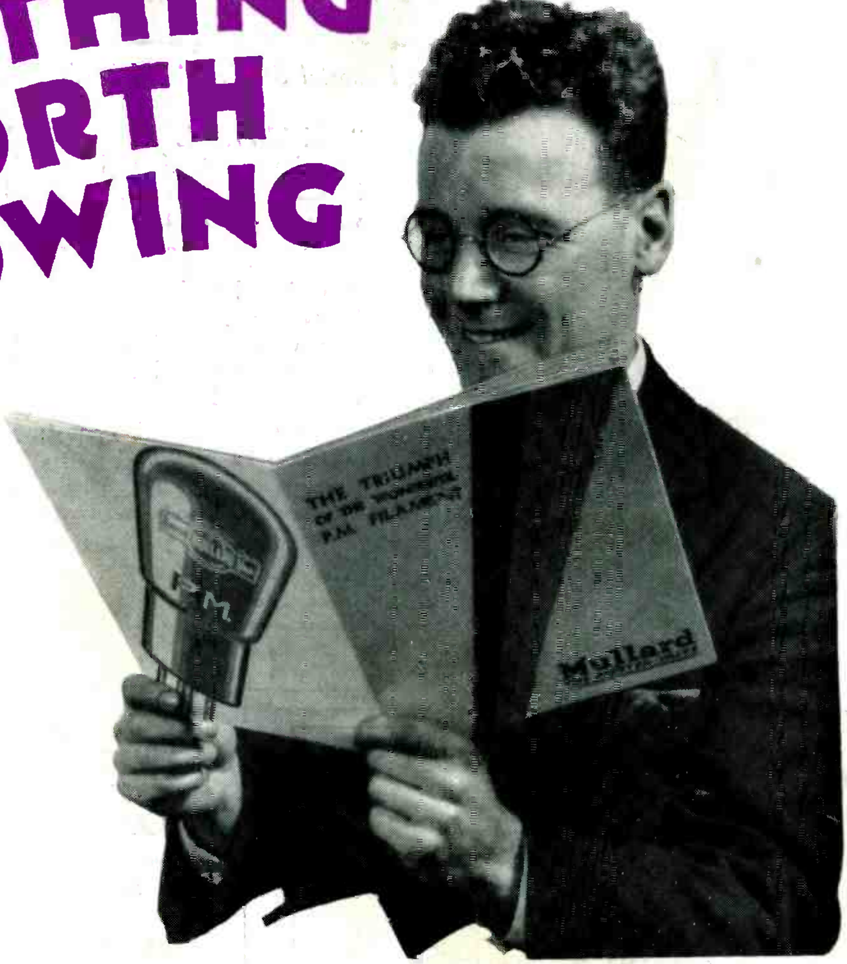


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