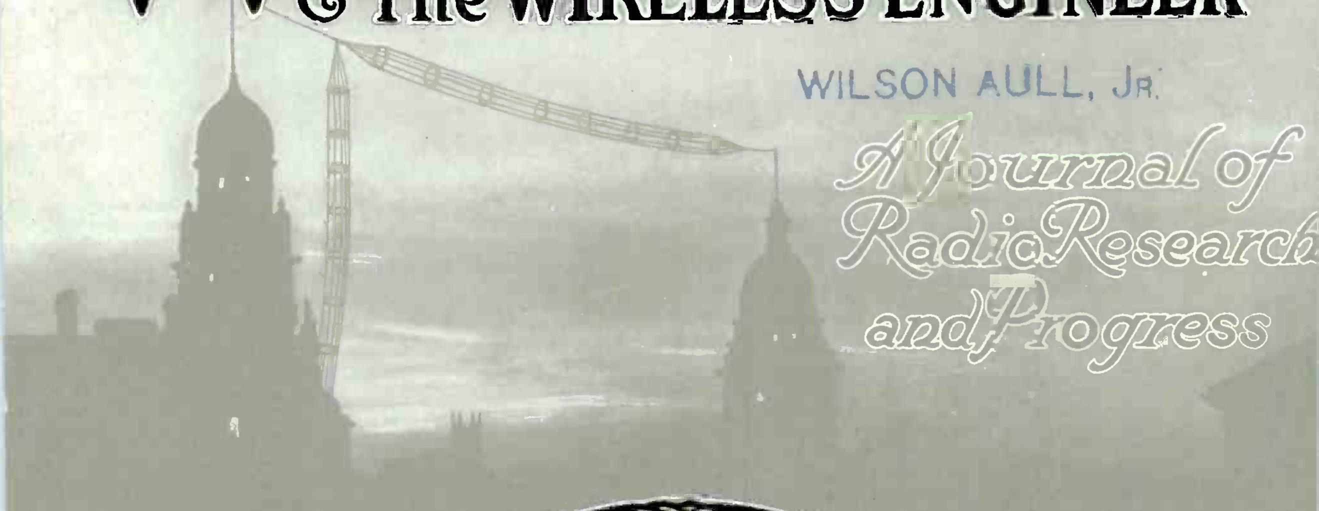
EXPERIMENTAL WIRELESS
& The WIRELESS ENGINEER



A Journal of Radio Research and Progress

Vol. IV No. 46. JULY 1927.

IN THIS ISSUE

THEORY OF THE FLAT PROJECTOR.

PRECISE MEASUREMENT OF TRANSMITTING WAVELENGTHS.

A WIRELESS WORKS LABORATORY.

AND OTHER FEATURES.

2/6 NET

Publishers
ILIFFE & SONS Ltd. DORSET HOUSE, TUDOR St. LONDON E.C.

EXPERIMENTAL WIRELESS

and The WIRELESS ENGINEER

A Journal of Radio Research and Progress

Technical Editor : Prof. G. W. O. HOWE, D.Sc., M.I.E.E.

Editor : HUGH S. POCOCK.

Assistant Editor : F. H. HAYNES.

VOL. IV. No. 46. JULY, 1927. MONTHLY.

CONTENTS OF THIS ISSUE.

The Editor is always prepared to consider suitable articles with a view to publication. MSS. should be addressed to the Editor, "Experimental Wireless and the Wireless Engineer," Dorset House, Tudor St., London, E.C.4. Especial care should be taken as to the legibility of MSS. including mathematical work.

Published Monthly, on the first of each month.

Editorial Offices : 139-40, FLEET STREET, LONDON, E.C.4. Telephone : City 4011 (3 lines).

Advertising and Publishing Offices : DORSET HOUSE, TUDOR STREET, LONDON, E.C.4.
Telegrams : "Experiwyr, Fleet, London." Telephone : City 2847 (13 lines).

COVENTRY : Hertford St. Telegrams : "Cyclist, Coventry." Telephone : 5210 Coventry.

BIRMINGHAM : Guildhall Buildings, Navigation St. Telegrams : "Autopress, Birmingham." Telephone : 2070 and 2071 Midland.

MANCHESTER : 199, Deansgate. Telegrams : "Iliffe, Manchester." Telephone : 8970 and 8971 City.

Subscription Rates Home and Abroad : One Year, **32/-** ; six months, **16/-**, post free ; single copies, **2/8**, post free.

PIEZO-ELECTRIC CRYSTALS for TRANSMITTING

CONTROL of frequency in a transmitting circuit is familiar to readers of this journal. It is now generally accepted that **every transmitting circuit should have quartz crystal control.**

FIFTY years' experience in making the highest quality of quartz prisms, and unequalled supplies of quartz crystals gave our scientific staff unique opportunities for studying the piezo-electric behaviour of quartz with all the technical resources developed in our laboratories for the selection, grinding, polishing, measuring and testing of quartz crystals.

TWO years' intensive research on the problem has placed us in a position to make Piezo-Electric Crystals with the following **Guarantees.**

1. EVERY CRYSTAL OSCILLATES FREELY WITHOUT THE USE OF ANY FORM OF REACTION.
2. THE FREQUENCY REMAINS CONSTANT BETWEEN WIDE WAVELENGTH LIMITS OF THE TUNING CIRCUIT.

PRICES

(In dustproof mounts ready for insertion in the circuit)

Wavelength (Metres)	**Stock wavelengths** (List of nearest wavelengths will be sent on application)	**Any desired wavelength** (Guaranteed to 1 metre)	**Any desired wavelength** (Guaranteed to ½ metre)
51-100	£5 13 0	£7 10 0	£10 0 0
101-250	4 14 6	6 6 0	8 8 0
251-500	4 10 0	6 0 0	8 0 0
501-1000	4 17 6	6 10 0	8 13 0

National Physical Laboratory Report on any crystal £1 1 0 extra.

ADAM HILGER LTD., 24, Rochester Place, LONDON, N.W.1, ENGLAND

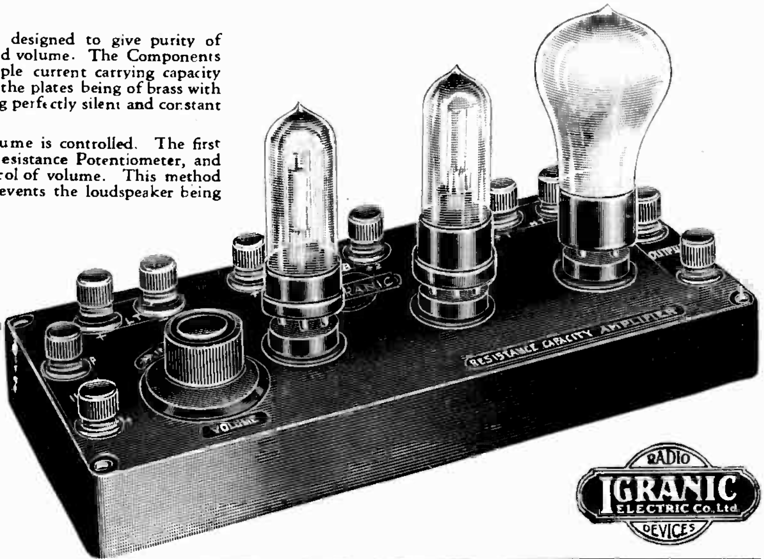
IGRANIC SETS A NEW STANDARD IN PURITY OF AMPLIFICATION

The Igranic Three-Valve Resistance Capacity Amplifier is designed to give purity of reproduction of outstanding quality, together with very good volume. The Components include Igranic Wire-Wound Resistances, these having ample current carrying capacity without variation of resistance; Igranic Fixed Condensers, the plates being of brass with best Ruby Mica di-electric; Igranic Fixed Leaks, these being perfectly silent and constant in operation.

A novel feature of the Amplifier is the means by which volume is controlled. The first grid leak is of similar construction to the Igranic High Resistance Potentiometer, and variations of this resistance effect smooth and complete control of volume. This method of volume control does not affect the purity of tone and prevents the loudspeaker being overloaded by very loud signals.

The whole Amplifier is built upon a moulded Bakelite base, measuring approximately 11 in. long by 4½ in. wide by 1½ in. high. The resistances, condensers and grid leaks are mounted on the under-side of the base with the valve holders and terminals on top, and the whole forming a particularly compact and neat unit.

Insulated terminals are provided. H.T. and grid bias can be supplied in two values, so as to permit of the use of a power valve in the last stage.



Write for List No. J253.

IGRANIC ELECTRIC Cº Lᵀᴰ
149, Queen Victoria St., LONDON
Works - - Elstow Road, BEDFORD

RADIO IGRANIC ELECTRIC Co. Ltd. DEVICES

EXPERIMENTAL WIRELESS & The WIRELESS ENGINEER

VOL. IV. JULY, 1927. No. 46.

Editorials.

A new Type of Loud Speaker.

IN a letter to Professor Tait written in 1863, Lord Kelvin, as he afterwards became, referred to the fact that a condenser emitted a sound on being charged and discharged. Since that time many attempts have been made to develop condenser-telephones or, as they are sometimes called, electrostatic telephones. Ort and Riegger, two German scientists, published an article in 1907 describing some very interesting experiments on the subject, but no practical commercial instrument was evolved, able to compete with the wonderfully simple, small and effective electromagnetic telephone receiver. So long as the receiver was intended for use as an earphone it was necessarily very limited in size and weight and consequently in capacity, and the sounds emitted by it were feeble. For use as a loud-speaker, however, these limitations are of smaller moment, and it is not surprising to learn that research work has been carried on with the object of evolving an efficient condenser loud-speaker. The experiments to which we refer have been made by Dr. G. Green, of the Applied Physics Department of Glasgow University, and have extended over several years. They have been very successful, for we recently had the opportunity of hearing the reproduction of broadcast speech and music from some of Dr. Green's condenser loud-speakers. These were only experimental models, but the quality while not perfect, was surprisingly good.

The principle of the condenser loud-speaker is easily understood. It consists of a large condenser built up of alternate sheets of metal foil and paper. The dielectric separating the metal sheets will be partly paper, and partly the unavoidable air, which will act as a cushion when the plates are under voltage.

The metal sheets are connected alternately to the two terminals as in an ordinary condenser, and a steady P.D. of, say, 200 volts is maintained between the terminals. The electrostatic attraction between the plates will tend to compress the whole condenser, and if the back plate is fixed the front one will be moved towards it. If now an alternating P.D. is superimposed upon the steady P.D. the compression of the whole condenser will be varied and the front plate will move backwards and forwards, setting the air in vibration and emitting a sound having a pitch corresponding to the frequency of the applied alternating P.D.

If the alternating P.D. is obtained from the output circuit of an audio-frequency amplifier, the speech or music will be reproduced, but the quality of the reproduction will depend upon several factors.

The steady applied P.D. is the electrical analogue of the permanent magnet of the electromagnetic telephone receiver. It introduces no difficulty since, by suitable circuit arrangement, it can be obtained from the H.T. battery of the amplifier, in fact it is only necessary to connect the condenser loud-speaker as a shunt across the battery and put a choke-coil in series with the battery so that the audio-frequency currents cannot pass through the battery, but are shunted round it through the condenser.

The mathematics of the subject have been published by Dr. Green in a paper entitled, "On the Condenser-Telephone," in the *Phil. Mag.*, for September, 1926, page 497, to which interested readers are referred

The experiments are being continued, and we look forward to this type of apparatus taking its place in the near future among high-class commercial loud-speakers.

Tramway Interference with Broadcast Reception.

BROADCAST reception in large towns is subjected to interference to a much greater degree than in the country. There is not only the proximity of a large number of receiving sets with the probability that some of them will oscillate at times, but electric motors and other electric apparatus, especially electro-medical apparatus, may cause serious interference, and electric tramways and railways in the immediate neighbourhood are known to cause trouble. The exact cause of this last named interference has been thoroughly investigated in Germany by the Post Office with the co-operation of the Berlin Tramway Company and the recently published results of the experiments are of great interest. The tests confirm the view of Burstyn that the trouble is due to damped oscillations set up by the interruption of the current passing from the overhead wire to the contact wheel or bow of the car. Contrary to what one might expect, however, no trouble is caused if the interrupted current is large, in fact, the current has to be less than about 2 amperes before any interference is caused by its interruption. Larger currents probably draw an arc between the separating metals and thus prevent the sudden break necessary to produce an oscillation. This peculiar effect explains why the interference is greater at night since then, even when the motors are switched off, there is the current taken by the car lighting, which amounts to something less than an ampere. With the car coasting at night every momentary interruption of the contact between the overhead wire and wheel breaks the lighting current and causes an oscillatory current which radiates a disturbance through the ether. One obvious, if somewhat wasteful, way of minimising the trouble is to connect a permanent leak in parallel with the lighting circuit so as to bring the total current above 2 amperes.

The trouble was found to be decreased whenever steps were taken to ensure a permanent smooth contact between the wire and wheel, thus preventing the interruptions of the current; relaying badly worn track, replacing worn overhead wire, using only freely rotating round wheels or smooth, broad-surfaced bows were all found to reduce the interference. Condensers connected between the collector-wheel and earth showed no marked improvement, but in some cases made matters worse. Since a current of 1 milliampere can cause considerable disturbance, leakage in the car wiring is important; in some cases the fact that the interference was as bad by day as by night was traced to this cause. Tests were made using different contact materials, but although carbon and zinc rubbing on copper were superior to other metals, the results did not lead to anything very practicable in this direction. The most promising direction in which improvement is to be looked for is in the design of trolley wheels kept in close contact with the wire by means of spring pressure acting on the trolley head itself. It is also stated that the trouble is eliminated by the use of properly designed and well maintained bow collectors as used in many Continental towns.

It will be interesting if those who live in the neighbourhood of tramway routes will keep notes of interference and try to correlate its intensity and frequency with the operation of the street cars.

Approximate Theory of the Flat Projector (Franklin) Aerial used in the Marconi Beam System of Wireless Telegraphy.

By Dr. J. A. Fleming, F.R.S.

IN the present Marconi system of Beam Wireless Telegraphy the projection of the wave and its confinement to a defined track is not accomplished by the use of a skeleton parabolic mirror with single aerial wire in the focal line as formerly, but is attained by means of a system of vertical aerial wires at equal distances and in one plane with a series of reflector wires behind in a parallel plane at a distance of one-quarter wavelength. The plane of the aerial wires is placed normally to a great circle line of the earth passing through the transmitting and receiving stations. These aerial wires are supplied with high frequency currents of exactly the same strength and exactly in phase with each other.

The distance between the aerial wires ($=d$) is made equal to half a wavelength or to some small odd multiple of half a wavelength. The distance between the reflector wires is the same or else half that between the aerial wires.

This type of aerial, as is well known, has been the subject of several important patent specifications by Mr. C. S. Franklin.

If stationary electric oscillations are set up in an aerial wire placed vertically to the earth's surface and if the frequency is so adjusted that the wavelength is equal to double the length of the wire, then electric radiation takes place which is a maximum in a plane at right angles to the wire and passing through its centre. If, however, harmonic oscillations are excited of greater frequency so as to create nodes and loops of potential and current on the wire, then, since the currents in adjacent half wavelengths are in opposite directions, these create opposing magnetic fields in the radiation and the effects at a distance on the median plane may be nullified.

Part of the inventions of Mr. Franklin have reference to means for suppressing the radiation from alternate stationary half wavelengths of the stationary waves on the wires, so that all the residual portions radiate waves which have their magnetic force in the same direction.

The result of this is equivalent to putting one on the top of the other a series of aerials each of which is half a wavelength long and radiate in step with each other, thus giving means for generating a very powerful electric radiation of short wavelength.

Concurrently with this the investigations and discoveries of Senatore Marconi have shown the important advantages of certain short wavelengths for long distance radio-telegraphy.

In one of Mr. Franklin's specifications a directive aerial is described comprising a number of vertical wires arranged parallel to each other and at equal distances in a plane perpendicular to the direction of propagation.

This aerial, under certain conditions of construction, has remarkable directive properties which appear to depend essentially on the phenomenon of wave interference.

The full mathematical discussion of this aerial is rather complicated and has not yet been given, but a certain reduced case can be treated without difficulty which shows why it is that such an aerial possesses these important directive properties.*

For the sake of simplicity the only case here considered is that in which each wire is supposed to be traversed by an electric current which is at any instant in the same direction all along the wire. The only region in which the radiation field is considered is in the equatorial plane of the wire and at a great distance.

Let Fig. 1 represent the plan of the aerial and its reflector wires on which the inter-

* The chief British patent specifications of Mr. C. S. Franklin on this subject are numbered Nos. 226246, 242342, 258942, 263943.

distance d may be taken as half a wavelength. Suppose that the point P is taken on the earth plane at such a large distance that lines drawn from P to the various aerial and reflector wires are very nearly parallel.

Let there be N such aerial wires and let γ be the distance from one end wire to the point P. Then the distances to the other aerial wires from P are respectively

$$\gamma,\ \gamma + d \sin\theta,\ \gamma + 2d \sin\theta, \text{ etc.}$$
$$\gamma + (N - 1)\, d \sin\theta.$$

Where θ is the angle between the direction to P and the normal to the aerial plane.

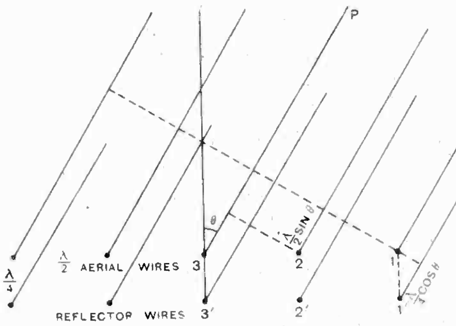


Fig. 1.

The magnetic field of each wire is propagated as a wave, and is also inversely proportional to the distance. Therefore at a distance γ and time t may be considered to be proportional to $\frac{1}{\gamma} \sin(m\gamma - nt)$ where $m = 2\pi/\lambda$ and $n = 2\pi/T$. T being the periodic time and λ the wavelength.

Since γ increases step by step as we go along the aerial we ought strictly to sum a number of terms of the type

$$\frac{1}{\gamma} \sin(m\gamma - nt),\ \frac{1}{\gamma + d\sin\theta} \sin[m(\gamma + d\sin\theta) - nt]$$

etc. But as the distance γ is very large compared with $(N-1)\, d \sin\theta$, we can consider the multiplier $1/\gamma$ to apply to each term and to be a constant. Also the direction at P of the magnetic field of each aerial wire is practically the same. Hence the resultant field at P is simply proportional to the sum of the terms

$$\sin(m\gamma - nt) + \sin[m(\gamma + d\sin\theta) - nt] + \text{etc.}$$
$$+ \sin[m(\gamma + \overline{N-1}\, d \sin\theta) - nt] \quad \ldots \quad (1)$$

By a well-known theorem the series

$$\sin\alpha, + \sin\overline{\alpha + \beta} + \sin\overline{\alpha + 2\beta} + \text{etc.}$$
$$+ \sin(\alpha + \overline{N-1}\,\beta) \quad \ldots \quad (2)$$

is equal to

$$\frac{\sin\left(\alpha + \overline{N-1}\,\frac{\beta}{2}\right) \sin N\frac{\beta}{2}}{\sin\frac{\beta}{2}} \quad \ldots \quad (3)$$

In our case $\alpha = m\gamma - nt$ and $\beta = md \sin\theta$. Accordingly, if we sum the series of sines in (1) and call that sum H, we have

$$H = \sin\left[(m\gamma - nt) + (N-1)\pi\frac{d}{\lambda}\sin\theta\right]\frac{F}{G}$$

where

$$\frac{F}{G} = \sin\left(N\pi\frac{d}{\lambda}\sin\theta\right)\Big/\sin\left(\pi\frac{d}{\lambda}\sin\theta\right) \quad (4)$$

and H is proportional to the magnetic field of all the aerial wire currents at P at a time t and distance γ.

In the next place we have to consider the effect of the reflector wires.

The current in the aerial wires is a simple sine curve current and creates a magnetic field of the same type. True radiation does not begin however until a distance of a quarter of a wavelength from the aerial wire. Hence the action of the current in the aeria wire on the reflector wire is a purely inductive action of its magnetic field.

When this field cuts the reflector wires it induces in them a secondary electromotive force proportional to the time rate of change of the field at that instant at the reflector wire.

Owing to the inductance of this reflector wire and its low resistance the electric current generated in it lags nearly $90° = \pi/2$ behind the inducing electromotive force in phase and as this inducing E.M.F. is 90° in phase behind the current in the aerial wire, it follows that the induced current in any reflector wire, as far as it is due to the current in the aerial wire just in front of it is 180° or π out of phase with it. In other words, the current induced in the reflector wire is in opposition as regards phase with that in the aerial wire in front of it. It may however be said that the current induced in each reflector wire is due to the currents in all the aerial wires to right and left, as well as to that wire exactly in front of it.

If, however, the aerial wires are spaced half a wavelength apart and the reflector wires also then a little consideration will show that the aerial wires, taken pair and pair on either side of one particular aerial wire, nearly neutralise each other's effect on the reflector wire immediately behind that particular aerial wire considered, since the distances of each of those pairs differs by nearly half a wavelength and therefore their propagated magnetic fields are in opposition as regards phase at the instant when they reach the reflector wire considered. Hence we may say that the current induced in any one reflector wire is for all practical purposes due only to the current in the aerial wire in front of it.

Since the aerial and reflector wires are only one-quarter of a wavelength apart and are long compared with that distance, the actual current induced in each reflector wire is not only in opposition as regards phase with the aerial wire current, but is practically equal to it in strength.

We have then to calculate the resultant field due to all the reflector wire currents at the point P. Referring to Fig. 1 it will be seen that the first reflector wire 1′ is at a distance from P equal to $\gamma+\frac{\lambda}{4}\cos\theta$ and that the second reflector wire is more distant than the first by a length $d\sin\theta$ if d is the interdistance of the reflector wires.

Taking account of the phase difference $T/4$ of the reflector wire current and E.M.F. creating it, we have the field at P due to the current in the first reflector wire proportional to

$$\sin\left[m\left(\gamma+\frac{\lambda}{4}\cos\theta\right)-n\left(t-\frac{T}{4}\right)\right]$$

or to

$$\sin\left[m\gamma-nt+\frac{\pi}{2}\cos\theta+\frac{\pi}{2}\right]$$

Also the distances of the reflector wires from P increase by steps $d\sin\theta$.

Hence, employing the same summation formula (3) as in the case of the aerial wire currents we have the total field H' at P due to the reflector wires given by

$$H'=\left[(m\gamma-nt)+\frac{\pi}{2}+\frac{\pi}{2}\cos\theta + (N-1)\,\pi\frac{d}{\lambda}\sin\theta\right]\frac{F}{G}$$

where

$$\frac{F}{G}=\frac{\sin\left(N\pi\frac{d}{\lambda}\sin\theta\right)}{\sin\left(\pi\frac{d}{\lambda}\sin\theta\right)} \quad \ldots \quad (5)$$

Since the current in the reflector wires is opposite in phase to that in the aerial wires we have to subtract (algebraically) H' from H to obtain the resultant current. The above formulæ are difficult to employ arithmetically except with certain limitations.

We shall, in the first place, consider that the reflector wires and aerial wires are both spaced apart by half a wavelength so that $d=\lambda/2$ and hence

$$\pi\frac{d}{\lambda}\sin\theta=\frac{\pi}{2}\sin\theta.$$

Also, to avoid merely mathematical difficulties, we shall suppose that the distance λ is an odd multiple of a quarter of a wavelength, so that

$$\gamma=\frac{\lambda}{4}+l\lambda$$

Where l is some integer.

Also we must select some epoch of time, and we shall assume that $t=kT$ where k is some integer and therefore $\cos nt=1$ and $\sin nt=0$.

In the next place we shall abbreviate these formulæ by writing

$$\sin\left(N\frac{\pi}{2}\sin\theta\right)=F\,;\ \sin\left(\frac{\pi}{2}\sin\theta\right)=G\,;\ m\gamma=L\,;$$

$$\frac{\pi}{2}+\frac{\pi}{2}\cos\theta=K \text{ and } L+F-G=X$$

$$L+F-G+K=Y.$$

The formulæ (4) and (5) then become

$$H=\sin(X-nt)\frac{F}{G};\ H'=\sin(Y-nt)\frac{F}{G}$$

and

$$H-H'=\frac{F}{G}\left\{\sin(X-nt)-\sin(Y-nt)\right\} \quad (6)$$

Expand the contents of the bracket in (6) and we have,

$$\sin X\cos nt-\cos X\sin nt- \sin Y\cos nt+\cos Y\sin nt$$

or

$$(\sin X-\sin Y)\cos nt-(\cos X-\cos Y)\sin nt.$$

For the epoch considered, viz., $t=kT$ when $\cos nt=1$, $\sin nt=0$, this reduces to

$$H-H'=\frac{F}{G}\left\{\sin X-\sin Y\right\} \quad \ldots \quad (7)$$

We have then reduced the formula to a condition in which it can be used arithmetically to predetermine the field of this flat aerial at a distance great compared with its linear dimensions.

For this purpose we shall assume that $N=30$, that is, that there are 30 aerial wires spaced half a wavelength apart.

The first thing is to calculate a table giving the value of F/G for various angles (θ) from 0° to 90° and for $N=30$.

This is given in Table I.

The next step is to calculate for the same constants the value of *sin* X and *sin* Y.

And take their algebraic difference. This is done in Table II for various values of θ.

Meanwhile we can see at once the nature of the radiation in three directions.

(i.) As regards the forward direction perpendicular to the plane of the aerial. In this case $\theta=0$. Hence we have

$$\sin\frac{\pi}{2}-\sin\frac{3}{2}\pi=2.$$

For the same value $\theta=0$, we have $F/G=N$. Therefore the radiation in a forward direction is proportional to 2 N or to 60.

(ii.) In the next place consider the backward direction. Then $\theta=180°$ $\sin\theta=0$, $\cos\theta=-1$, hence the radiation is

$$\sin\frac{\pi}{2}-\sin\frac{\pi}{2}=0.$$

There is therefore a complete projection of the radiation forward and a complete prevention of all radiation in the backward direction.

Since radiation and absorption are always proportional it follows that such an aerial absorbs all rays coming straight towards the aerial and prevents all waves from reaching the aerial from behind the reflector. The

TABLE I. $N=30$.

θ	$\sin\theta$	$\frac{\pi}{2}\sin\theta$	$N\frac{\pi}{2}\sin\theta$	$\sin\left(\frac{\pi}{2}\sin\theta\right)$	$\sin\left(N\frac{\pi}{2}\sin\theta\right)$	Ratio F/G $\dfrac{\sin\left(N\frac{\pi}{2}\sin\theta\right)}{\sin\left(\frac{\pi}{2}\sin\theta\right)}$	θ
0°	0	0	0	0	0	30.0	0°
1°	.0174	1° 34′	47°	.0276	.7316	26.5	1°
2°	.0349	3° 8′ 27″	94° 13′ 48″	.0550	.9972	18.0	2°
3°	.0523	4° 42′ 25″	141° 12′ 36″	.0820	.6260	7.6	3°
3° 30′	.0610	5° 30′	165°	.0958	.2588	2.7	3° 30′
4°	.0697	6° 16′ 23″	188° 11′ 24″	.1090	—.1427	—1.3	4°
4° 30′	.0784	7° 3′	211° 42′	.1227	.5249	—4.3	4° 30′
5°	.0871	7° 50′ 20″	235° 10′ 12″	.1363	—.8208	—6.02	5°
10°	.1736	15° 37′ 26″	468° 43′	.2686	.9469	3.52	10°
15°	.2588	23° 17′ 31″	698° 45′ 36″	.3960	—.3624	—0.91	15°
20°	.3420	30° 46′ 48″	923° 24′	.5113	—.3960	—0.77	20°
25°	.4226	38° 20′ 24″	5141° 1′ 12″	.6202	8.746	1.41	25°
30°	.5000	45°	1350°	.7070	—1.000	—1.414	30°
35°	.5736	51° 37′ 26″	1548° 43′ 12″	.7840	.9469	1.21	35°
40°	.6428	57° 51′ 6″	1735° 33′ 36″	.8465	—.9018	—1.06	40°
45°	.707	63° 38′	1908° 54′	.8962	.9460	1.05	45°
50°	.766	68° 56′ 24″	2068° 12′	.9330	—.9994	—1.07	50°
60°	.866	77° 56′ 24″	2338° 12′	.9778	.0320	.032	60°
90°	1.000	90°	2700°	1.000	0°	0°	96°

We shall assume that

$$\gamma=\frac{\lambda}{4}+l\lambda$$

where l is some integer.

Hence $m\gamma=\frac{\pi}{2}+l2\pi$. Since $m=2\pi/\lambda$.

We have then to obtain the numerical values of

$$\sin\left[\frac{\pi}{2}+\frac{N-1}{2}\pi\sin\theta\right]$$

and of

$$\sin\left[\frac{\pi}{2}+\frac{\pi}{2}+\frac{\pi}{2}\cos\theta+\frac{N-1}{2}\pi\sin\theta\right]$$

combination is, in fact, a perfectly "black body" on the aerial surface and a perfectly opaque or reflecting body on the opposite side.

To obtain the radiation in other directions we have to consult Table II, which gives it for various values of θ, and the last column gives a series of numerical values which

TABLE II. $m\gamma = \frac{\pi}{2} + l2\pi = L$

θ	X $\frac{\pi}{2} + \frac{N-1}{2}\pi \sin\theta$	K $\frac{\pi}{2} + \frac{\pi}{2}\cos\theta$	Y $\frac{\pi}{2} + \frac{\pi}{2} + \frac{\pi}{2}\cos\theta + \frac{N-1}{2}\pi\sin\theta$	$\sin X - \sin Y$ $\sin\frac{\pi}{2} + \frac{N-1}{2}\pi\sin\theta - \sin\left[\pi + \frac{\pi}{2}\cos\theta + \frac{N-1}{2}\pi\sin\theta\right]$	$\frac{F}{G}$ From Table I.	Radiation $= \frac{F}{G}(\sin X - \sin\gamma)$	θ
0°	90°	180°	270°	2	30	+60	0°
1°	135° 26′	180°	315° 26′	1.4	26.5	+37.1	1°
2°	181° 5′ 21″	180°	361° 5′ 11″	—0.038	18.0	— 0.68	2°
3°	226° 30′ 11″	180°	406° 30′ 11″	—1.45	7.6	—11.0	3°
3° 30′	249° 30′	180°	429° 30′	—1.87	2.7	— 5.05	3° 30′
4°	271° 55′	180°	451° 55′	—2.0	— 1.3	+ 2.6	4°
4° 30′	294° 39′	180°	474° 39′	—1.82	— 4.3	+ 7.8	4° 30′
5°	317° 20′	180°	497° 20′	—1.36	— 6.0	+ 8.16	5°
10°	543° 5′	177° 20′	720° 41′	+0.042	3.52	+ 0.15	10°
15°	765° 28′	177°	942° 28′	+1.39	— 0.91	— 1.26	15°
20°	982° 37′	174° 30′	1157° 7′	—1.96	— 0.77	+ 1.51	20°
25°	1192° 40′ 48″	171° 30′	1364° 11′	+1.89	1.41	+ 2.66	25°
30°	1395°	168°	1563°	—1.54	— 1.41	+ 2.18	30°
45°	1935° 16′	153° 36′	2068° 52′	+1.71	1.05	+ 1.79	45°
60°	2350° 15′	135°	2485° 15′	+0.4	0.032	+ 0.013	60°
90°	2610°	90°	2700°	+2.0	0	0	90°

Moreover, the reflection from the reflector wires strengthens the effect in the aerial when used as a receiver.

(iii.) In the third place, let us consider the radiation along the plane of the aerial wires that is for $\theta = 90°$. Then $\sin\theta = 1$ and $\cos\theta = 0$.

The value of F/G or of

$\sin\left(N\frac{\pi}{2}\sin\theta\right) \Big/ \sin\left(\frac{\pi}{2}\sin\theta\right)$ for $\sin\theta = 1$

can be found as follows :—

It is shown in books on trigonometry that

$$\frac{\sin N\phi}{\sin\phi} = N\cos\phi\left(1 - \frac{N^2-4}{L^3}\sin^2\phi + \frac{(N^2-4)(N^2-16)}{L^5}\sin^4\phi - \frac{(N^2-4)(N^2-16)(N^2-36)}{L^7}\sin^6\phi \cdot \text{etc.}\right.$$

If $\sin\phi = 1$ and $\cos\phi = 0$, then $\sin N\phi/\sin\phi$ is zero when ϕ is 90°.

Therefore the value of F/G is zero for $\theta = 0$. In other words, there is no radiation in the direction of the plane of the aerial.

may be taken to be proportional at a given distance from the aerial of either the magnetic or electric force in the wave in that

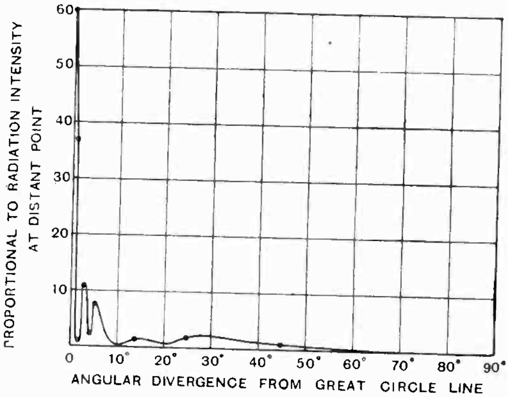


Fig. 2.

azimuth. This radiation intensity for various angular deflections is plotted graphically in Fig. 2.

Now one thing shows itself at once from these figures, and that is the rapid rate at which the radiation falls off for a very slight angular deviation from the great circle or normal line. Even two degrees deviation in the case considered drops it from 60 to 0.68. In other words, the beam is very sharply defined. At a distance of 3,000 miles a length of 100 miles subtends an angle of 2°. Therefore, such a beam should not spread at 3,000 miles over more than 100 miles, without falling to zero on either side. As a matter of fact this is found to be the case.

The next thing which is striking is that after falling off to nearly zero at 2° deviation, the radiation recovers again a little, for greater deviation, and falls again to nearly zero for 10° deviation. Beyond 10° it again rises and then falls nearly to zero at 60° and quite to zero at 90°.

Thus there are a series of directions of nearly zero radiation with intermediate directions of decaying maxima. In short, there are a series of *interference bands* just as shown in optical experiments.

Each of the aerial wires is, in fact, like an incandescent filament sending out monochromatic radiation.

There is a well-known experiment of Thomas Young in which two small holes or slits in a metal plate placed very close together are illuminated from behind with monochromatic light. On a white screen placed a little way in front of the slits are then seen a series of bright and dark bands called interference bands. A point in front at equal distance from both slits is a bright band region. A little way on either side, such that the distances from that point to the two slits differ by half a wavelength or an odd multiple of half a wavelength, there is a dark band with bright bands in between.

There appears to be an exactly similar effect in the case of a Franklin flat projector aerial as above described. This is predicted theoretically, and it could be tested practically by a ship with a single vertical aerial wire moving transversely across the great circle line of projection of such an aerial and ascertaining at what distances from that central line the wireless signal strength dies away and revives again at rather farther distances. It has been found by experiment that such interference bands as predicted theoretically do actually exist in the case of this flat projector aerial. It has generally been the custom to plot the radiation diagrams of projection aerials in polar form, as may be seen from the diagrams in the Papers read by Senatore Marconi to the Royal Society of Arts in the July 25th, 1924, and December 26th, 1924, issue of their Journal.

The plotting in rectangular form as here given brings out rather better the *interference effects* which present themselves in these cases and are responsible for the sharply marked beam properties of these grid aerials.

Laboratory Note.

An improvement on the "Double Click" method of measuring the resonant wavelength of a circuit.

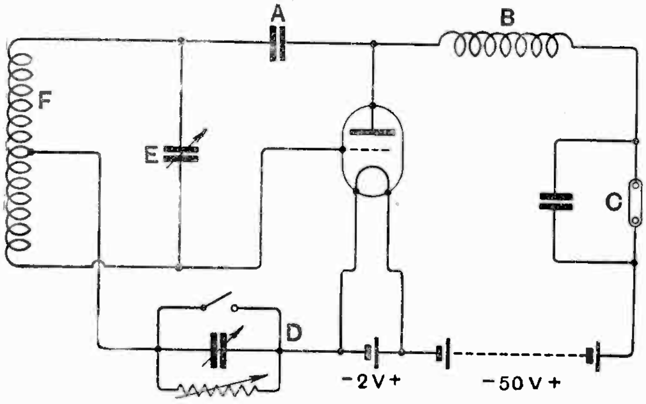
THE wavelength of a circuit, such as a coil with a condenser connected across its terminals, may be measured by the well-known "double click" method, the chief advantages of which are that no subsidiary apparatus need be connected to the circuit under test, and that an oscillating wavemeter ("heterodyne" wavemeter) is the only instrument required.

The usual method is to bring the circuit to be tested near a valve wavemeter, emitting C.W., in the anode circuit of which phones are connected; on rotating the wavemeter condenser through the resonant wavelength of the circuit under test, clicks are heard in the phones, and it is then assumed that the reading of the wavemeter midway between the clicks is the wavelength required. The method has two disadvantages: first, the clicks only occur when the circuit under test is fairly tightly coupled to the wavemeter, which is liable to cause appreciable error in the wavemeter readings; secondly, when the coupling is reduced as much as possible to reduce the error, the clicks are very faint, and can only be distinguished with difficulty.

By the use of the grid-leak interrupter effect described by F. M. Colebrook* a much louder indication of resonance may be obtained, with looser coupling.

the usual method, it can literally be done "with the phones on the table"; and owing to the looser coupling that we can now use, there is less likelihood of the wavelength of the meter being affected by the proximity of the circuit under test.

If the coupling between test circuit and wavemeter is further loosened, the buzz of the interrupter does not completely stop when the resonant wavelength is passed through, but the note of the "buzz" changes,



Circuit of heterodyne wavemeter.

The figure shows the diagram of Mr. Colebrook's wavemeter, in which *D* represents the interrupter device. By reducing the capacity of the interrupter condenser, a point will be found where the interruptions cease, and on increasing the capacity they will start again. Adjust the condenser until the interruptions only just restart (the adjustment alters with change of coil *F* of wavemeter), place circuit to be tested near the wavemeter, and rotate wavemeter condenser through the resonant wavelength of the circuit under test, when it will be found that the interruptions suddenly cease over a portion of the wavemeter scale roughly corresponding to the space between the "clicks" of the usual method. By loosening the coupling between wavemeter and test circuit, the width of this "silent space" can be reduced to about half a scale division of the wavemeter. The "silent space" is much easier to hear than the "clicks" of

it becomes "woolly" and drops a semitone or two. The wavemeter condenser should have some form of fine adjustment, or this may be missed, as it only occurs over a very small portion of the scale. The interrupter condenser needs careful adjustment to produce the effect with the minimum possible coupling. A little practice is needed to distinguish the flattening of the "buzz" note, it is not so obvious as the complete cessation of sound with closer coupling, but it is far easier to distinguish a change of pitch of a loud note than it is to hear the very faint "click" of the usual method.

While no measurement of this sort can claim to very high precision, it is suggested that the use of the Colebrook interrupter in the manner described increases the convenience of the method considerably, it should also increase the accuracy owing to the looser coupling employed; a probable error of $\frac{1}{2}$ to 1 per cent. may be expected, which approaches the inaccuracy of a commercial wavemeter.

C.R.C.

* "Design for a Wavemeter," *Wireless World*, 6th October, 1926, p. 481.

The Exact and Precise Measurement of Wavelength in Radio Transmitting Stations.

By RAYMOND BRAILLARD, Engineer A. & M., E.S.E., Advisory Engineer of Radio-Belgique, President of the Technical Commission of the Union Internationale de Radiophonie; and EDMOND DIVOIRE, Engineer A.I.Br., in charge of classes at Brussels University, Secretary of the Technical Commission of the Union Internationale de Radiophonie.

(*Continued from page* 330 *of June issue*.)

Description of Wavemeter (*continued*).

B. Indicator Circuit.

IN order to form an idea of the way in which the adopted arrangement behaves, it is useful to place the problem in equation form.

Fig. 4 shows the resonant circuit, Circuit No. I, and the indicator circuit, Circuit No. II.

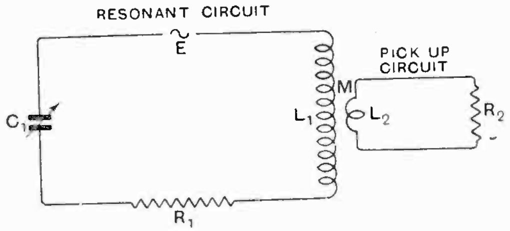


Fig. 4.

We will call E the effective electromotive force in the resonant circuit; we will say that it is constant, seeing that in principle the reaction of the wavemeter on the transmitting station to be measured should be negligible.

We will also assume that the direct induction between the transmitter and the indicator circuit is inappreciable (which is true) and consequently that there is no electromotive force acting in this circuit other than that induced by the primary (resonant circuit).

We will call M the coefficient of mutual inductance.

Under these conditions, the equations of electrical equilibrium of the two circuits read as follows, adopting imaginary annotations for the purpose :—

$$E = I_1\left[j\left(L_1\omega - \frac{I}{\omega C_1}\right) + R_1\right] + M\omega j I_2$$

$$O = I_2[jL_2\omega + R_2] + M\omega j I_1$$

Whence we derive, eliminating I_2 :—

$$E = I_1\left[j\omega\left(L_1 - L_2\frac{M^2\omega^2}{L_2{}^2\omega^2 + R_2{}^2}\right) - \frac{j}{\omega C_1} + \left(R_1 + R_2\frac{M^2\omega^2}{L_2{}^2\omega^2 + R_2{}^2}\right)\right]$$

The coefficient $j\omega I$ is *the apparent self-inductance of Circuit No. I*; it is composed of two terms: L_1, self-inductance, properly so called, of such circuit, and

$$L_2\frac{M^2\omega^2}{L_2{}^2\omega^2 + R_2{}^2},$$

which, representing the supplementary self-inductance carried into I by the reaction of II, we will call *equivalent self-inductance of Circuit II.*

Likewise,

$$R_1 + R_2\frac{M^2\omega^2}{L_2{}^2\omega^2 + R_2{}^2}$$

the *apparent resistance* is made up of Circuit I's own resistance and the equivalent resistance of Circuit II.

L_1, R_1 and C_1, being defined as we have said above, we have now to find what are the most favourable values of R_2, L_2 and M.

The first consideration is that of decrement; it is necessary that the equivalent resistance of Circuit II should be as low as possible.

Now, in examining its expression

$$R_2 \frac{M^2\omega^2}{L_2{}^2\,\omega^2 + R_2{}^2}$$

we see that it is necessary to have M small and L_2 large. As for R_2, we may bear in mind that, for R_2 varying from 0 to infinity, the above expression starting from 0 will go through a maximum corresponding to the equality of the two terms of the denominator to revert again towards 0.

There are, therefore, two interesting solutions; but there is a further consideration which is more important for a wavemeter, and that is the necessity of a strict constancy of standardisation.

Now, the value of R_2 does not always remain constant; we know, as a matter of fact, that on one hand the resistance of a lamp of the four-volt type varies with intensity of current flowing through it (it may go from 3 to 4 ohms at dark red to 7 to 8 ohms at bright red). On the other hand, if we use thermoelectric couples the replacing of one couple by another gives rise almost inevitably to differences in resistance.

It is necessary, therefore, to ward off such variations and consequently to choose for R_2, L_2 and M values such that they should give above all a self-inductance equivalent to Circuit II as little dependent as possible on R_2.

The equations permit us to draw the equivalent resistance and self-inductance curves as a function of R_2 for various values of M and L_2, and we can thus form an approximate idea of the most favourable values to be adopted.

Nevertheless it has been deemed prudent not to be content with this theoretical tracing and to plot the curves in question experimentally.

We will not enter into details of this work, which is long and critical, in view of the extremely low variations of resistance and self-inductance which we have to measure; we know the difficulties involved in these high frequency measurements.

We will confine ourselves to pointing out that the measuring instrument used was an amplifying triode voltmeter of the type built by the Cambridge Instrument Co., under the name of the Moullin voltmeter. This instrument, which is a very sensitive one, has the great advantage of not affecting in any great degree the circuit characteristics. All we need bear in mind is its resistance.

For measuring resistance a concurrent use is made of the method known as "resistance variation" including in the circuit different known resistance values, and the method known as "reactance variation" making use of the properties of the resonance curve where such is possible, that is to say, when circuits comprise a variable condenser.

We will not enlarge on this work, which is well known.

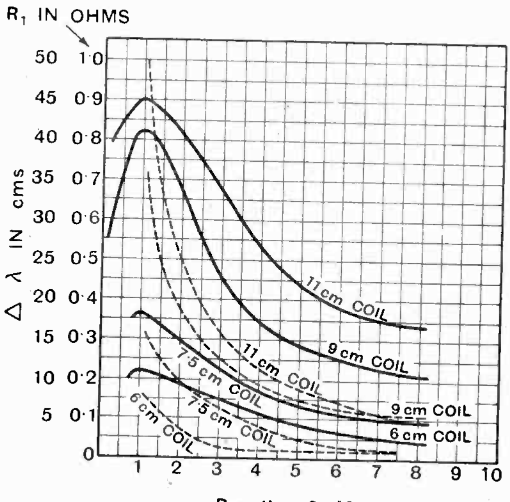


Fig. 5.

We give, by way of example, in Fig. 5 the results of measurement of the frequency of 1,130,000 cycles (265.5 metres wavelength).

We there differentiate between the curves giving the value of equivalent resistance of Circuit II acting on R_2—which is the proper resistance of such a circuit and shows a maximum, as has already been foreseen—and curves giving the value, not of self-inductance but rather the increase of wavelength, involved in the wavelength of Circuit I by the presence of Circuit II (these different curves are plotted as a function of R_2).

These curves have been drawn for various diameters of winding, forming the inductance L_2—the distance between the two coils remaining constant.

The values of M and L_2 have not been measured in each case, but they are of the order of 1 to 3 microhenries.

The value of R_1 is about 3 to 5 ohms, that of L_1 105 microhenries.

The examination of these curves shows that for a winding of 7.5 centimetres diameter (value adopted) a variation of R_2 between 4 and 7 ohms involves a variation of wavelength lower than 2.5 centimetres or 1/10,000 of the wavelength to be measured. As for the supplementary resistance brought into the circuit it is lower than 0.15 ohm and does not vary more than 0.05 ohm. It is obvious that we might have been able by increasing R_2 in some way or another, or by diminishing L_2 and M, to get even better conditions. But we must not lose sight of the fact that a diminution of current I_2 would be the result, perhaps sufficient to stop the lamp from glowing even at a dull red. This could only be got over by tighter coupling to the transmitter, which would involve undesirable reactions.

The wavemeter, being intended eventually to measure the wavelength of stations not having more than 200 watts power, and the 3.5-volt glow lamp requiring a current of 100 to 150 milliamperes to heat the filament to dark red, we must therefore confine ourselves to these limits.

Let us point out in passing that the thermocouples supplied with wavemeters have a resistance on the high frequency side of 5 to 7 ohms, approximately equivalent therefore to the resistance at dull red heat of the filament of a pocket lamp, which ensures constancy of standardisation no matter what system of indicator be used.

C. *Method of Standardisation—Precision of Measurements.*

Standardisation of these wavemeters has been carried out in absolute values by means of a method derived from the use of an instrument studied by Messrs. Abraham and Bloch* and well known under the name of "multivibrator."

We tune the fundamental frequency of the multivibrator to a tuning fork. This tuning fork as a rule produces the note C″ (1,024 periods). Another triode oscillator of any given type is tuned in by the beat-method to successive harmonics of the multivibrator. We thus get a series of known frequencies which we can use to standardise the wavemeter.

Should the multivibrator not produce sufficiently high harmonics the operation indicated above is repeated using an ordinary heterodyne. In this case the first heterodyne plays the part of a multivibrator with a high fundamental frequency, and a second heterodyne serves to select harmonics by the beat-method.

It is this last-named procedure which we have used, seeing that the frequencies which interest us extend from 500,000 to 1,500,000 cycles, while the multivibrator does not allow of use being made of harmonics above the 175th or a frequency of 175,000 approximately.

Arrangements Used. (See Figs. 6 and 7.)

We do not propose to describe in detail the apparatus used; we will confine ourselves to giving a few short notes as to the precautions taken to secure an accuracy of standardisation of the order of 1/10,000.

(*a*) *Tuning Fork and Multivibrator.*

Generally it is sufficient to compare from time to time the fundamental note of the multivibrator with that of the tuning fork by the beat method.

There is a risk of the fundamental period of the multivibrator varying a little, in the interval between tests, due to batteries dropping in voltage, etc. That is why we have used a method already described, which consists in maintaining the multivibrator in synchronisation with the tuning fork during the whole working time, by the following procedure :—

The tuning fork is kept vibrating by one or several triodes in the well-known way, and the secondary of a transformer connected in the plate circuit of the multivibrator. The primary of the transformer is connected in the plate circuit of one of the several triodes used to maintain the vibration of the tuning fork. In this way, when the multivibrator is adjusted approximately to the tuning fork frequency, a synchronising effect occurs which tends to pull into step the fundamental frequency of the former, this effect occurring even within broad limits of mistuning.

A word of precaution, however, is necessary. The maintaining of a tuning fork by a triode gives rise to a very slight variation

*See description in the book "High Frequency Measurements" by Armagnat and Brilloin.

of its natural frequency. That is why we compare, from time to time, the note of the maintained fork with that of a fork mounted on its resonance case, *which forms the real standard instrument.*

We have thus been able to observe that, due to the heating of maintenance triodes, the period of the maintained fork may vary by several points in 100,000.

We have thought it to be indispensable to carry out an experimental test of the theory, and we have carried out a series of tests at different temperatures: these showed that the theoretical law was correct, at least within very wide limits (from 15 to 25 degrees Centigrade approx.).

We have therefore enclosed the maintained fork and the standard fork, used as a check, in a case lagged internally with a thick layer of felt so as to keep a uniform and sufficiently constant temperature during measurement. This case was fitted with a thermometer so that it was convenient to read the temperature and deduce therefrom the corresponding correction coefficient.

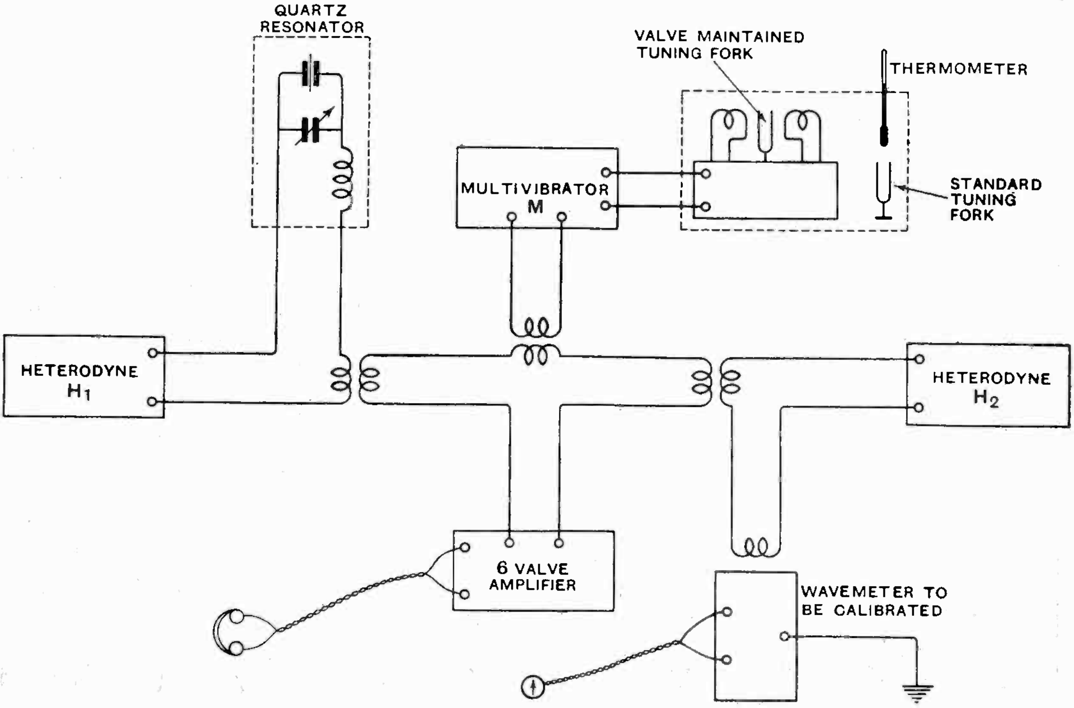


Fig. 6. *Circuit arrangement used for wavemeter calibration.*

The standard fork, whose frequency is 1,024 (C″) has been standardised to within 1/10,000 at the Conservatoire of Arts and Crafts. It is of steel, as we have not had time to get a special fork made of alloy with a very small coefficient of expansion, and we must therefore allow for a certain working temperature variation.

Theory shows that the period of a fork is inversely proportional to the square root of the coefficient of elasticity, this varying with temperature according to a linear law, at least within the limits which interest us, and that the coefficient of variation is of the order of 2.4/10,000 per degree Centigrade; whence it results that the period varies 1.2/10,000.

Local Oscillators H_1 and H_2.

These two instruments are completely screened, so as to avoid stray effects which might modify the transmitting constancy; the control condensers have geared-down controls. As a means of control we have coupled up to H_1 a piezo-electric resonator of the Loewe luminous quartz crystal type.

This resonator has been standardised to 2/10,000 by the Reichsanstalt Laboratory, Berlin.

The principal use of this resonator is to test, from time to time, by a rapid method, the yield of harmonics of the multivibrator.

The beats between these harmonics and the fundamental waves of H_1 and H_2 are picked up and amplified by an arrangement consisting of a 4-stage resistance-coupled amplifier of the Brillouin type, followed up by a 2-stage L.F. amplifier.

This amplifier is sufficiently sensitive to pick up, without much difficulty, beats of the order of 4 to 10 per second, either side of the silent point of the beat between M and H_1, and beats of the order of 50 to 100 covering the silent point between H_1 and H_2.

We are accustomed to carry out these measurements by keeping the various instruments working simultaneously, so as to ensure that inevitable reactions between circuits may not modify the period of the two others, if one of the oscillators is switched off.

This method of procedure requires much attention and a certain amount of experience in beat measurements, but it has the great advantage of allowing a constant control of experimental conditions and so avoiding certain causes of error.

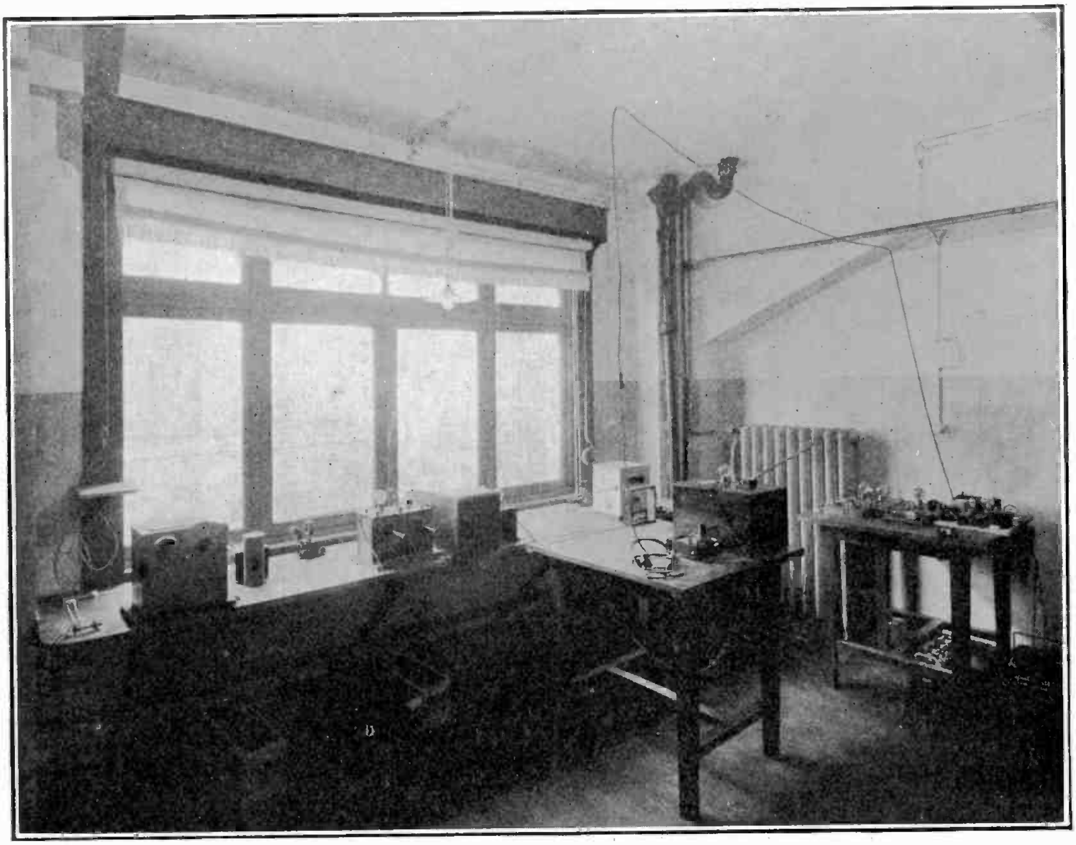


Fig. 7. *A corner of the laboratory arranged for wavemeter calibration.*

Standardisation of Wavemeter on Fundamental Wave H_2.

The indicator circuit of the wavemeter is fitted up with a thermocouple having an H.F. resistance of 7 ohms (corresponding therefore to the normal working resistance), and of which the sensitiveness is 5 millivolts on open circuit for 20 milliamps H.F.; the galvanometer used was of the Cambridge unipivot type.

We can in this way get a long extension lead to the measuring instrument without any appreciable reaction on hererodyne H_2.

The resonance point is not found by observing the peak of the resonance curve, which is always a trifle inaccurate, but by finding two points of equal amplitude on either side of it, a procedure which gives all the accuracy desired and can be adopted, thanks to the stability of working of H_2.

Accuracy of Wavemeter Standardisation.

Different causes of error arise as follows :—

(*a*) That due to standardisation of the tuning fork.

The error due to the tuning fork is lower than 1/10,000, according to certified standardisation.

(*b*) That due to inaccuracy of successive operations above described for producing a standardised wave.

The production of a standardised wave comprises several operations :—

1. Reading the thermometer with a view to estimating the temperature correction, the accuracy being about 0.2° C. This, therefore, gives us an error of 2/100,000 in estimating the frequency.

2. "Pulling" of multivibrator by maintained fork; error, 0.

3. Tuning of H_1 on a harmonic of multivibrator. Approximate error, 1 to 2 beats per 150,000 average, or 2/100,000.

4. Tuning of H_2 on a harmonic of H_1. Approximate error, 10 to 20 beats per 500,000 to 1,000,000, or an average of 3/100,000.

(*c*) That which arises in adjusting the wavemeter to the standardised wave.

Effect on wavemeter being standardised:

1. Accuracy of resonance reading. Let us suppose that we find the resonance point by means of two readings of equal amplitude on either side of the resonance curve (see Fig. 8).

We know for this position we have :—

$$\delta \frac{\pi}{2} \frac{f_1 - f_2}{f_0}$$

determining the comparative width of resonance curve.

Now $\delta = 0.016$

whence $\frac{f_1 - f_2}{f_0} = 0.01$ approx.

As this width may be appreciable at about 1/75, thanks to the steepness of the two sides of the curve, this gives us an error of appreciation lower than

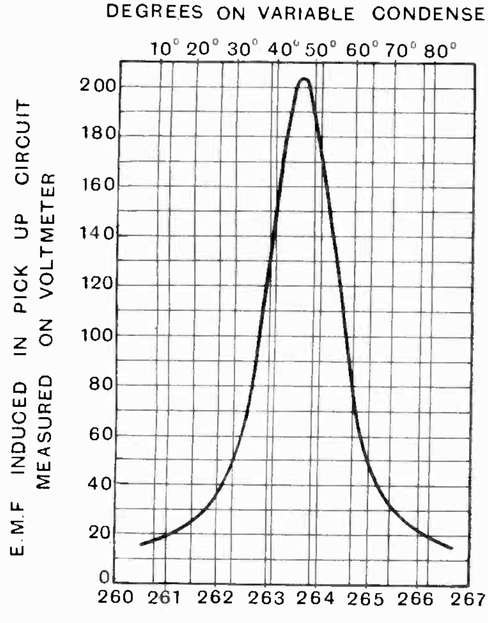


Fig. 8.

1.5/10,000 (as is shown by Fig. 8, representing the resonance curve of wavemeter considered above).

2. The error in reading the graduated scale may be valued at 0.8 of a degree, *i.e.*, at an average of 0.8/10,000.

(*d*) Lastly, that which may arise from an accidental modification of the geometrical dimensions of instruments.

Care has been taken never to deliver an instrument which has not been standardised twice by two different observations, at several days' interval, so as to eliminate systematic errors of observation, as well as those which may arise from the fact that different parts of the instrument may not have yet acquired their state of molecular equilibrium owing to various processes carried out. As to ulterior modifications, they do not appear to be appreciable according to tests carried out up to the present.

For instance, we may quote the case of the wavemeter of Radio Belgique Station. After having timed the station by means of this instrument, we brought the instrument to our laboratory and completely dismantled it, including the condenser. This was later re-assembled and re-standardised, when it was found that the new standardised curve coincided practically with the first.

To recapitulate the various causes of error, we find that the *error limit* of standardisation is—

$$\frac{1\ (10 + 2 + 1 + 15 + 8)}{100{,}000}$$

or about $$\frac{4}{10{,}000}$$

As to the *probable error*, it is

$$\frac{1}{100{,}000}\sqrt{10^2+2^2+1^2+3^2+15^2+8^2}$$

or about $$\frac{2}{10{,}000}$$

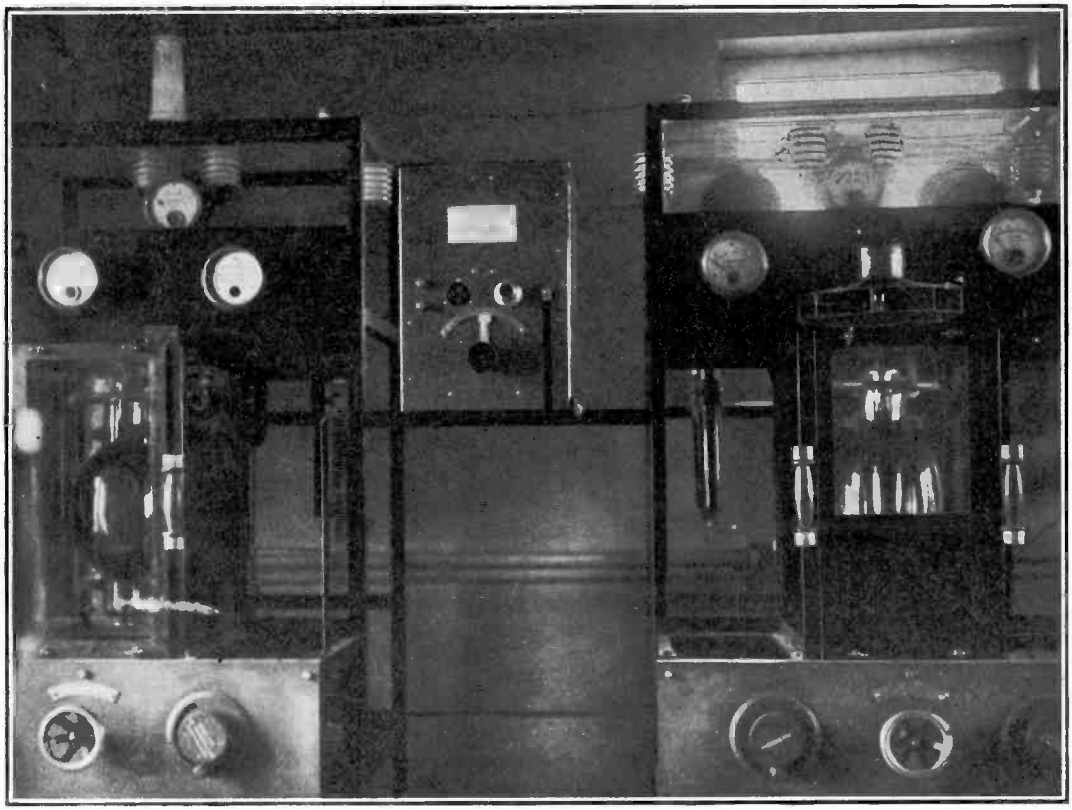


Fig. 9. *Showing the standard wavemeter installed in the Radio-Belgique station at Brussels.*

Now, as each standardisation curve is formed by half-a-dozen points, we may admit that it is exact down to less than about

$$\frac{2}{10{,}000}$$

As to the order of accuracy of measurements which we may expect of this wavemeter, it evidently depends on the indicator used.

If this is a thermocouple with a millivoltmeter, an experienced observer can get an accuracy of 1.5/10,000, as we have shown above; if it is an incandescent or glow lamp, the accuracy is not more than 2 to 3/10,000, according to the operator's ability, and according to the degree of incandescence of filament.

Influence of Surrounding Atmosphere.

It is possible to assess theoretically the modification of standardisation involved due to temperature variation.

As far as the condenser is concerned, we can easily see that its capacity depends directly on the coefficient of linear expansion of the aluminium, or a variant of 2.3/100,000 per degree C.

As for inductance, we must first of all consider that the coefficient of expansion of copper (1.9/100,000) neighbours on that of aluminium, so that the sections of the coil forming the facets of the hexagonal prism will expand about the same amount as the aluminium stars forming the bases, and consequently the surface of the coil will grow but not show any deformation.

The wavelength of the circuit varies therefore as

$$\left(1 + \frac{2}{100,000}\right)^{\frac{3}{2}}$$

The result of this is a variation of 3/100,000 approximate per degree C., which it is easy to allow for on standardisation curves.

We have started a series of systematic experimental researches intended to verify our mathematical accuracy. Nevertheless, as these tests are very critical, owing to the accuracy of measurements to be carried out, and also the presence of numerous causes of error, we have not yet obtained results which are sufficiently trustworthy.

Stray Electrostatic and other Effects.

The wavemeter is remarkably well shielded from stray effects depending on the presence of the observer, due to the careful lay-out, in which the various components are mounted on a metal panel which is connected to earth, and to the condenser, of which the outer electrode forms a screen. This encloses the moving plate as well as the dielectric.

Investigations carried out to study the effects of the observer's movements, and particularly his passage between the wavemeter and the transmitting circuit, have shown us that the variations at resonance point resultant therefrom do not arise, as one was tempted to suppose, from a modification of the standardisation of the instrument by the stray effect of capacity, but really from *the modification of the transmitted wavelength*, due to the presence of the body of the observer.

This effect is even appreciable in stations with a power of 1,500 watts to the oscillators.

Conclusions.

We think we have shown by this paper that the problem of the exact and accurate measurement of wavelengths of broadcasting stations may be solved in an industrial manner by the aid of simple and handy instruments.

Fig. 9 shows the installation of the wavemeter above described in Radio Belgique Station, Brussels. It is fitted close to the independent oscillator circuit which fixes the wavelength (drive circuit).

It is extremely easy for technical experts on duty to correct the wavelength transmitted by adjusting the variometer of this circuit, and by observing the glow of the diminutive glow lamp on the wavemeter.

Accurate daily measurements taken at a distance on nearly all of the European stations controlled by such wavemeters, show that the constancy of wavelength transmitted may be easily maintained at about 3 to 4/10,000, no matter how few operators pay attention thereto, and that stations afford the requisite technical qualities, as to stability and accuracy of wavelength adjustment (independent oscillating circuits, variometers, etc.).

There is no doubt that such solutions will soon be imposed in all branches of radio-electrical applications, by reason of the incessant multiplication of transmitting stations.

Design and Construction of a Superheterodyne Receiver.

By P. K. Turner, A.M.I.E.E.

(*Concluded from page* 348 *of June issue.*)

COMING next to the stage comprising the I.F. output and the detector, there is rather more to say. Fig, 24 shows the simplest possible form of this. The first point to be realised here is that the I.F. transformer must be different from the others. They have had, as a secondary load, the grid-filament circuit of a biased valve, of an impedance (at 3,000 metres) probably somewhere between 0.1 and 0.5 megohm. This one is loaded with a crystal which, if galena is used as in this case, is probably in the neighbourhood of 10,000 ohms. Conditions of efficiency obviously dictate a smaller secondary. Theoretically, this secondary should be to the others as the *square root* of its load is to theirs—say about one-fourth. But the matter is slightly complicated by the question of reaction.

It was desired to include reaction over the intermediate amplifier, and one's first instinct was to arrange the circuit as in Fig. 25. But reflection indicated that this was

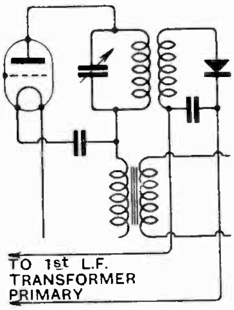


Fig. 24. *If no I.F. reaction is to be used, this circuit is correct for the 2nd detector.*

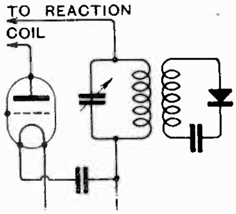


Fig. 25. *An obvious reaction circuit, but not likely to be successful.*

not likely to work well. The transformer is tuned to the working frequency, and therefore, it, with its tuning condenser, will behave as a rejector. That is to say, that it will offer a very high resistance to this frequency; hence the I.F. current in the anode circuit as a whole is very small, although there will be comparatively large I.F. currents circulating round between the primary itself and its condenser. But the reaction coil of Fig. 25 is not within this "circulating circuit," so it will only have a minute I.F. current, and hence will not be very effective.

An alternative is that shown in Fig. 26, in which the reaction coil *is* included with

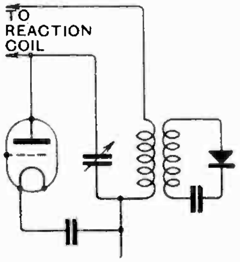


Fig. 26. *This is a more satisfactory reaction arrangement than that of Fig.* 25, *but it is still by no means the best.*

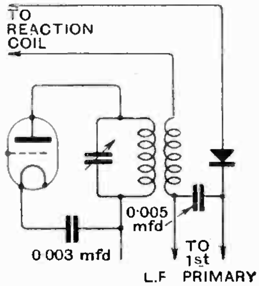


Fig. 27. *Here we have the reaction circuit finally adopted, which proved very satisfactory.*

the transformer primary within the scope of the tuning condenser. It must, of course, be remembered that in this set it is proposed to operate all the condensers by a mechanical connection, so that the effective inductance across each must be the same. Now the effective inductance of the transformer primary depends on its load. If we leave the secondary rather too large, so that the crystal acts as a bigger load, comparatively, than the valves in the case of the other transformers, the effective inductance of the primary will be less, so that the condenser will still tune, even with the extra inductance of the reaction coil.

But we are still in a difficulty, for any change in the reaction coil will upset the tuning, and it is practically impossible to say, before completing the set, what coil is required, so that we want to be free to change it if necessary.

To meet these conditions, we tried, as a new experiment, the circuit of Fig. 27, which has been a complete success. The transformer secondary was re-wound to one-half its former turns, which means that any coil used for reaction only affects the tuning one-quarter as much as it would if used as in Fig. 26. It might be thought that the current in the crystal circuit would be too small to give effective reaction with a reasonable coil, but—at any rate with a galena detector—this is not the case. Quite a small coil (of the order of 50 turns) is needed, and the effect on tuning of a change in the coil seems quite negligible.

As to the detector itself, I never had any intention of using anything else but galena. This hinges on the fact that *with the right holder, or detector*, from the mechanical point of view, galena is perfectly stable and simple to handle, while its efficiency as a transformer of energy is on the average higher than that of the other types that I have measured. Many of the various brands of galena on the market average over 50 per cent. efficiency, occasional samples ranging up to over 90 per cent., while other crystals seldom, in my own experience, average above 30 to 40 per cent., these percentages being input power to actual useful power in the output transformer.

Further, galena has two useful characteristics in connection with distortion. First, its characteristic is very often practically straight above the bend, which, as shown by Colebrook,* is a necessary condition for distortionless rectification of telephony. Second, it has a low apparent output resistance. This means that the output impedance of the transformer primary is likely to be much larger than the output impedance of the crystal at all working audio-frequencies, which in turn, means greater freedom from distortion in this transformer.

I have set in italics a few words above on the matter of the "holder" or detector in which the crystal is arranged. It is bad mechanical arrangement here that is the cause of just about one-half of the present neglect of crystal rectifiers—the other half is due to the fact that so few people seem to have realised that the proper place for crystals is after one or more H.F. valves. The detectors I use take about $1\frac{1}{2}$ in. square on the panel, and project about the same distance. There are two on the set, and they have done the following "records":—

> Shepherds Bush to Golder's Green by taxi: Needed *no* adjustment on arrival.
>
> London-Halifax by train, taxi each end: One perfect, the other fair, improved by using a new point.
>
> London-Leicester, train and taxi: One perfect, the other shaken out of contact.

In ordinary domestic use, I usually adjust then about once in six weeks, when I give the set a clean-up all round; they have only *needed* adjustment about three times.

These detectors are on the market at quite a reasonable price (needless to say, I have nothing to do with them except as a satisfied user); they are known as the "Eccentro." As will be seen in the final wiring diagram, two are used, with a switch, to guard against the remote possibility of having one go off during a programme, and to give a check by trying either one if the signals are weak and one suspects the crystal.

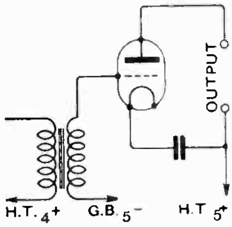


Fig. 28. *As a matter of form, the power valve circuit is given, although it is of standard type.*

The by-pass condenser across the L.F. transformer primary is important. It has a large effect on the input resistance of the detector. Also, it is intended to keep the I.F. component of the rectified current out of the transformer primary, whence (as already explained) it may be transferred back to an earlier valve, leading to uncontrolled reaction. As will be noted shortly, the primary of this transformer is comparatively small, hence an extra effort is made to keep down the reactance of the by-pass condenser by increasing its capacity from the 0.003 used in the other anode

* F. M. Colebrook, "The Rectifying Detector," *E.W. & W.E.*, March, 1925.

circuits to 0.005. This is permissible from the L.F. point of view, for the same reason that the transformer primary is of comparatively low inductance.

As to the transformer, the reason for the small primary suggested above is the obvious one that it is working in a circuit (the crystal) of a few hundred ohms output impedance, as compared with the ten thousand or so of an average valve.

If, as is normally the case, a 1 : 4 transformer is successful with a valve of such anode impedance, which is about 25 times that of a galena crystal, we should think at first of a 1 : 20 transformer after a crystal. But in actual fact the primary of the 1 : 4 transformer is almost always really too small for its job, so we do not make such a large jump. In actual practice a 1 : 8 or 1 : 10 transformer is very satisfactory, and as the 1 : 8 is on the market as a standard article it was adopted on this set.

Now the output from this transformer, as will be seen from Fig. 23, goes back to a valve of which we have already considered the I.F. operation. It is hardly necessary to give new illustrations showing the L.F. side of these valves, for the essentials are shown in Fig. 23. The two L.F. transformers between valves were selected as 1 : 4 ratio, this being the largest ratio likely to give reasonable absence of distortion with valves of fairly high μ. All three I.F. valves have the H.T.+ leads connected together, also the G.B.—. In use, the grid bias is $1\frac{1}{2}$ to 3, and the H.T. 90 to 120, depending on the valves in use.

It will be remembered that the bottom end of the primary of each I.F. transformer is connected to filament *via* a 0.003 by-pass

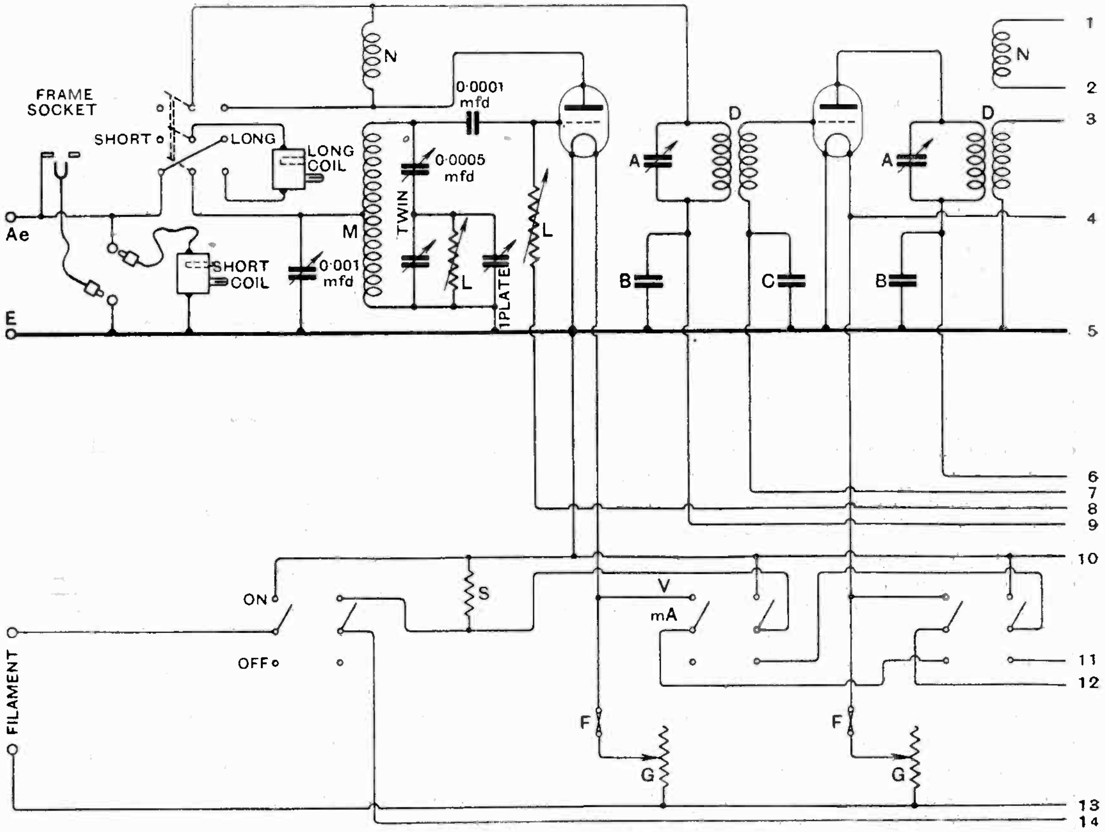
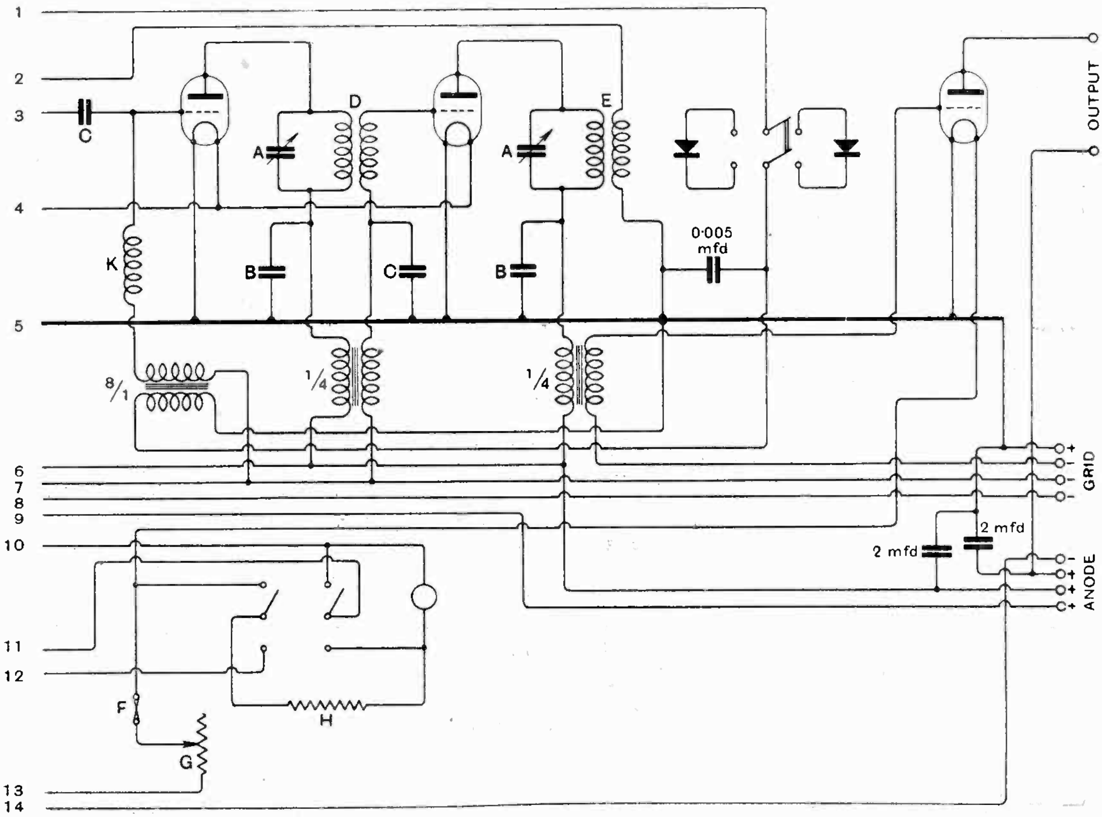


Fig. 29. *The complete schematic diagram. In order to make this fairly easy to read, it has been increased in size. Note that the numbers given to each wire at the break correspond with one another. The values of components are given in some cases in the drawing, the remainder are as follows:* A, .0003μF *max.;*

condenser. Provision is also made to by-pass the H.T. battery for L.F. purposes, by connecting a 2μF condenser from the H.T.+ to filament — before the branches to the three valves separate. Theoretically, the grid battery should have a similar by-pass; but it was not considered really necessary here, and is not inserted.

Two in parallel are better, or a "500-ohm" type or two of these in series, or even a "200-ohm" or "low resistance" or two of these. I myself use a "500-ohm" Kone and a 500-ohm horn loud-speaker in parallel, and find the combination the pleasantest thing I have yet struck.

We are now ready to draw a complete



B, $.003\mu F$; C, $.0003\mu F$; D, *McMichael air-core, No. 3;* E, *As "D." but secondary rewound to ½ turns;* F, *Burndept fixed resistor in holder;* G, *Filament rheostat;* H, *Series resistor for meter;* K, *1,800 or 1,500 coil of low self-capacity;* L, *Variable leak, 1–5MO;* M, *McMichael "Autodyne" unit;* N, *McMichael reactor.*

Finally, there is the circuit of the power valve. The primary of its transformer is shown in the anode circuit of Fig. 24, and for the sake of completeness the valve circuit is shown in Fig. 28, though it is so simple that this is hardly needed. There are only two points to mention. First, there is another 2μF condenser to by-pass the H.T. battery. Second, with the normal modern power valve of 4,000 to 10,000 ohms anode impedance the usual type of "2,000 ohm" loud speaker is too high in impedance.

schematic diagram of the set, and this is shown in Fig. 29, complete with switchgear. The values of some of the components are marked; those that are repeated several times are given key letters, and the values are given beneath the diagram.

We have now arrived at the time when the actual layout must be considered. There are one or two points about the set which make this rather tricky. My own preference is for the tuning adjustments to be on a vertical front panel, with the non-adjustable components on a baseboard. Obviously one must be able to get to the inside of the set to change coils or replace valves. In this instance it was also necessary to have the I.F. transformers accessible; partly because they are interchangeable, but also because the I.F. reaction and the oscillator coupling are controlled by reactors sliding into the transformers.

Another point was that it was desired to have a front lid which would completely enclose the set, while, at the same time, I do not myself like tuning on a sunk panel. This seemed to indicate a deep front lid, which would again be expensive and cumbrous. So it was decided to make the case deeper than the set, and to arrange the base and front to slide right in when the set was to be shut up, or to come forward flush with the front of the case for operation.

Obviously the front panel had to carry

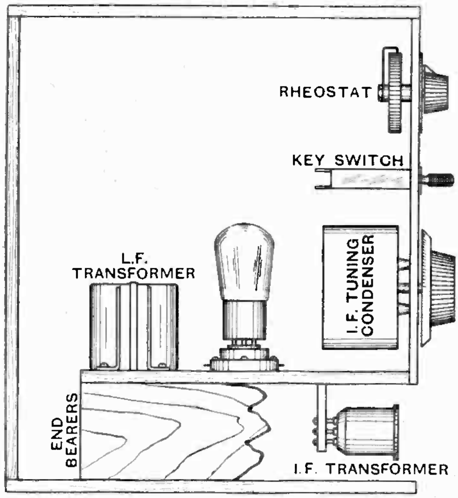


Fig. 30. *The arrangement of the intermediate stages. All these components are centred on the same line.*

the switches, rheostats, keys, meter, detectors, and condensers. It was decided to put the connections on the ends of the cabinet: they are in the way on the front, and (in my opinion) too inaccessible on the back. After much thought, concerned with getting the transformers accessible but not projecting, and at the same time keeping I.F. wiring short, it was decided to adopt for the repeated stages the scheme shown in Fig. 30. The panel is some inches less in height than the case, and the "baseboard" is above the floor, the I.F. transformers being below it. The whole rests on two end bearers, which could be either fixed to the base-board (making it like Fig. 31 from the front) or in the form of runners within the case. We finally adopted the former alternative, as we wished the

Fig. 31. *How the baseboard is supported clear of the cabinet.*

case to be fairly light and therefore not (if it could be avoided) to have to carry the weight of the "innards" except directly through the bottom.

Having got thus far, we started the pleasing pastime of trying to arrange everything to save space without crowding. We decided that all large components appertaining to one stage should be fixed on one centre-line, so as to allow of the insertion of screens between stages; and so the fullest equipment, that of valves Nos. 2, 3, and 4, became as in Fig. 30. Beyond this, on the right of the set as viewed from the front, is the power valve (L.F. only) and, on the panel, the two crystal detectors and their switch. To the left of the second valve is a stage with no L.F. transformer, but otherwise similar; and to the left of the first valve the aerial and oscillator equipment. Screens are inserted between valves 1-2, 2-3, and 3-4.

The location of most of the accessories can be seen in Fig. 32, which is a diagrammatic plan view, and is numbered for reference: 1 is a socket terminal strip, for aerial and earth (or frame) and L.T.+ and —. The plugs which enter these sockets are on flex leads about 18 inches long, terminating in duplicate Clix which fit in the cabinet: the complete connection from an external wire through the cabinet is as shown in Fig. 33. In this way there it is possible to slide the base-board right in for travel or flush with the front for operation, or even just out of the cabinet for examination, without affecting the connections.

Further, one can if desired disconnect at *A* and *B*, remove the set completely, and connect *C* direct to *D* for test operation away from the cabinet.

2 is the meter, 3 the main switch, 4 and 5 the balancing condenser and resistance for the bridge circuit, 6 the .001 condenser, 7 the twin condenser; 8 and the similar rectangles beside the valve-holders are the fixed H.F. by-pass condensers; 9 is the leak for the first detector, 10 the grid battery. 11 and three similar rectangles are the I.F. tuning condensers; 12 is the long-short switch, and 13 the loading coil socket. 14 are the screens; 15 are the L.F. transformers; 16 the meter keys; and 17 the rheostats.

In the last compartment, 18 are the two H.T. by-pass condensers, 20 the switch for the detector, 21 the detectors, and 22 the H.T.—, two H.T.+, and the output, which are on a strip similar to 1. The I.F. transformers and the autodyne unit are under the baseboard, in the positions indicated by the letters *M D D D E* shown under the sketch.

Fig. 34 shows the front panel, again in diagrammatic form. On the left are the main switch and meter. Next come the aerial and oscillator condensers, and below them the oscillator coil unit with reactor. The square object next at the top of the panel is a calibration chart: under it are the long-short switch, the first I.F. condenser (which controls all four) and the first I.F. transformer: above (not shown) is the socket for the frame aerial. There are now three similar divisions, each containing rheostat, meter switch, and I.F. transformer, one of the latter having a reactor. (The flex leads from the reactors go to Clix in the baseboard.) Lastly, there are the two second detectors with their switch. The "valve" sockets for the I.F. transformers are of course of the "behind panel" type, as in Fig. 35.

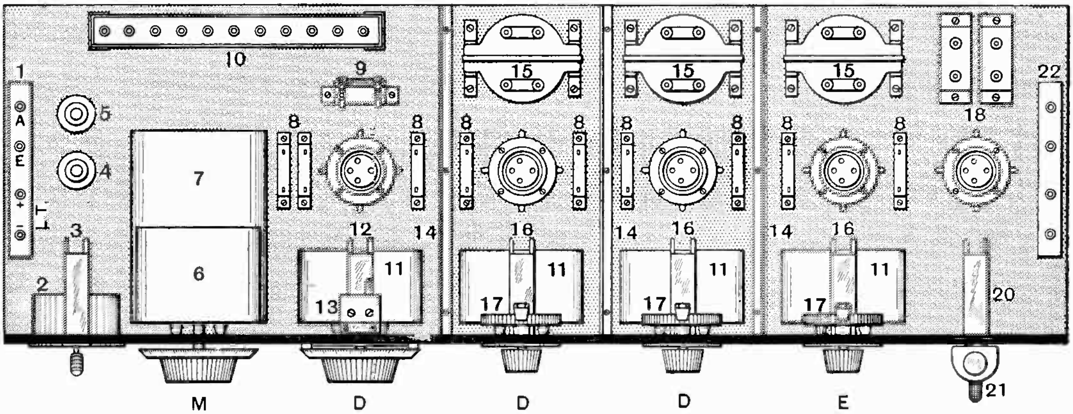


Fig. 32. *The whole layout as far as it can be seen from above. The key to the reference numbers is in the accompanying description.*

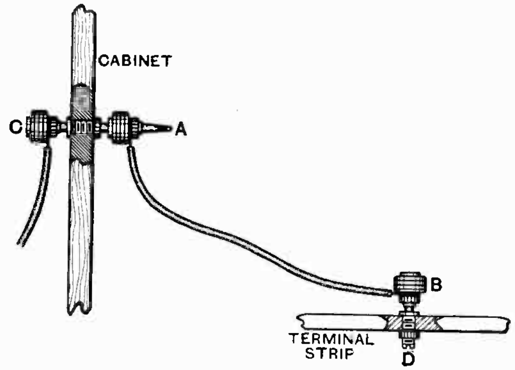


Fig. 33. *All the outside connections are made to the cabinet, and short flex leads go thence to the baseboard.*

One or two constructional points are to be mentioned, as they may be useful to others building similar sets.

The "ganging" of the four condensers was simple. Four pulleys were made in $\frac{1}{8}$ in. ebonite, as in Fig. 36. They were of 2 in. diameter, with brass bushes to fit the condenser spindles. When the condensers were in place a double-length of mandoline-string (high tensile steel wire, about 34 S.W.G.) was given a complete turn round each, and the ends brought to a miniature turnbuckle, as used for model aeroplanes, etc., the wire being arranged as in Fig. 37. The left-hand condenser had to receive a knob as well, and its spindle was too short. This was extended by a half-jointed piece made of brass rod, with hack-saw and file, and soldered. In spite of being rather a beginner's job, it worked quite well. When the whole was assembled, it behaved most admirably—no slip nor backlash, but quite smoothly; it is also quite easy to slack the grub-screws and adjust each condenser independently. Two points are important: The pulleys *must* be well made, or there will be tight and loose spots; and the wire joint must be so placed that it only goes from *A* to *B* (Fig. 37) during the whole movement: it naturally won't go round the pulleys.

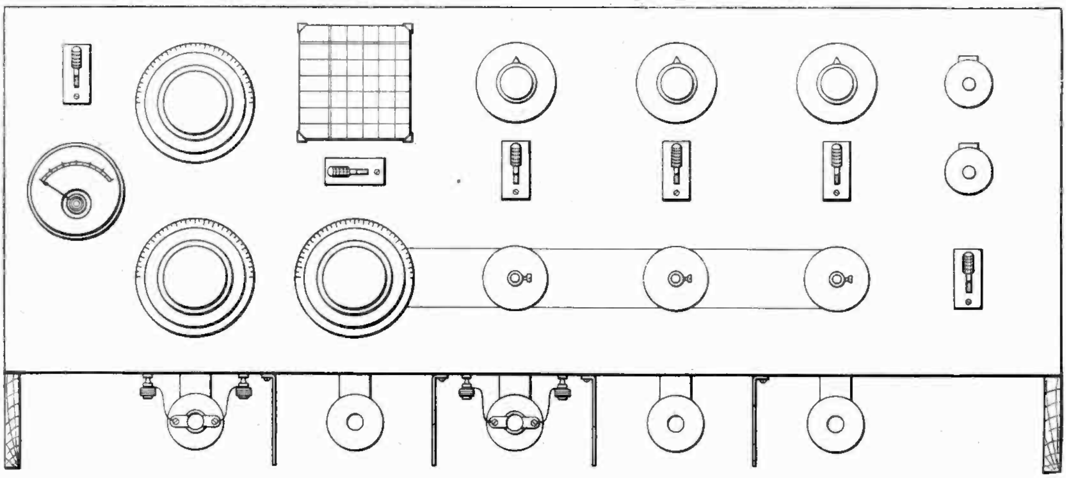


Fig. 34. *From the front we have access to all adjustments, including the reactors. See the neighbouring reading matter to identify the various controls.*

The frame aerial used with this set was enclosed in the removable front of the box. As already stated, the whole set was made to slide within the cabinet, so that a front lid could be put on to enclose it completely when slid back, but allowing the front panel to come forward flush with the box for operation. This was worked as shown in Fig. 38; the two runners below the ends of the baseboard were fitted with bolts (common household variety) which dropped into holes in the bottom of the cabinet.

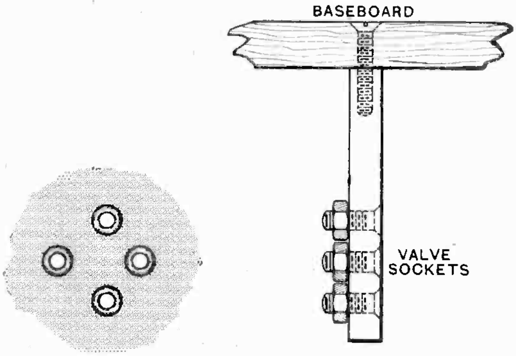


Fig. 35. *Sockets for the transformers.*

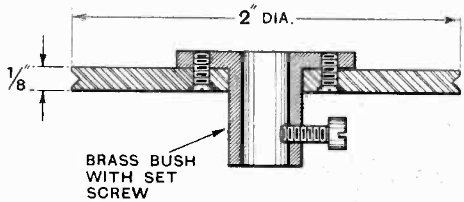


Fig. 36. *To enable all the I.F. condensers to be worked from one control, they were fitted with these pulleys.*

Two pairs of holes were provided to give the two positions.

The fittings of the front lid itself comprised (*a*) two pegs on the lower edge, engaging with holes inside the lower front edge of the cabinet. The pegs were short, and the holes loose enough to let the lid tilt back so that it could be lifted clear. (*b*) Two ball catches let into the upper edge, engaging in holes within the upper edge of the cabinet. (*c*) A lock engaging with a socket on the upper edge of the cabinet.

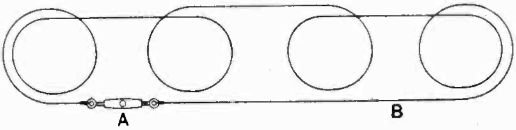


Fig. 37. *Round the pulleys of* Fig. 36 *goes a fine steel wire, linking all together.*

Besides these fittings, enabling it to act as a lid, the lid was also fitted as a frame aerial. Its general construction is shown in Fig. 39. A sheet of mahogany veneer 3-ply was fitted with three strips of mahogany, $\frac{3}{4}$ in. wide and $\frac{1}{2}$ in. thick, round three of its edges, the fourth having a strip 2 in. wide; and also with four ebonite combs 4 in. long by $\frac{1}{2}$ in. thick by $\frac{5}{8}$ in. wide. One of the combs is shown separately in the circle, which shows how the slots in it were undercut to prevent the wires slipping out, and were slightly deeper than half the thickness of the comb, so that the wire winding comes central in the open space within the lid. After winding the frame, a second sheet of 3-ply was screwed down over the winding, the whole forming a hollow lid.

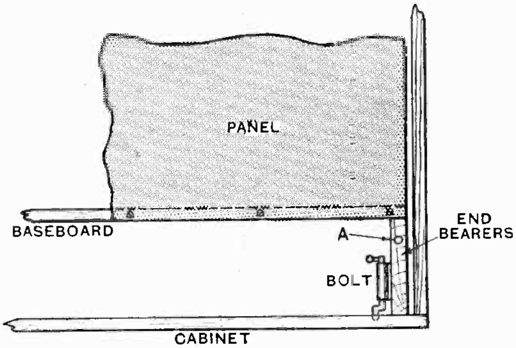


Fig. 38. *Bolts lock the baseboard in either the working or travelling position. A is the carrying socket for the frame aerial spindle when the set is closed up.*

The frame, when in use as such, rotates on a spindle fitted in the lid of the set, the arrangements for location and contact being shown in Fig. 40. Here the upper sketch shows a section of part of the frame, and the lower the corresponding part of the cabinet top. *A* is the 2 in. wide mahogany strip forming one end of the hollow lid, *B* being part of the 3-ply cover. *A* is drilled to take *C*, which is a brass tube, $\frac{1}{4}$ in. inside and about $\frac{3}{8}$ in. outside, sweated to an oblong flange $\frac{1}{2}$ in. by 2 in. *C* is made a tight tapping fit in the hole, and when the flange is screwed down is quite secure. The most important point is to see that *C* is truly square with the lower edge *D* of the whole frame. *A* is cut away about $\frac{1}{8}$ in. deep on its lower edge for two or three inches each side of *C*, and the two hard brass

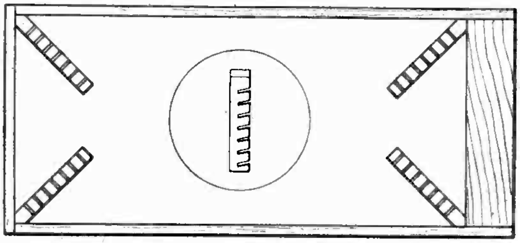


Fig. 39. *The general design of the frame-lid: in the circle, a side view of one of the combs.*

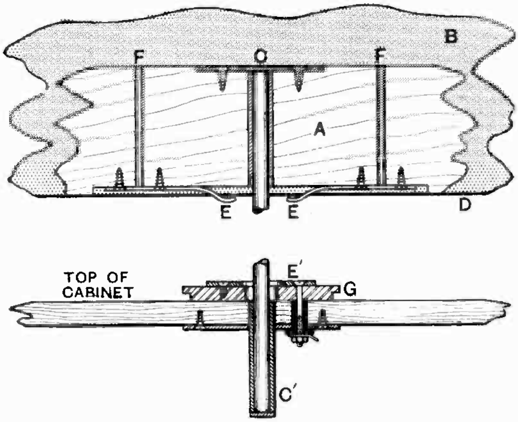


Fig. 40. *Details of the combined spindle and contact arrangements for the frame. The disc* G *is undercut to take the compass card.*

springs E affixed. Contact to the two ends of the frame is made by C and E, the leads to E being in parallel (*i.e.* both springs E are one contact). The leads to E go down the holes F.

In the cabinet, a corresponding tube C' is fitted. This, however, has a flange the right distance along it to make its upper end flush with the outside of the cabinet. Its lower end is enclosed by a disc sweated on.

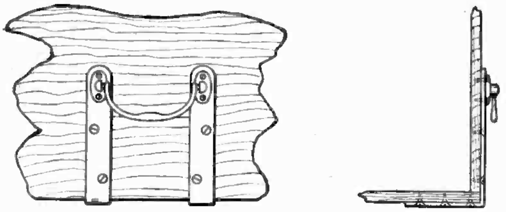


Fig. 41. *A useful tip for transferring lifting stresses in a heavy set with a light cabinet.*

The two springs E of the frame rub on a brass ring E' mounted on an ebonite ring G, the latter being screwed to the cabinet.

The spindle itself is loose, for otherwise it would make an awkward projection when the set is closed up. When the set is to be erected, the spindle—a plain piece of $\frac{1}{4}$ in. brass rod with rounded ends—is dropped into C', and the frame lowered onto its projecting upper end. The length of the spindle and the strength of springs E need a certain care. The strength of E should be such that the frame's own weight just makes them go flush with the edge D, from which they should project about $\frac{1}{8}$ in. when there is no weight on them. Then the length of the spindle should be adjusted so that when it is in contact with the ends of C and C', D is $\frac{1}{16}$ in. above E'. Under these conditions, half the weight of the frame is taken by the springs and half by the spindle, and both will make first-class contact. Connection from E' to the set is made by making one of the screws for E' a long bolt which goes right through a clearing hole in the timber, with an ebonite bush on the inside end. It was originally intended to provide ebonite insulation for springs E, but it was found quite unnccessary.

When the frame is not in use, the loose spindle is housed as shown in Fig. 38. The hole A in the runner is long enough to take all but $\frac{1}{2}$ in. of the spindle, which is a loose push fit therein.

This frame has, for its middle turn, an area of just about 1 ft. by 2 ft., and has 8 turns. It was quite successful, though naturally not so powerful as a larger frame built later on. Nevertheless, it was good enough to get practically everything in Europe of 1kW or over, at good loud-speaker strength.

Going back for a moment to the wiring diagram, Fig. 29, it may be noticed that arrangements are made to put a coil socket (marked " Short Coil ") in series or parallel with the frame, or across A and E. This socket, and the four Clix which bring it and the frame into action, are fitted to the *cabinet*, flex leads from the A and E terminals going to the set as already stated.

Other fittings on the cabinet are to make the set easier to carry. A brass drop handle is fitted at each end, and since the set is heavy and the cabinet none too strong, $\frac{1}{16}$ in. brass straps from the handles are taken down under the bottom of the cabinet and screwed there, as shown in Fig. 41.

Lastly, there is the compass-card. This is a disc of thin 3-ply, about 7 in. diameter, with a hole large enough to be a loose fit round the lower part of the ebonite bush G

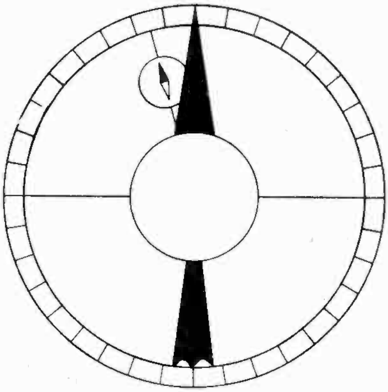


Fig. 42. *For checking bearings: a large compass card, set by means of a small compass and then locked. The actual card is of course marked in degrees.*

(Fig. 40). It is thus held in place, but is free to rotate. It is marked with every 10° of bearing, and has also a line drawn for 345°, corresponding to the Magnetic North. On this line is centred a hole about 1 in. diameter, into which fits a small pocket compass; there is also, screwed to the cabinet, a locking device like a gramophone brake, to hold the card in position when it has been set with the compass needle lying along its radius.

The Set in Operation.

The set was a success from the first. It was completed and first had the batteries connected up two days before the first all-European broadcast tests in the autumn of 1925. There were the usual minor troubles in getting the adjustments right, but during the six hours of the tests (12 p.m. to 2 a.m. on three successive nights) we averaged 29 stations per night, definitely identified, 10 more per night tentatively identified by direction and wavelength, and 8 more unidentified—not bad for a brand-new set.

Trials were made on an outdoor aerial—quite justified, since radiation is negligible on account of the bridge circuit. Generally speaking the results gave little increase in *effective* power over the frame. Signals were, of course, more powerful, but even with the frame the limiting range of reception was simply that at which interference became excessive.

On the frame (which was almost always used) it was noticeable that the oscillator tuning was very sharp indeed, while the frame tuning was not very sharp. So sharp was the oscillator that we found tuning quite tricky at the short end of the scale even with an 80 : 1 geared dial; one could get and lose a distant station in the thickness of a degree line! As to effective selectivity: at the end of 1925 we were located just two miles west of 2LO, and at that time Manchester and Cardiff were more or less equally spaced each side of 2LO's wave.

Manchester could be easily got, because the frame helped. But for Cardiff, the frame had to be right for London at the same time, the set being dead on the line between the two stations; and the best we could do was to reduce London to the same strength as Cardiff.

As we got used to handling the set, it soon became obvious that the strength was usually excessive. We placed a Bretwood variable anode resistance across the primary of one of the L.F. transformers, with good results; but finding that it was almost always reduced to about 5,000 ohms or less, we eventually cut one L.F. stage right out, reflexing to the fourth valve (see Fig. 29) instead of the third. This rather improved the tone, as one could use more I.F. amplification and so get a greater input to the detector before the strength got too great at the loud-speaker.

The set remained in this condition, giving complete satisfaction, until the end of 1926, when it was decided to do some more experimental work. It has since been altered in various ways—perhaps in a few months' time it will reach a stable condition again!

Now as to suggestions for improvement. As we have already hinted, the use of a variable intermediate frequency was not entirely successful, owing to instability when the condensers are reduced. The obvious cure for this is neutralisation, but this means a change in the I.F. transformers, the McMichael ones originally used not being suited to this in their purchased form.

As regards the detector-oscillator circuit, this was completely successful; but there are some interesting methods known now in which the circuits are made simpler by using a tetrode instead of a triode.

In view of the improvement in loud-speakers since the set was made, the L.F. end can no longer be considered good enough for one of fastidious taste. The first transformer, between crystal and valve, may be considered to give negligible distortion, but it would probably be best to use resistance coupling between the reflexed valve (only one now, not two as in Fig. 29) and the power valve.

Mathematics for Wireless Amateurs.

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

(Continued from page 354 of June issue.)

12. An Important Geometrical Proposition (the Pons Asinorum).

As a matter of fact we have already crossed this bridge (the reader must excuse the imputation) in the preceding section, but its very important geometrical significance must be made more clear.

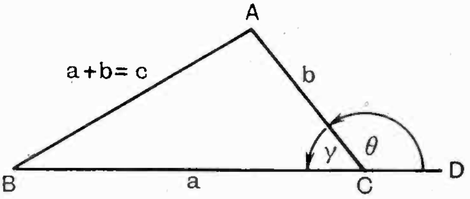


Fig. 24.

The vectors **c**=**a**+**b**, **a**, and **b** form a triangle as shown in Fig. 24.

From Section 11,

$$\mathbf{c}^2=(\mathbf{a}+\mathbf{b})^2=\mathbf{a}^2+\mathbf{b}^2+2\ \mathbf{a}\cdot\mathbf{b}$$

Putting in the scalar magnitudes of these scalar products and squares,

$$c^2=a^2+b^2+2ab\cos\theta$$
$$=a^2+b^2-2ab\cos\gamma$$

since $\theta+\gamma=\pi$ (180°).

Applications and Deductions.

(*a*) Given two sides of a triangle (a and b) and the angle between them the magnitude of the third side can be calculated from the formula

$$c^2=a^2+b^2-2ab\cos\gamma$$

(*b*) Given the three sides of a triangle, a, b, and c, the angle γ between a and b is given by

$$\cos\gamma=(c^2-a^2-b^2)/2ab$$

which, together with the fact that γ must be less than 180° defines γ completely.

It follows from this that if two triangles are equal as to the lengths of their sides they are equal in every respect. (See Section 5, Part II).

(*c*) The special case known as the Pons Asinorum (*Euclid* I, 47)

If $A\hat{C}B$ is a right angle (Fig. 25) then

$$\cos\gamma=0$$

and $$c^2=a^2+b^2$$

Thus, in a right-angled triangle, the square on the hypotheneuse is equal to the sum of the squares on the other two sides.

This leads to the functional relationship between the trigonometrical ratios of an angle to which a reference was made in anticipation in Section 7. Since (Fig. 25)

$$a^2+b^2=c^2$$
$$(a^2/c^2)+(b^2/c^2)=1$$

or $$(a/c)^2+(b/c)^2=1$$

i.e., $$(\cos\beta)^2+(\sin\beta)^2=1$$

or, as it is usually written,

$$\cos^2\beta+\sin^2\beta=1$$

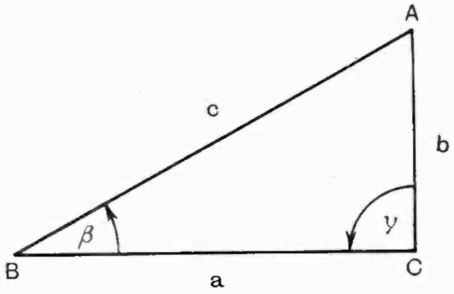


Fig. 25.

This relationship can of course be expressed in a variety of ways. For instance division by $\cos^2\beta$ gives

$$1+\tan^2\beta=\sec^2\beta$$

and so on.

13. The Operator "j".

This introduces a somewhat controversial topic. The symbol "j" is very widely employed in alternating current analysis, but there is a divergence of opinion as to its essential character and occasionally discussions arise as to the legitimacy of certain applications of it or as to the interpretation of expressions in which it appears.

Of course any system of ideas which, to put it colloquially, "delivers the goods" and which is self-consistent, can be used as the basis of a system of symbolic logic. The operator interpretation here described is not put forward as the inspired word and only

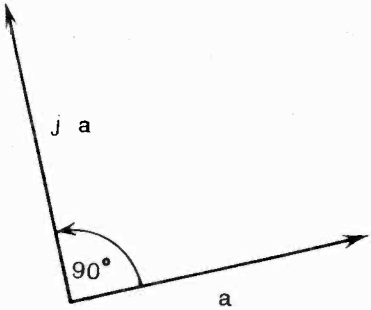


Fig. 26.

true gospel. All that is claimed for it is that it is clear and self-consistent and avoids some of the difficulties of interpretation associated with the imaginary quantity and complex number nomenclature.

Two types of operator with a vector operand have already been introduced. The first is simple scalar multiplication represented by the a in $a\mathbf{a}_1$, which increases the length of its operand without altering its direction. The second is the operator -1 which reverses the direction of its operand without changing its magnitude. A third will now be introduced. The operator j rotates its vector operand through $\pi/2$ (90°) in a positive direction in a given plane without changing its magnitude. The vectors $\mathbf{a}$ and $j\mathbf{a}$ will therefore be as shown in Fig. 26. (The plane of the operation will be taken throughout as the plane of the paper.)

It follows from the definition of j that

$$j\,(j\mathbf{a}) = -\mathbf{a}$$

For shortness $j(j\mathbf{a})$ can be written $jj\mathbf{a}$ and still more compactly as $j^2\mathbf{a}$ but the real significance of j^2 should be borne in mind. Then

$$j^2(\ ) = -1\,(\ )$$

Similarly $$j^3 = -j$$

and $$j^4 = 1$$

so that the relationship between "powers" of j and j and 1 is the same as that between powers of $\sqrt{-1}$ and $\sqrt{-1}$ and 1. Whether or no this establishes any identity between j and $\sqrt{-1}$ is irrelevant to the present purpose. The important point is the effect of powers of j, *i.e.*, of successive operations with j.

The operator j can obviously be combined with a scalar number or multiplier and the association is commutative, for $aj\nu$ is the same vector as $ja\nu$, from which it follows that the operator aj is the same in effect as ja.

14. (*a*) The Operator $(a+jb)$.

The obvious interpretation of $(a+jb)\nu$ is $a\nu+jb\nu$. This is illustrated in Fig. 27. Notice that

$$(a+jb)\nu = (jb+a)\nu$$

by elementary geometry. In the above a and b can be any positive or negative numbers or fractions.

It follows from para. (*c*) of Section 12 that (Fig. 27)

$$BA^2 = BC^2 + CA^2$$

i.e., writing r for the magnitude of BA,

$$r^2 = a^2 + b^2$$

or $$r = +\sqrt{a^2+b^2}$$

while θ is defined by

$$\sin\theta = b/r \quad \cos\theta = a/r \quad \tan\theta = b/a$$

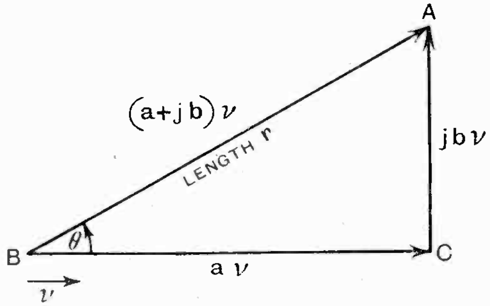


Fig. 27.

which make θ quite definite for given signs and magnitudes of a and b. The effect of the operator $(a+jb)$ is thus seen to be a rotation through θ specified as above, combined with a multiplication by $r = \sqrt{a^2+b^2}$, and this effect is quite independent of the actual operand, which may be a unit vector as in Fig. 27, or any other vector whatever. Further by a suitable choice of a and b, r and

θ can be made to assume any values whatever and any vector in the plane of the operation can be represented in the form $(a+jb)\nu$. The operator $(a+jb)$ can therefore be regarded as the most general possible form of co-efficient in any given plane. Its importance for students of electricity lies in the fact (to be demonstrated later) that any alternating current impedance can be expressed in this form. The fairly detailed study of this co-efficient and its combinations is therefore a practical necessity. The calculus of such co-efficients will prove to be identical in form with that of complex numbers, but its full geometrical significance will probably be missed if this is simply taken for granted.

The effect of the operator can be specified exactly in terms of a scalar product. If the vector **u** is of length u and direction ψ with respect to ν, then

$$\mathbf{u} \cdot \nu = u \cos \psi$$

and from the preceding it follows that

$$(a+jb)\, \mathbf{u} \cdot \nu = ru \cos (\psi + \theta)$$

a result which should be noted carefully because of its later significance in alternating current analysis.

(*b*) Addition of Operators.

By applying the laws of commutation and association in the addition of vectors

$$\{(a+jb)+(c+jd)\}\nu=(a+jb)\nu+(c+jd)\nu$$
$$=a\nu+jb\nu+c\nu+jd\nu$$
$$=a\nu+c\nu+jb\nu+jd\nu$$
$$=(a+c)\nu+(jb+jd)\nu$$

therefore

$$=\{(a+c)+j(b+d)\}\nu$$

The reader is advised to interpret all these steps geometrically. It appears that the addition of operators follows the same rules as that of complex numbers. The result can obviously be extended to the additon (or subtraction) of any number of operators.

(*c*) Equality of Operators.

The equation

$$(a+jb)\nu=(c+jd)\nu$$

clearly implies the operator equality

$$(a+jb)=(c+jd)$$

If to each of the equal vectors in the first equation we add the vector $(-jb-c)\nu$ we get

$$(a-c)\nu=(d-b)\, j\nu$$

i.e., a vector equal to another which is perpendicular to it; but this is impossible by the definition of a vector unless each is zero.

Therefore if $(a+jb)=(c+jd)$

then $a-c=0$ and $d-b=0$

i.e., $a=c$ and $b=d$

This process can be compared with the separate equating of the real and imaginary parts of equal complex numbers. In operators the components can be referred to as the "a" and "b" parts, or, perhaps better as suggested by A. Eagle, of the Victoria University, the "axial" and "non-axial" parts. Neither of these alternatives is quite satisfactory, but either is better than the customary "real" and "imaginary" which are misleading and confusing.

As a special case of the above we have, if

$$a+jb=0$$

then $a=0$ and $b=0$

(*d*) Multiplication of Operators.

By the geometry of similar triangles it is easy to show that

$$a\{(c+jd)\nu\} = a(c\nu+jd\nu)$$
$$= ac\nu+ajd\nu$$
$$= ac\nu+jad\nu$$

and similarly

$$b\{(c+jd)\nu\}=bc\nu+jbd\nu$$

and

$$jb\{(c+jd)\nu\}=jbc\nu+jjbd\nu$$
$$=jbc\nu-bd\nu$$

and by addition

$$(a+jb)\{(c+jd)\nu\}=ac\nu+jad\nu+jbc\nu-bd\nu$$
$$=\{(ac-bd)+j(ad+bc)\}\nu$$

The intermediate brackets on the left-hand side can be omitted, though they are required for a comprehensible interpretation. Then

$$(a+jb)\ (c+jd)\nu=\{(ac-bd)+j(ad+bc)\}\nu$$

or considering the operators only

$$(a+jb)\,(c+jd)\ =(ac-bd)+j(ad+bc)$$

which again is similar to the same operation with complex numbers.

The above two results for addition and multiplication can be extended to division, powers, etc., precisely as for the same operations with real or complex numbers described in Part I, and no new rules have to be learnt. The interpretations will be sufficiently obvious in most cases. For instance the equation

$$\mathbf{u} = \frac{1}{a + jb}\mathbf{v}$$

really means that $\mathbf{u}$ is that vector which, operated on with $(a+jb)$, gives $\mathbf{v}$,

i.e., $$(a + jb)\mathbf{u} = \mathbf{v}$$

Operating on each of these equal vectors with $(a-jb)$ gives

$$(a-jb)\ (a+jb)\ \mathbf{u} = (a^2+b^2)\ \mathbf{u} = (a-jb)\ \mathbf{v}$$

or $$\mathbf{u} = \frac{(a-jb)}{(a^2+b^2)}\mathbf{v}$$

which is the process corresponding to the rationalisation of complex numbers.

The interpretation of roots of operators will require a little more care and will be considered more fully later on.

Before leaving this part of the subject it will be well to point out the distinction between $(a+jb)\ (c+jd)v$, which implies successive operations on v, and $(a+jb)v \cdot (c+jd)v$, which is the scalar product of two vectors. By applying the results of Section 11 it is easy to show that the latter is simply the number $(ac+bd)$. This latter form will be met later in connection with expressions for the power in alternating current circuits.

15. Alternative Form for $(a+jb)$.

Referring back to Fig. 27,

$$a = r\cos\theta \text{ and } b = r\sin\theta$$

so that $$(a+jb) = r\ (\cos\theta + j\sin\theta)$$

and since the effect of $(a+jb)$ is multiplication by r and rotation through θ in a positive direction it is clear that the operator $(\theta\ \cos\ \theta + j\ \sin\ \theta)$ represents the rotation through θ. (Fig. 28.)

So far θ is inherently a positive number, but this restriction can be removed, for if

$$\mathbf{u} = (\cos\theta + j\sin\theta)\ \mathbf{v}$$

be written in the form

$$\mathbf{v} = \frac{1}{\cos\theta + j\sin\theta}\mathbf{u}$$

it is clear that $1/(\cos\theta + j\ \sin\theta)$ means a rotation of amount θ in a negative direction, *i.e.*, a rotation $-\theta$. But by the preceding section

$$\frac{1}{\cos\theta + j\sin\theta} = \frac{\cos\theta - j\sin\theta}{\cos^2\theta + \sin^2\theta}$$
$$= \cos\theta - j\sin\theta$$
$$= \cos(-\theta) + j\sin(-\theta)$$

so that $\cos(-\theta) + j\sin(-\theta)$ effects a rotation of $-\theta$. Therefore for positive or negative values of θ, $(\cos\theta + j\sin\theta)$ effects a rotation θ.

Successive rotations of θ_1 and θ_2, these being positive or negative, are obviously equivalent to a single rotation $(\theta_1+\theta_2)$. Therefore $(\cos\ \theta_1 + j\ \sin\ \theta_1)\ (\cos\ \theta_2 + j\ \sin\ \theta_2) = \cos\ (\theta_1+\theta_2) + j\ \sin\ (\theta_1+\theta_2)$

This remarkable formula, which, in its operator interpretation is self-evident, embodies what is known in pure mathematics as

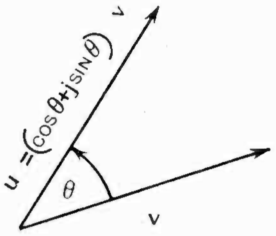


Fig. 28.

De Moivre's Theorem. Many results of far-reaching importance can be deduced from it. Some of these will now be considered.

16. The Addition Formulæ of Trigonometry.

Since

$$\cos(\theta_1+\theta_2) + j\sin(\theta_1+\theta_2)$$
$$= (\cos\theta_1 + j\sin\theta_1)\ (\cos\theta_2 + j\sin\theta_2)$$
$$= \cos\theta_1\cos\theta_2 - \sin\theta_1\sin\theta_2 + j(\sin\theta_1\cos\theta_2 + \cos\theta_1\sin\theta_2)$$

by multiplication, as in Section 14D, then equating separately the a and b parts

$$\cos(\theta_1+\theta_2) = \cos\theta_1\cos\theta_2 - \sin\theta_1\sin\theta_2$$
$$\sin(\theta_1+\theta_2) = \sin\theta_1\cos\theta_2 + \cos\theta_1\sin\theta_2$$

From these two important formulæ many others can be derived as special cases. For instance, if $-\theta_2$ be written for θ_2,

$$\cos(\theta_1-\theta_2) = \cos\theta_1\cos\theta_2 + \sin\theta_1\sin\theta_2$$
$$\sin(\theta_1-\theta_2) = \sin\theta_1\cos\theta_2 - \cos\theta_1\sin\theta_2$$

and if in the first pair we put $\theta_1 = \theta_2 = \theta$

$$\cos 2\theta = \cos^2\theta - \sin^2\theta$$
$$= 2\cos^2\theta - 1$$
$$= 1 - 2\sin^2\theta$$

(since $\cos^2\theta + \sin^2\theta = 1$) and

$$\sin 2\theta = 2\sin\theta\cos\theta.$$

Similarly formulæ for the tangent and cotangent of sums and differences, and for the ratios of 3θ, 4θ, etc., can be obtained by inserting appropriate special values in the original formulæ. The product formulæ $2 \sin \theta_1 \sin \theta_2 = \cos(\theta_1 - \theta_2) - \cos(\theta_1 + \theta_2)$ etc., etc., should be noted as they have many applications in wireless telegraphy and telephony. However, the only ones that really need be remembered by heart are the formulæ for the sin and cos of $(\theta_1 + \theta_2)$ for the others can be derived from them very simply.

17. The Exponential Form for $(\cos \theta + j \sin \theta)$.

Since n equal rotations of θ are equal to a single rotation $n\theta$, n being a positive integer.

$$\cos n\theta + j \sin n\theta = (\cos \theta + j \sin \theta)^n = \cos^n \theta (1 + j \tan \theta)^n$$

Now put $n\theta = \phi$, then

$$\cos \phi + j \sin \phi = \cos^n \frac{\phi}{n} (1 + j \tan \frac{\phi}{n})^n$$

This formula will remain true however large n may be so that

$$\cos \phi + j \sin \phi = \lim_{n \to \infty} \cos^n \frac{\phi}{n} \left(1 + j \tan \frac{\phi}{n}\right)^n$$

Now by sufficiently increasing n, $\tan \frac{\phi}{n}$ can be made to differ from ϕ/n by as little as we please, and $\cos^n \frac{\phi}{n}$ can be made to differ from 1 by as little as we please. This can easily be appreciated by drawing a diagram showing θ, $\tan \theta$, and $\cos \theta$ for a very small angle θ. Therefore, remembering the definition of "limit" (Section 8 of Part I, January, 1927)

$$\lim_{n \to \infty} \cos^n \frac{\phi}{n} \left(1 + j \tan \frac{\phi}{n}\right)^n = \lim_{n \to \infty} \left(1 + j \frac{\phi}{n}\right)^n$$

It has been shown that the multiplying together of operators follows the same rules as the multiplication of real or complex numbers. Therefore the product $\left(1 + j \frac{\phi}{n}\right)^n$ can be written down by the Binomial Theorem for a $+ve$ integral index (Section 10 of Part I) and the limit when n tends to infinity can be found in exactly the same way as is shown in full in Section 11 of Part I. The result is

$$\cos \phi + j \sin \phi = 1 + j\phi + \frac{(j\phi)^2}{2!} + \frac{(j\phi)^3}{3!} \text{ etc., etc., } ad\ inf.$$

The infinite series on the right will be written $S(j\phi)$ for shortness. If x is any real number

$$S(x) = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \frac{x^4}{4!} + \text{etc., etc., } ad\ inf. = \epsilon^x$$

(Section 11, Part I) where ϵ is the number 2.71828 . . . . But this does not mean that $S(j\phi)$ is similarly $\epsilon^{j\phi}$, for how can any number be multiplied by itself $j\phi$ times? Nevertheless $\epsilon^{j\phi}$ will be adopted as a convenient short way of writing $S(j\phi)$ or the operator $(\cos \phi + j \sin \phi)$ which has the same effect, and this practice will not lead to any errors for it has already been shown that

$$(\cos \theta_1 + j \sin \theta_1)(\cos \theta_2 + j \sin \theta_2) = \cos(\theta_1 + \theta_2) + j \sin(\theta_1 + \theta_2)$$

which in the exponential form becomes

$$\epsilon^{j\theta_1} \epsilon^{j\theta_2} = \epsilon^{j(\theta_1 + \theta_2)}$$

which is in formal agreement with the index law. The $j\phi$ in $\epsilon^{j\phi}$ does actually function as an index as far as combinations of such quantities are concerned, and the exponential form of writing is therefore a convenient and legitimate way of expressing this fact. Remember, however, that the index behaviour is derived first and independently and is not a deduction from the exponential form. On this understanding any operator $(a + jb)$ can be written in the form

$$(a + jb) = r(\cos \theta + j \sin \theta) = r\epsilon^{j\theta}$$

where r and θ are as specified in Section 14A. The convenience of this last form for calculation will be apparent later on. Remembering the effect of the operator $r\epsilon^{j\theta}$, it is easy to see that $r\epsilon^{j\theta}\nu$ is a vector of magnitude r making an angle θ with the direction of ν, so that

$$r\epsilon^{j\theta}\nu \cdot \nu = r \cos \theta$$

In particular the vector $\hat{e}\,\epsilon^{j\omega t}\nu$ is of magnitude $\hat{e}$ and makes with ν an angle which increases at the rate ω radians per second (t representing the time in seconds from some definite zero or starting point), *i.e.*, it is a vector of constant magnitude rotating with constant angular velocity, and

$$\hat{e}\epsilon^{j\omega t}\nu \cdot \nu = \hat{e} \cos \omega t$$

Such an operator can therefore be used to specify an alternating E.M.F. in the vector form $\hat{e}\epsilon^{j\omega t}\nu$. In practice it will not be necessary to write in the unit vector of reference ν but its implicit existence as the operand of $\hat{e}\epsilon^{j\omega t}$ should be borne in mind and will generally facilitate the interpretation of vector calculations. The significance of this will appear more fully later on.

18. Series Form for Sine and Cosine.

Another very interesting result is derived from De Moivre's Theorem as follows:—

$$\cos\theta + j\sin\theta$$
$$= 1 + j\theta + \frac{(j\theta)^2}{2!} + \frac{(j\theta)^3}{3!} + \frac{(j\theta)^4}{4!} + \frac{(j\theta)^5}{5!} + \text{etc., etc. } ad\ inf.$$
$$= 1 + j\theta - \frac{\theta^2}{2!} - \frac{j\theta^3}{3!} + \frac{\theta^4}{4!} + \frac{j\theta^5}{5!} + \text{etc., etc. } ad\ inf.$$
$$= \left(1 - \frac{\theta^2}{2!} + \frac{\theta^4}{4!} + \text{etc., etc.}\right) + j\left(\theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - \text{etc., etc.}\right)$$

Therefore equating separately the *a* and *b* parts of these operators

$$\cos\theta = 1 - \frac{\theta^2}{2!} + \frac{\theta^4}{4!} - \text{etc., etc. } ad\ inf.$$
$$\sin\theta = \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - \text{etc., etc. } ad\ inf.$$

These series are rapidly convergent for small values of θ and give as convenient approximations for such small values

$$\cos\theta = 1 - \theta^2/2$$
$$\sin\theta = \theta - \theta^3/6$$

19. Roots of Operators.

By analogy with the ordinary arithmetical meaning of "root" the *n*th root of the operator $r(\cos\theta + j\sin\theta)$ will be taken to mean any operator which repeated n times, *i.e.*, raised to the nth power, has the same effect as $r(\cos\theta + j\sin\theta)$. We shall now see that if n is an integer there will be n different operators which fulfil this condition. First let $r^{1/n}$ be written for that positive number which, raised to the nth power, gives r. For given values of r and n there is only one such number. Now if m is any integer

$$\left[r^{1/n}\left\{\cos\left(\frac{\theta}{n} + \frac{2m\pi}{n}\right) + j\sin\left(\frac{\theta}{n} + \frac{2m\pi}{n}\right)\right\}\right]^n$$
$$= r\{\cos(\theta + 2m\pi) + j\sin(\theta + 2m\pi)\}$$

as already shown in Section 17. By drawing a simple quadrant diagram it will be easy to see that for all integral values of m

$\cos(\theta + 2m\pi) = \cos\theta$ and $\sin(\theta + 2m\pi) = \sin\theta$

so that

$$\left[r^{1/n}\left\{\cos\left(\frac{\theta}{n} + \frac{2m\pi}{n}\right) + j\sin\left(\frac{\theta}{n} + \frac{2m\pi}{n}\right)\right\}\right]$$
$$= r(\cos\theta + j\sin\theta)$$

and all the operators obtained by giving m any integral value in

$$r^{1/n}\left\{\cos\left(\frac{\theta}{n} + \frac{2m\pi}{n}\right) + j\sin\left(\frac{\theta}{n} + \frac{2m\pi}{n}\right)\right\}$$

are nth roots of $r(\cos\theta + j\sin\theta)$. This seems rather a lot, but actually they are not all different. For instance if n is 3, then putting 0, 1, 2, 3 for m gives

$$r^{\frac{1}{3}}\{\cos(\theta/3) + j\sin(\theta/3)\}$$
$$r^{\frac{1}{3}}\left\{\cos\left(\frac{\theta}{3} + \frac{2\pi}{3}\right) + j\sin\left(\frac{\theta}{3} + \frac{2\pi}{3}\right)\right\}$$
$$r^{\frac{1}{3}}\left\{\cos\left(\frac{\theta}{3} + \frac{4\pi}{3}\right) + j\sin\left(\frac{\theta}{3} + \frac{4\pi}{3}\right)\right\}$$
$$r^{\frac{1}{3}}\left\{\cos\left(\frac{\theta}{3} + 2\pi\right) + j\sin\left(\frac{\theta}{3} + 2\pi\right)\right\}$$

But the last is a repetition of the first. It will be found that putting higher values for m, or giving it any negative integral value, will only give a repetition of one or other of the first three roots. In general there are only *n different* values of the *n*th root of any operator. Any reader to whom this is new should draw out the various operators in a simple case, say, for $n=3$. The geometrical significance of this many-valuedness will then be apparent. The value obtained by putting $m=0$ is called the "principal value," and is sometimes written $\{r(\cos\theta + j\sin\theta)\}^{1/n}$ the alternative form

$$\sqrt[n]{r(\cos\theta + j\sin\theta)}$$

being used to indicate all or any of the roots. The many-valuedness of the root sometimes enters into calculations and should always be borne in mind. The following are some important special cases. (*a*) If $\theta=0$

$$\sqrt[n]{r} = r^{1/n}\left(\cos\frac{2m\pi}{n} + j\sin\frac{2m\pi}{n}\right)$$
$$m = 0, 1, 2, \ldots n-1.$$

the principal value being $r^{1/n}$. If n is 2

$$\sqrt{r}=r^{\frac{1}{2}}(\cos 0+j\sin 0)\,;\; r^{\frac{1}{2}}(\cos \pi+j\sin \pi) = = +r^{\frac{1}{2}}\,;\,-r^{\frac{1}{2}}.$$

$$i.e., \sqrt{r}=\pm r^{\frac{1}{2}}$$

(*b*) Putting $\theta=\pi$

$$\sqrt[n]{r\,(\cos\pi+j\sin\pi)}=\sqrt[n]{-r}$$

$$=r^{1/n}\left\{\cos\frac{(2m+1)\pi}{n}+j\sin\frac{(2m+1)\pi}{n}\right\}$$

and the principal value is

$$r^{1/n}\left\{\cos\frac{\pi}{n}+j\sin\frac{\pi}{n}\right\}$$

For instance, if n is 2

$$\sqrt[2]{-r}=r^{\frac{1}{2}}\left\{\cos\frac{\pi}{2}+j\sin\frac{\pi}{2}\right\}$$

or

$$r^{\frac{1}{2}}\left\{\cos\frac{3\pi}{2}+j\sin\frac{3\pi}{2}\right\}$$

$$=\pm jr.$$

20. Generalisation of the Index Formula.

It has already been shown that for any positive or negative integral value of n

$$\{r(\cos\theta+j\sin\theta)\}^n=r^n(\cos n\theta+j\sin n\theta).$$

Also, by the preceding section, the same is true for the principal value when n is $1/m$, m being a positive integer. This leads without difficulty to the complete generalisation that for any positive or negative integral or fractional value of n, the principal value of

$$\{r(\cos\theta+j\sin\theta)\}^n \text{ is } r^n(\cos n\theta+j\sin n\theta).$$

Space cannot be spared for a detailed development of this generalisation, which follows exactly the same lines as the generalisation of the interpretation of an index given in Part I (September, 1926.)

21. Calculations with Operators.

We have seen that any operator $(a+jb)$ can be put in the form $r\epsilon^{j\theta}$, where $r^2=a^2+b^2$ and θ is one of the angles having b/a as tangent. Referring to the quadrant diagram (Fig. 14) it will be seen that if a and b are positive, θ will be an angle in the first quadrant, *i.e.*, less than 90°. If b is positive and a negative θ will lie in the second quadrant, and so on. Writing $|b|$ and $|a|$ for the magnitudes of b and a, then the angle $\alpha = \tan^{-1}|b|/|a|$ is between 0 and 90 and can be determined from the ordinary table of tangents, and θ will be $+\alpha$, $\pi-\alpha$, $\pi+\alpha$, or $-\alpha$ according to whether it is in the first, second, third or fourth quadrant. An example will perhaps make this clearer. For the operator $3-j4$, r is 5 and θ is an angle in the fourth quadrant. Now $\tan 4/3$ is 53.1°, so that θ is $-53.1°$. For the operator $-3+j4$, on the other hand, θ will be in the second quadrant, so that it is given by $(180-53.1)°$, *i.e.*, 126.9°.

By using the form $r\epsilon^{j\theta}$ the single operator which is equal to, *i.e.*, has the same effect as, any given combination of operators, can be written down at once. For instance, if

$$a+jb=r\epsilon^{j\theta}$$

$$c+jd=s\epsilon^{j\phi}$$

then

$$(a+jb)^2/(c+jd)=(r\epsilon^{j\theta})^2/s\epsilon^{j\phi}=r^2\epsilon^{j2\theta}/s\epsilon^{j\phi}$$
$$=(r^2/s)\epsilon^{j(2\theta-\phi)}$$

which can then be put in the form $A+jB$ if desired, where

$$A=(r^2/s)\cos(2\theta-\phi)$$
$$B=(r^2/s)\sin(2\theta-\phi)$$

A simple type of calculation which will occur frequently in alternating current calculations is exemplified by the following.

Given that $\mathbf{e}=\hat{e}\epsilon^{j\omega t}\nu$

and that $\mathbf{i}=\mathbf{e}/(R+jX)$

R and X being numbers, find $\mathbf{i}\cdot\nu$.

Notice that

$$\mathbf{e}\cdot\nu=\hat{e}\epsilon^{j\omega t}\nu\cdot\nu=\hat{e}\cos\omega t$$

is the instantaneous value of an alternating E.M.F. It will be shown later that $\mathbf{i}\cdot\nu$ is similarly the instantaneous value of the "steady state" alternating current produced by this E.M.F. in a circuit of impedance $(R+jX)$. Expressing this impedance in the form

$$R+jX=Z\epsilon^{j\phi}$$

where $Z^2=R^2+X^2$ and $\tan\phi=X/R$

then

$$\mathbf{i}=\frac{\mathbf{e}}{R+jX}=\frac{e\epsilon^{j\omega t}}{Z\epsilon^{j\phi}}\nu=\frac{\hat{e}}{Z}\epsilon^{j(\omega t-\phi)}\nu$$

so that

$$\mathbf{i}\cdot\nu=(\hat{e}/Z)\epsilon^{j(\omega t-\phi)}\nu\cdot\nu=(\hat{e}/Z)\cos(\omega t-\phi).$$

An alternative form for this result may sometimes be more convenient. The reciprocal of $(R+jX)$ can be expressed in the form

$$\frac{1}{(R+jX)}=\frac{R-jX}{R^2+X^2}=\frac{R}{Z^2}-\frac{jX}{Z^2}=\frac{R}{Z^2}+\frac{X}{Z^2}\varepsilon^{-j\pi/2}$$

since $-j=\varepsilon^{-j\pi/2}$.

Therefore

$$\begin{aligned}\mathbf{i}\cdot\nu &= (R/Z^2)\,\hat{e}\varepsilon^{j\omega t}\nu\cdot\nu + (X/Z^2)\,\hat{e}\varepsilon^{j\omega t}\varepsilon^{-j\pi/2}\nu\cdot\nu \\ &= (R/Z^2)\,\hat{e}\cos\omega t + (X/Z^2)\,\hat{e}\cos(\omega t-\pi/2) \\ &= (R/Z^2)\,\hat{e}\cos\omega t + (X/Z^2)\,\hat{e}\sin\omega t.\end{aligned}$$

So much for a brief introductory survey of the main features of vectors and vector operators. The more detailed study of the subject will be confined to those regions where it comes into immediate contact with the field of alternating current phenomena, in the discussion of which it will be found to infuse a beautiful simplicity; but first we must see how it comes to be associated with what would at first sight seem to be a quite different set of ideas. The nature of the connection has already been foreshadowed, but for its complete delineation some little knowledge of the differential and integral calculus will be required, and to this branch of mathematics the next part of this series will be devoted.

Answers to Examples in June Issue.

1. (i.) 60°. (ii.) 8° 11′. (iii.) .17 radians. (iv.) 22 radians.

2. (i.) 88.8 units of area. (ii.) 25 units of area.

3. The unit of area is increased in the ratio π : 1. The number of units in a given area will therefore be reduced in the same ratio.

(i.) 28.26 units of area. (ii.) 7.95 units of area.

4. (i.) 14.55 cms. at 39.9°. (ii.) 6.197 cms. at 186.2°. (iii.) 43.3 cms.^{2} (iv.) 146° 18′; 75 cms.^{2} (v.) 211.7 cms.^{2} (vi.) 38.4 cms.^{2}

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.

H.T. and L.T. from a 250-volt D.C. Supply.

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

SIR,—Mr. E. J. Baty has raised a few points in connection with my article on the above subject (*E.W. & W.E.*, p. 111, February, 1927). The double circuit tuner was not adopted for the purpose of assisting the smoothing of hum, as he suggests, but to prevent the aerial from becoming alive, which, with a single coil tuner, would attain a potential of 130 volts when the H.T. supply is taken from a 250-volt main with the + side earthed.

The apparatus described in Fig. 2 is used in conjunction with a three-valve multi circuit receiver which embodies several types of valve coupling including tuned anode, resistance capacity and transformer coupling. The arrangement permits an instantaneous change over to be made from one combination to another. Various types of tuner were tried out and experimental results proved the single coil tuner to be fully as good as the double circuit.

If the user does not object to a "live" aerial there is no reason why he should not use a single coil tuner if he so desires.

The resistance capacity circuit was found to be the most sensitive as regards picking up of the town main hum, particularly when a high impedance valve was used as a detector. This was most noticeable when a certain rotary converter was running in the sub-station in which there appeared to be at least three types of convertor each having a totally different ripple characteristic.

I agree with your correspondent that, in the arrangement he describes, two chokes would be better than one of the same total value and that the condensers between the H.T. + and H.T. — contribute towards smoothing, but I do not agree that this is the case in the potentiometer system, described in the article referred to, where only one choke coil is necessary provided it is situated at the "live" town main terminal. The reservoir condensers in this case perform very little smoothing. I would advise your correspondent that the H.T. positive should on no account be connected to earth but should be connected to the neutral main.

I agree that for ordinary broadcast receivers there is no necessity to employ 12 lamps in series in the potentiometer, probably three lamps of a correspondingly higher resistance would suffice, but for experimental purposes it is necessary to have a wider range of voltage available and it is desirable that this supply should be reasonably constant irrespective of the demands of several valves in a receiver. The potentiometer method is much superior, in this respect, to the resistance arrangement, described by Mr. Baty, the voltage of which will vary considerably according to the load and will automatically rise to that of the town supply mains when all the valves are switched out. Mr. Baty makes the statement that no supply company would allow the apparatus to be used on the low rate of 1d. per unit. He is doubtless unaware that in Glasgow a special tariff is allowed to domestic consumers, under which electrical energy for lighting and domestic appliances is measured by a single meter. A fixed number of units is charged at the rate of 4½d. per unit and all further units at ¾d. per unit. My electricity bill for the corresponding period of last year (9th February—11th May) was as follows :—

	13 units at	4½d. =	4s. 11d.
	227 ,,	,, ¾d. =	14s. 2d.
Total	240 ,,	cost	19s. 1d.

which is even less than the 1d. per unit mentioned.

Your correspondent holds the opinion that the L.T. should be kept clear from the town mains entirely but if he intends using this supply for his H.T. I am afraid this is impossible as the L.T. must necessarily be connected to the town mains through the H.T. negative. No further risk would be introduced by going a step further and using this supply for charging the L.T. battery while the receiver is in operation. There is no undue risk in lighting the valve filaments from the town mains, in series with the potentiometer, when all the valves are run in series. Your correspondent may be surprised to learn that I have not yet burned out a valve filament.

An advantage of the arrangement just described is that a receiver can be switched on by means of a tumbler switch and loud-speaker reception obtained when desired. No battery of any kind would be required ; grid bias being obtained by means of a small resistance connected at the negative filament supply. By means of a second switch connected to a suitable tapping on A.T.I. an alternative station can be obtained on loud speaker. The success of this arrangement will of course depend upon the locality in which the receiver is situated. The writer experiences no difficulty in changing over from Glasgow to either Belfast or Dublin by means of this switch without any further tuning.

Glasgow. A. ROBERTSON.

That Audio Transformer Problem.

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

SIR,—My object in this correspondence has been to show that the general principle of equality of anode impedance with the given impedance of the valve for maximum amplification at a given frequency is not inapplicable to the case of the volt-amplification of an *audio*-frequency valve-transformer combination, and that we are, in fact, in progressively increasing the inductance of the transformer primary with the object of improving low note reproduction, knowingly or unknowingly applying this principle at progressively lower frequencies.

It has been somewhat of a surprise to me that my various critics have not seen this matter in the aspect which, I submit, is undoubtedly the correct one, and I am hoping that my answers contained in this letter to points raised in the contributions of your correspondents, Messrs. T. R. Lupton and J. Baggs in your April and May issues respectively, will supply the necessary additions to my previous explanations.

The discussion centres largely round the successful amplification of low audio frequencies, in which direction some simplification arises from the fact that parallel capacity and eddy current effects become of relatively small magnitude. Hysteresis, it is true, remains, but can be shown not to affect materially the general argument.

As the inductance of the primary winding in a given winding space is progressively increased, the frequency at which its impedance is equal to that of the valve becomes progressively lower and lower. At each such frequency the winding is for the moment such that its ampere turn effect, and therefore the amplification for that particular frequency have reached their maxima (approximately when parallel capacity is present) and if the inductance be further increased, the amplification at that frequency would again become reduced ; that at all higher frequencies would become still further reduced than previously and that at any lower frequency would be rising towards its maximum. In so far, therefore, as it were true to say that we require to amplify an indefinitely low frequency, it would be correct to say that we require to use the highest possible primary inductance. We do not, however, require to amplify indefinitely low frequencies.

The remarks contained in Mr. Baggs's third paragraph are agreed to—the 0.707 figure on the assumption of negligible winding resistance and capacity—nevertheless for the moment the primary ampere-turns, and therefore the amplification for the particular frequency referred to, are at their maxima and any further increase in primary inductance will reduce these, and those of higher frequencies still more, bringing the amplification ratios for these various frequencies more nearly the same, it is true, but nevertheless reducing the amplification on all these frequencies. Though the voltage applied to the primary increases, the number of turns increases in a greater proportion and the exciting ampere turns and volts per turn fall. Only the amplification of lower frequencies will be increased. The point is that we cannot, with the idea of rendering the amplification at all frequencies (low and moderately high) more and more nearly equal, increase the primary inductance unduly, because by so doing we are reducing the general amplification to such an extent as to be out of the question.

So much depends upon what interpretation is put upon the expression " highest possible (primary) impedance."

My objection to that expression is that it has undoubtedly been used by my critics to imply the maximum inductance that is technically possible mechanically, *vide* Mr. Baggs's fourth paragraph and the various other references to making this infinitely great. In advocating indefinitely great primary inductances, they appear to lose sight of the questions of the secondary and transformer ratio. The utilisation of the whole of the amplification factor μ of the valve, or of the whole amplified voltage, is *not* the correct aim, except indirectly for uniform amplification at various frequencies, and it is scarcely correct to say in this case (as it would be more reasonable to do in the case of a power transformer on open circuit) that " the secondary winding merely steps up the voltage applied across the primary" as if the transformer ratio remained constant when we alter the primary winding and there were no external resistance in series with it.

My objection is also that there appears to be no reason why the primary winding should not be wound of equal fineness with the secondary, producing say a 1 to 1 transformer, thereby seriously reducing the overall amplification on all required notes. It should be clear, therefore, that it is out of the question to utilise the "highest possible primary impedance" in the generally accepted sense, and that the limit of primary inductance depends upon the valve used, being lower for a lower impedance valve. The way in which the matter must be viewed is to settle upon some low frequency in the region of the lowest which we desire to amplify, and to arrange the primary inductance so that its impedance at that frequency will be equal to that of the valve, in which case the primary winding will correspond to a maximum amplification for that particular frequency.

There is not, as suggested by Mr. Baggs, any confusion of requirements of a good high and a good low frequency amplifier. It is quite true that we do not want a low frequency amplifier to amplify one frequency particularly, but we do want maximum amplification of a selected low frequency, and it is at that low frequency that the principle of equality is applicable, and *only a percentage of the voltage used*. The lower this selected frequency the more nearly uniform the amplification over the audio range of frequencies, except as regards high frequency limitations mentioned by himself, but there is a natural limit beyond which the gain of uniformity is not worth the loss of general amplification. This general amplification at the higher frequencies is very much less than it could be, because the impedance at those frequencies, or the tuned impedance when the reactance becomes capacitive, is so much higher than that of the valve.

I would remind Mr. Baggs concerning his second paragraph, that it is not "energy" (watts) that is required in a H.F. primary but activity (volt-amperes). We can have more of the latter with less of the former with improved result.

With regard to Mr. Lupton's letter :—

1. All my statements have clearly referred to valve plus transformer combination, the valve being given and the transformer windings variable. Mr. Lupton will see that the word "valve" was used in my statements 1 and 3.

2. The power transformer problem is a different one involving as it does the transformer only—with a given primary voltage and no questions of series resistance and maximum amplification. Several power transformers have been designed and made by the writer.

3. The erroneous parts of recent advertisements should be clear from explanations herein contained.

4. The problem of the primary of the output transformer is the same in relation to its valve as in the case of the stage transformer. Owing to the use of a power valve, its primary impedance at any given frequency can be lower.

We are all agreed as to the improvement in results by increasing the primary inductance of a transformer *up to a certain point*, the reason being that it increases the amplification of progressively lower and lower notes, and so gives more foundation to the reproduced music. In spite of the fact that the amplification of the higher frequencies is reduced, the general volume of reproduction does not, up to that point, appear to be reduced. If, however, the inductance be too far increased, then although quality may remain good provided high frequency effects are correct, the general amplification of the transformer will go down and the transformer will be incorrect. It is an easy experiment to try a transformer the wrong way round to realise this effect.

The reason for the non-appreciation by my critics of the application of the fundamental equality principle appears to have been the fact of the necessity of applying the principle not to an average frequency of the audio range, but to a very low frequency in that range, thus resulting in a high (but not indefinitely high) primary inductance.

The reasons of this necessity may be said to be :—

(*a*) The optimum amplification for any given frequency is, with some qualifications, much larger for the higher frequencies.

(*b*) The space factor of the primary winding gets worse as the winding is made finer, putting the resistance up disproportionately.

(*c*) At low and lower frequencies, a *given transformer* requires more than proportionately more magnetising ampere turns for the same primary P.D. so that the resistance effect of the circuit is disproportionately enhanced and the amplification falls rapidly, whereas at higher frequencies the amplification remains roughly constant as the frequency increases until pulled down by capacity, etc., effects.

(*d*) The actual amplitude of potential swing on the low frequencies is on the average greater than that at high frequencies, still further increasing the (*c*) effect.

(*e*) Loud speakers of types which are not very low pitched, and therefore not readily capable of reproducing low notes, require for better musical effect as much stimulus on low frequencies as possible.

May I thank you, sir, for the space you have devoted in various recent issues to my contributions on this subject

You have permitted me to refer to a small error which crept into my contribution in your February issue. The word "changes" on p. 302 (first paragraph) should have been "lowers."

E. Fowler Clark,
B.Sc., B.A., A.M.I.E.E.

A Wireless Works Laboratory.

Paper read by Mr. P. K. TURNER, A.M.I.E.E., before the Wireless Section, I.E.E., on 18th May, 1927.

ABSTRACT.

IN opening this, the final meeting of the Session for the Wireless Section, the Chairman, Mr. E. H. Shaughnessy, O.B.E., announced that premiums had been awarded to Mr. T. L. Eckersley, and (jointly) to Dr. R. V. Hansford and Mr. H. Faulkner, for papers read during the Session.* He also announced the nomination of Lieut.-Colonel A. G. Lee as Chairman for the next Session.

The paper describes the equipment of the Laboratory of the Research Department of Messrs. Burndept Wireless, Ltd.

1. Functions. †

The functions of the Laboratory are stated by the author to be: Development work on, and electrical design of, all new apparatus for the firm; building first samples and examining first production models, examining apparatus of other makers; building apparatus for the department which does routine testing of production apparatus, etc.

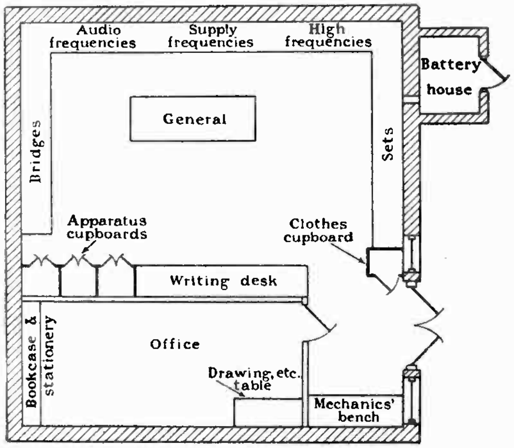


Fig. 1.

2. Location and General Arrangements.

The Laboratory is located on the flat roof of the works. To provide maximum wall space there are no windows, roof lighting being ample. Fig. 1 shows the general lay-out The various parts of the main work bench are not strictly reserved, the location of any particular job being selected according to whether any fixed apparatus is to be used.

3. D.C. Work.

(A) *D.C. Supply.*—Since the majority of the work is on valves and valve circuits, a suitable D.C. supply was practically the first matter to be considered. Secondary batteries were decided upon (except possibly for grid biasing), and it was also decided to make battery power available everywhere on permanent wiring.

It was believed that by care in arranging the wiring, and by the use of by-pass condensers, mutual interference could be avoided.

The batteries actually installed are :—

Voltage.	Amp. hours.	No.	Total voltage.	
2	50	2	4	
6	50	8	48	
2–6	50	4	24 (max.)	
6	100	1	6	
2–20	50	1	20 (max.)	
				102V, 5A
50	1	4	200	
100	1	2	200	
60 or 80–120	1	5	600 (max.)	
				1,000V, 0.1A
10–100	5	1	100 (max.)	
50–400	5	1	400 (max.)	
				500V, 0.5A
				1,602V

The main points of the distribution scheme are shown in Fig. 4, the central feature being the intermediate distribution frame adapted from telephone practice. At intervals along the backboard of the working bench are switch boxes, as in the photo, giving from two to five supplies, with leads to sockets on the distribution frame.

(B) *Measuring Instruments and Standards.*—It has been found important to have plenty of rough instruments in the form of cheap moving coil meters of 3 in. dial of 0—1mA to 0—5A and from 0—12 to 0—120V. Accurate D.C. meters comprise a "Century" testing set (Elliott Bros.) and a large Weston meter of 0-2 to 1-1,000V and 0-20mA to 0-40A. "Unipivots" of 0-240 and 0-24μA are also extremely useful.

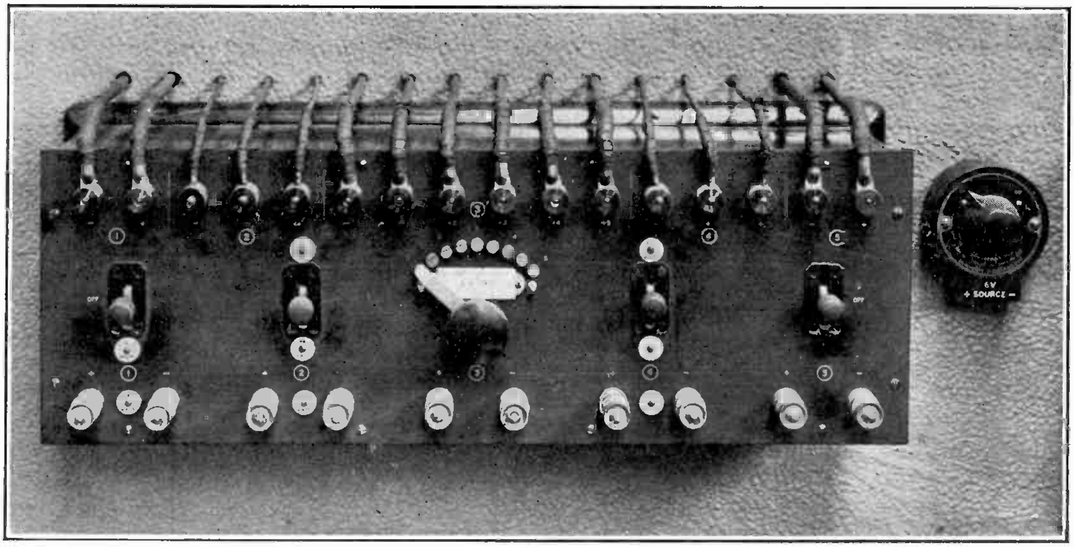
An anti-vibration method of mounting reflecting galvanometers is described and illustrated, and the author also described a new pattern of lamp and projection system for use with these instruments.

(C) *Resistors.*—A varied assortment of resistors, rheostats, etc., was found necessary. A useful item is a decade box of accuracy 1/3,000 and accurate

* See Abstracts in *E.W. & W.E.*, January, 1927, and April, 1927.

† The author's original section numbers and figure numbers are adhered to throughout this Abstract.

to 0.5 per cent. at 1,000,000 cycles. Standards are four resistors, nominally 1, 10, 100 and 1,000 ohms, oil sealed and checked to high accuracy at the N.P.L.



Showing the switch boxes for obtaining various supplies on the benches.

(D) *Bridge.*—The D.C. resistance bridge is also an A.C. bridge and is described later.

(E) *Condenser Tests.*—Fig. 11 shows a valve method of testing condenser leakage. With the key up the valve is biased to — 9V. and the condenser charged to 109V. On pressing the key the condenser discharges through its own leakage in parallel with the apparatus causing the grid potential and anode current to rise. The time taken for the pointer to move between definite marks is multiplied by a constant and divided by the capacity, to give megohms. It is essential that the circuit shown in heavy lines should have very high insulation; in the instrument described this is of the order of 50,000 to 100,000 megohms. The instrument has a range of about 50—50,000 megohms on condensers of 1μF.

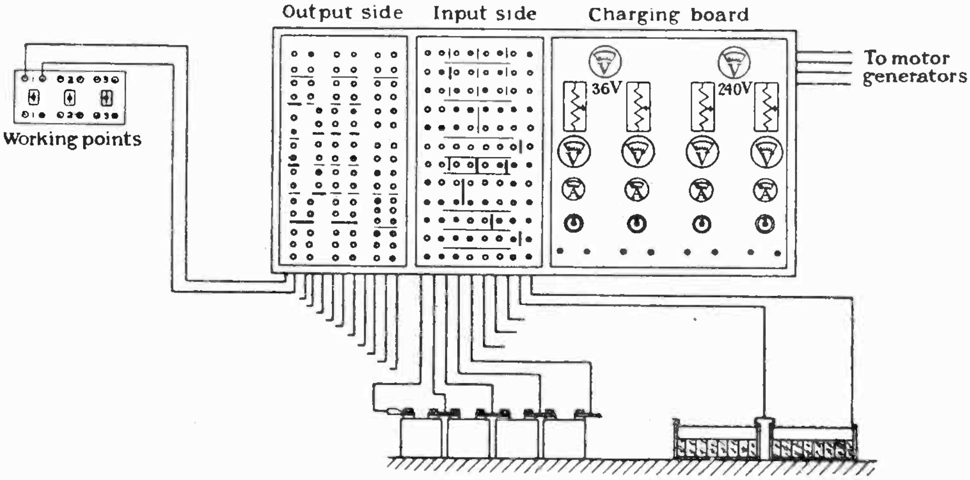
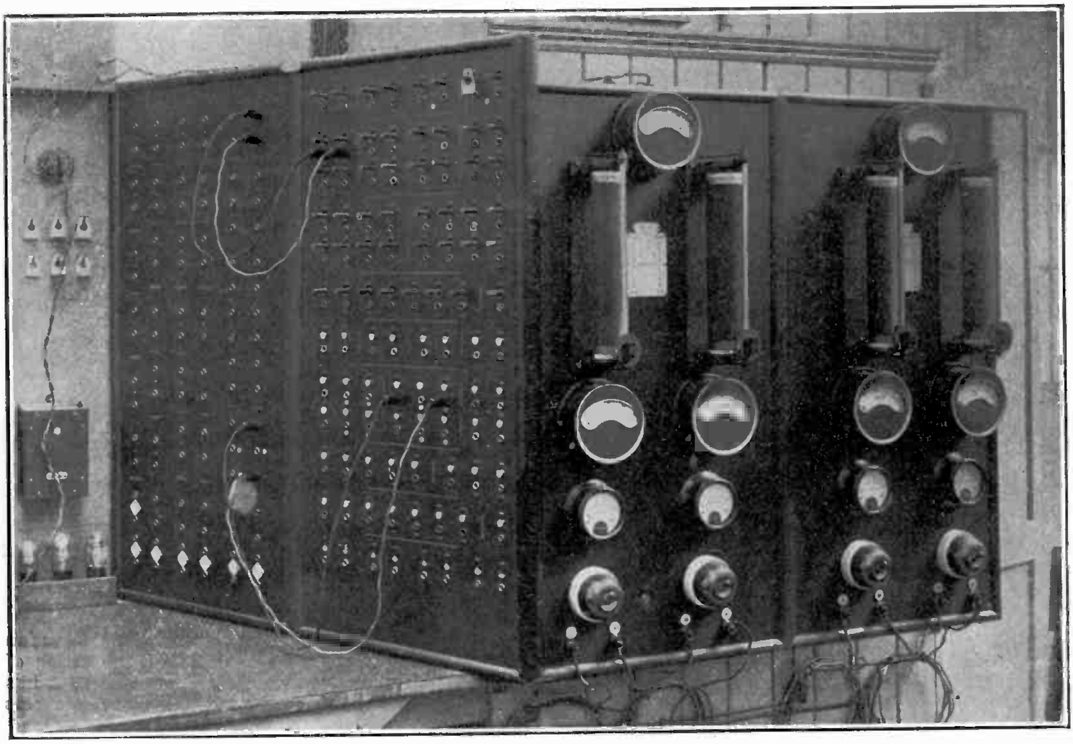


Fig. 4.

(F) *Valve Tester.*—After considering dynamic methods of finding the A.C. resistance and amplification constant, it was decided that no method is so satisfactory as an actual plot of the characteristic. An instrument was therefore produced simply to apply definite D.C. potentials and measure the

(B) *Wattmeter.*—For measurement of rather small A.C. power a special Elliott wattmeter is provided indicating 11 to 44 watts at full scale.



Showing the battery supply panels and charging board.

resultant currents. The schematic diagram is shown in Fig. 12, while the following ranges are given by the range switches :—

Anode current : 0-1, 5, 20, 100, 500mA.
Anode voltage : 0-25, 125, 250, 1.250V.
Filament current : 0-0.1, 0.25, 1.25, 2.5A.
Filament voltage : 0-2.5, 12.5V.
Grid voltage : 0-2.5, 12.5, 25, 125V.

4. Supply Frequency Work.

(A) *Supply and Instruments.*—A very useful meter, which is the Laboratory's standard for both A.C. and high frequency work, is a multirange thermal meter by the Cambridge Co. It embodies a set of vacuum thermojunctions and Unipivot millivoltmeter, and has ranges of 0—10 to 0—1,100mA with a pure resistive impedance which is fairly low and accurately known. It can be simply and accurately calibrated on D.C., the reverse effects being negligible. In series with resistance up to 10,000 ohms, it can also be used for calibrating A.C. voltmeters.

For the measurement of A.C. voltage, considerable use is made of a "diode voltmeter." There are two of these, one being a separate instrument, while the other is permanently connected as part of the low-voltage A.C. supply board.

5. Audio-Frequency Work.

(A) *Source.*—For the Laboratory work it was essential to have a practically pure note. This has been obtained by the now well-known method of using the rectified beats from two heterodyning

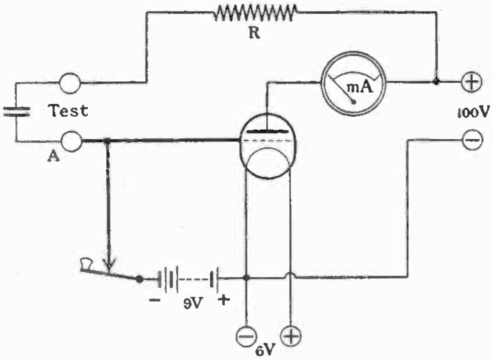


Fig. 11.

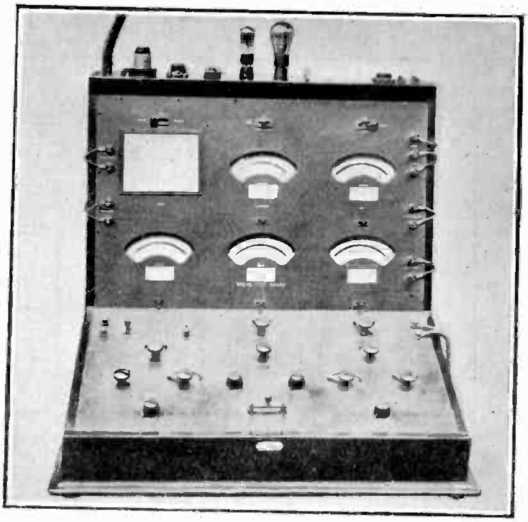
oscillators. The author's arrangement is shown in Fig. 16, where (1) is the "weak" oscillator of fixed frequency. Its output is weakly coupled to the tuned and neutralised amplifier (2), which is, in turn, loosely coupled to the rectifier 4. It is thus practically impossible for the output of the "strong" oscillator (3) to get back via the detector coupling and affect (1). Until (2) was neutralised, it was not found possible to work down to really low frequencies without "pulling-in" effects. The beating frequencies used in the author's source are of the order of 300kC. The weak couplings and sharp tuning of (2) effectively weed out the harmonics of (1), which, if allowed to reach (4) would combine with the harmonics of (3) to give multiples of the desired beat frequency.

It is estimated that in its final form the source has no harmonic exceeding 3 per cent. of the fundamental.

(B) *Voltage and Current.*—For measuring audio-frequency currents the multi-range thermojunctions instrument already referred to, is used, but it is usually found preferable to measure voltages rather than currents, by using valve voltmeters. This is, of course, on account of the much smaller power absorbed by the valve voltmeter. Such voltmeters are frequently merely bench assembled for a particular job, but a standard valve voltmeter is kept permanently assembled. The author formulates the following conditions for the instrument :—

1. To secure sensitivity, the indicator should be a multi-range instrument, and after "setting" the valve to reproduce the conditions of calibration, the steady anode current should be balanced out and the indicator "unshunted" if necessary.

The circuit is shown in Fig. 19, the valve being a bombarded one taking half an ampere at 4V. The normal anode current (used in calibration) is 40μA,



Apparatus for taking valve characteristics.

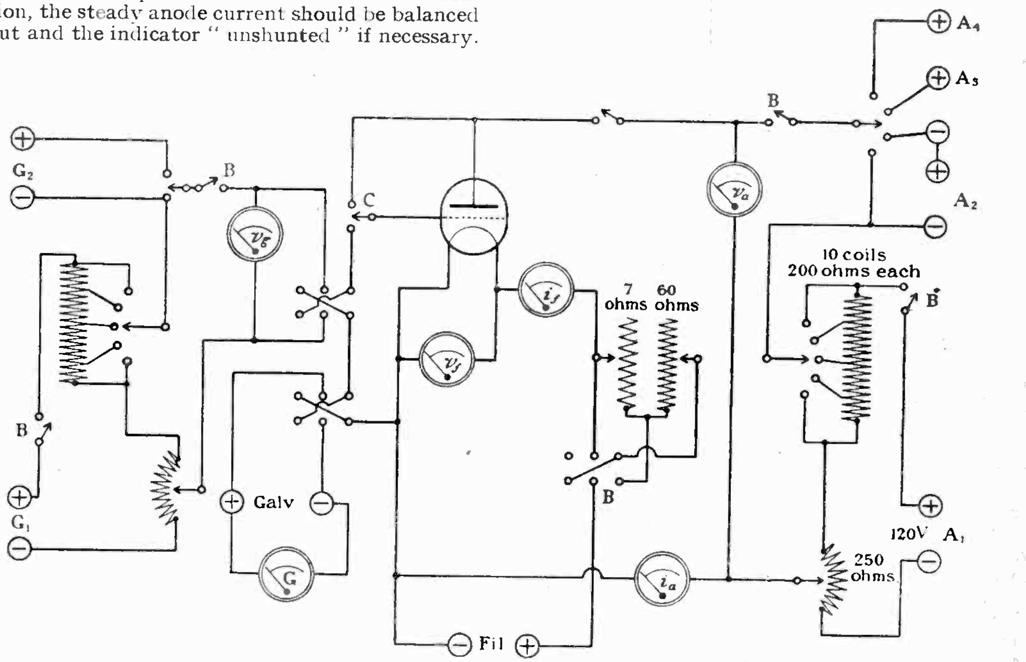


Fig. 12.

2. To secure low power consumption and independence of frequency the grid should be connected directly to the circuit to be measured, and ample bias used.

3. To secure permanence of calibration, the valve should be bombarded, not "gettered."

and small deviations of operating voltage can be corrected by adjustment of R_g. Balancing-out current is then switched on at A and R_1 adjusted until the indicator returns to zero. In use as a voltmeter, the instrument behaves as a capacity of about 12$\mu\mu$F, with a power factor of 0.01 approximately.

(c) *Capacity Bridges.*—Two such bridges are in use, the basic standards being variable condensers, instead of mutual inductors. This is done on account of the power factor of inductors at high frequencies, the power factor of a good condenser being approximately independent of frequency, and readily checked at the N.P.L. Details are given of the variable condensers used.

(D) *Combined A.C. and D.C. Bridge.*—A very useful bridge is that shown in Figs. 21 and 22. It is of very wide range, permitting measurement of inductance from 100μH to 100H; capacity from 0.001μF to 10μ and also of D.C. resistance. The circuit is that of an Anderson bridge, as in Fig. 21. *A* and *B* can each be made, 1, 3, 10, 30, 100, 300 or 1,000 ohms, and P., Q. and M. are variable by single ohms up to 10,000. The lower end of the variable condenser can also be joined alternatively to the junction *Bx* where it permits the measurement of unknowns having a capacitive reactance. The full circuit showing the relay change over methods of changing from A.C. to D.C. and *vice versa* are shown in Fig 22. The resistance arms are accurate to 0.1 per cent. on D.C. and 0.5 per cent. at 1,500kC.

The author then refers to the difficulty of measuring iron-cored inductors which also carry a polarising current. He therefore suggests the circuit of Fig. 23, where the inductances in the sub-bridge are either equal or one of them is known. The balance of the sub-bridge for D.C. can be adjusted by using the galvanometer of the main bridge. The sub-bridge is not necessarily balanced for A.C.; the current through one coil can be calculated in terms of that shown in the A.C. meter.

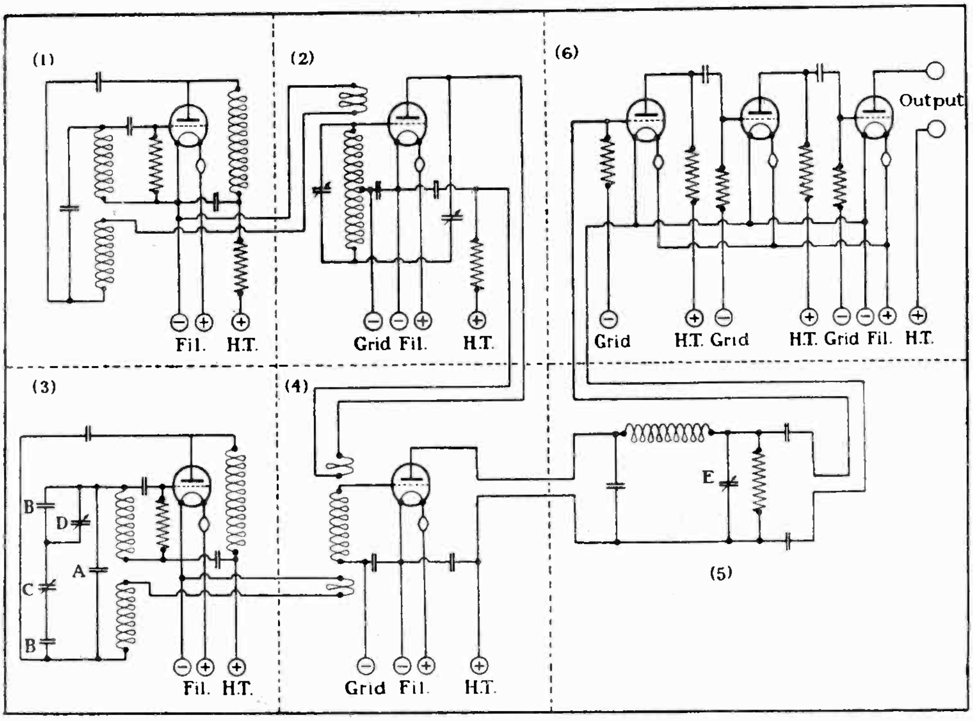


Fig. 16.

(E) *Frequency Measurement.*—As the L.F. source described cannot be relied upon for constancy from day to day, a monochord or stretched-wire frequency meter (on lines due to Dr. D. W. Dye) has been built. The wire carries the current from the source and is made to vibrate by passing through the air gap of a magnet. The natural frequency is adjusted by moving the lower bridge and so altering the effective length.

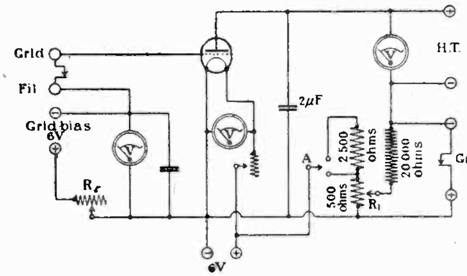


Fig. 19.

(F) *Audio-frequency Measurements carried out.*—The audio source and valve voltmeter have been used to measure the amplification of a stage as shown in Fig. 25. R_1 and R_2 are adjusted to a ratio suitable for the amplification to be measured and R_3 is adjusted until the voltmeter remains unmoved on throwing over the switch A. For a given input the A.C. component through R_3 is thus known; and the amplification can be calculated.

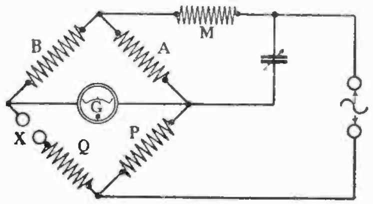


Fig. 21.

6. Radio-Frequency Work.

(A) *Sources and Voltage, etc., Measurement.*—The multi-range vacuo junction meter can be used for the measurement of radio frequency currents, but it is as a rule, preferred to calculate these currents by observing, with the valve voltmeter, the voltage across a known reactance or resistance.

(B) *Frequency.*—The laboratory has a standard wavemeter in the form of an oscillator of normal type, but arranged so that the conditions of calibration are easily reproduced. The calibration is checked from time to time against the N.P.L. standard waves.

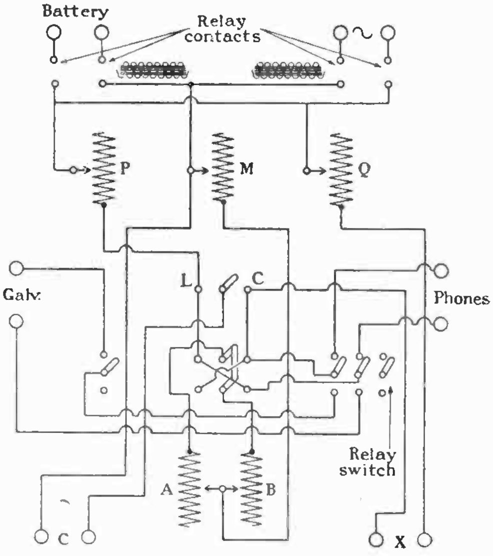
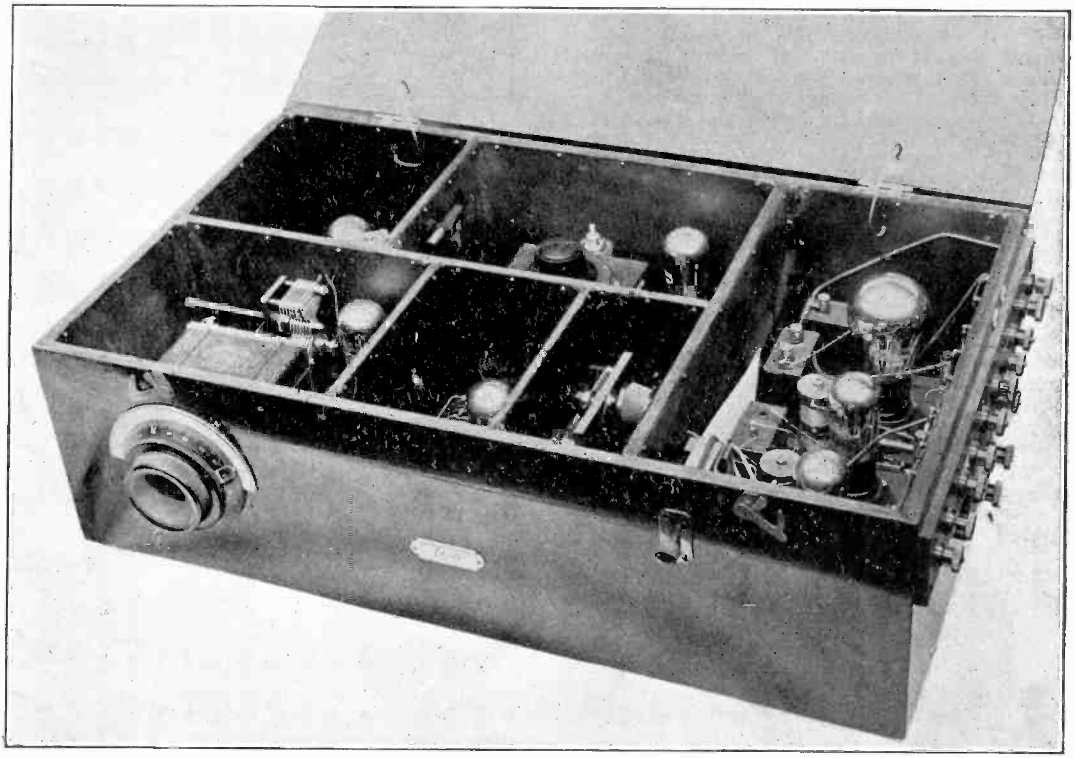


Fig. 22.



A view of the heterodyne L.F. oscillator.

(c) *Capacity and Inductance.* — Condensers are only measured at radio frequencies when the value is expected to differ from that at lower frequencies. Self-capacities are usually measured at radio frequencies. This is done in the usual manner by a series of measurements of resonant frequency with different external capacities, the valve voltmeter being used as a resonance indicator. The author illustrates the method for the determination of self-capacity due to Mr. W. A. Barclay who has contributed various notes on such methods to *E.W. & W.E.* Each reading of λ against external capacity is plotted as a straight line. These should meet in a point, but actually they form a small polygon of error. A line drawn from the λ zero through the polygon will meet the capacity scale at a point above zero, giving the self-capacity. If desired, the diagonal line between the two zeros may be calibrated in microhenries, the readings being taken on the point of the scale vertically below the centre of the polygon.

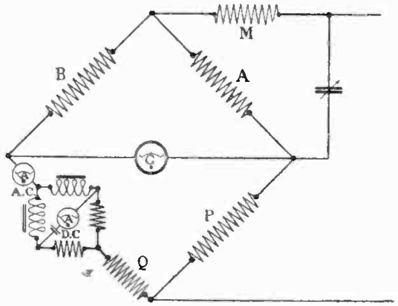
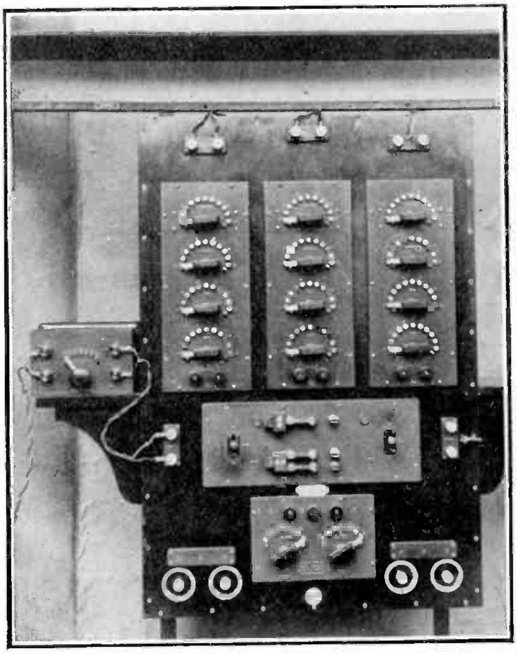


Fig. 23.

employed, with terminals for coil socket, straps for condenser and valve voltmeter, and a socket for the insertion of a special fixed high-frequency resistor, the construction of which is illustrated in the paper.



The combined A.C. and D.C. bridge.

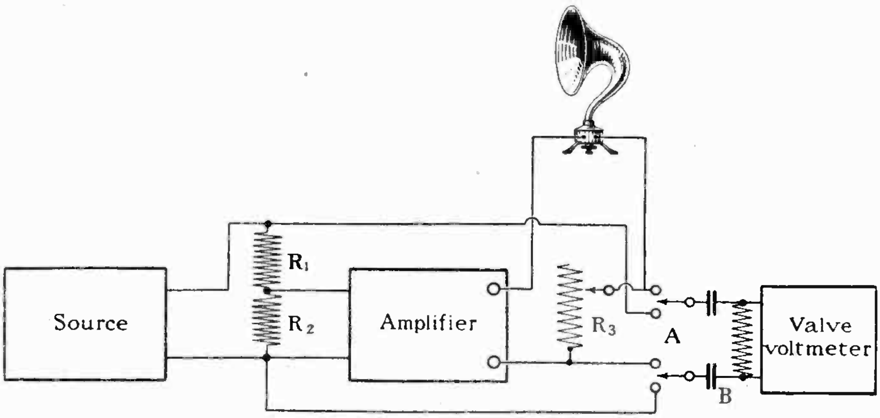


Fig. 25.

(D) *Resistance.*—The resistance-variation method is used, the total resistance of the circuit being measured and correction made for resistances outside the coil. A special connection box is

After finding, by the usual method, the resistance of the whole circuit, corrections are made for losses in various parts of it. From the results of various tests it appears that these losses all enter as if they were due to small condensers of high power factor. As examples, there are the following :—

	Capacity, $\mu\mu$F.	Power factor.	$\frac{\psi C_s}{0.1885}$
Standard valve voltmeter	12.4	0.0096	0.63
Connection box ...	14.4	0.0104	0.80
Coil holder	2.4	0.0254	0.32

The last column gives a factor which is convenient in converting the loss into apparent series ohms in any given resonant circuit.

If C_s = capacity of accessory, as in col. 2 of above table,

ψ = power factor of accessory, as in col. 3 of above table,

C_t = total capacity (= condenser + self-capacity of coil and all accessories) in $\mu\mu$F,

λ = wavelength,

R' = apparent series resistance due to the accessory,

then $$R' = \frac{\psi C_s}{0.1885} \times \frac{100\lambda}{C_t^2} \text{ ohms.}$$

In a typical case, where $C_t = 250\mu\mu$F, $\lambda = 400$ metres, $R' = 1.12$ ohms for all the accessories together.

(During the reading of the paper, the audio-frequency source was demonstrated, and several other of the instruments described were on exhibition.)

DISCUSSION.

A lengthy discussion followed the reading of the paper.

Mr. L. B. Turner first referred to the neat method of the "polygon of error" for the determination of self-capacity, and to the neutralised triode in the amplifier used in the low frequency source. He thought that the information on this source could be added to by more experimental data. With reference to Fig. 23, he did not think the internal bridge arrangement was necessary, and outlined a simpler bridge circuit. Lastly he discussed arrangements for D.C. supply, illustrating the arrangements used in the Engineering Laboratory at Cambridge, with the precautionary devices employed.

Mr. P. R. Coursey expressed interest in the paper, since he was connected with a commercial laboratory for a similar type of work. He then dealt with the D.C. supply arrangements in this laboratory, showing slides which illustrated the switchboards, etc., for voltage supplies, low tension and high tension. With reference to the condenser leakage testing arrangement, he sketched another circuit for this test, shown in Fig. A. This was a very useful method for a quick test, and the leakage test was a more useful specification of performance than was a mere statement of megohms. He also discussed the heterodyne L.F. source as compared with a coupled generator.

Mr. P. W. Willans first referred to the general difficulty of "mush" in a works laboratory. He asked for information as to the capacity effects of long battery leads, especially in a non-earthed circuit. Regarding value tests, he noted that only D.C. characteristics were used, but suggested the need of dynamic characteristics also. In measurement of amplification he urged the need for the use of vector methods, as well as scalar. Lastly he dealt with the measurement of high frequency resistance, and described a resonance method of measurement.

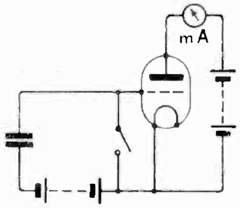


Fig. A.

Prof. McClinton referred briefly to a plug-board system of battery distribution, employing no flexible connections. Such a scheme had been in use for 20 years without a single short circuit.

Captain H. J. Round referred to the heterodyne generator as an L.F. source and to its use in conjunction with a method of measuring air pressures for loud-speaker tests, etc.

Mr. E. B. Moullin sought information on several points, more especially why single scale instruments were used, the accuracy of the General Radio high frequency resistors, use of wattmeter, etc.

Mr. J. H. Reyner did not think the methods described were too precise. He discussed several points in connection with the L.F. source, and dealt with the use of the quartz crystal as a frequency standard, illustrating a method of using the crystal for the measurement of frequency and capacity.

Mr. Bainbridge Bell described experiences of "mush" in a works laboratory, when improvement had been effected by the electrical bonding of shafting supports.

Mr. MacPherson discussed the L.F. source as against a coupled oscillator, and said he had had a satisfactory oscillator working as low as 15 cycles. He had found that a great deal of "mush" could be cured by enclosing the apparatus in a wire netting screen.

The author briefly replied to several of the matters raised in the discussion, and on the motion of the Chairman (Mr. E. H. Shaughnessy, O.B.E.) was accorded a hearty vote of thanks for his paper.

The Internal Action and Principles of Design of Thermionic Valves.

A Lecture before the Radio Society of Great Britain by A. C. BARTLETT, delivered at the Institution of Electrical Engineers, on Wednesday, 20th April, 1927.

I PROPOSE to speak to-night chiefly of the internal action of valves and of some of the points that present themselves in the design of larger types and to point out that the design of thermionic valves is by no means empirical but is a quite well-developed branch of electrical engineering.

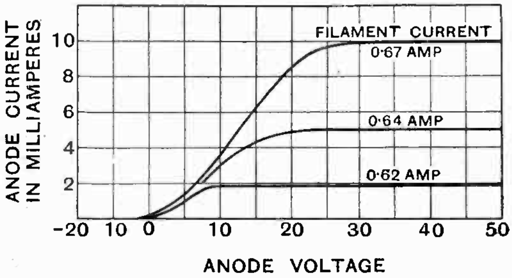


Fig. 1.

First, take a small two-electrode valve, which may be regarded as a modern edition of the original Fleming valve; it has an anode of nickel sheet 25 mm. long and 4 mm. diameter; mounted axially inside it is a tungsten filament 30 mm. long by 0.06 mm. diameter. The whole is mounted in a glass bulb and exhausted to the obtainable degree of vacuum.

Some characteristic curves of this rectifier are shown in Fig. 1.

The lower curve shows the anode current with 0.62 amp filament current and varying anode voltage (the anode volts measured from the negative end of the filament). It will be seen that with negative volts on the anode there is no anode current, but that as soon as the anode becomes positive with respect to the filament an anode current appears increasing with anode volts up to a limit of 2mA, after which increase of anode volts causes practically no increase. With larger filament current 0.64 and 0.67 amp, the curves are of the same general form, but the limiting value of anode current increases with filament current.

There are three main points to be considered in connection with these curves :—

1. There is no anode current with negative anode volts. This is because the only carriers of electricity available are the electrons which are emitted by the hot tungsten cathode—when there is a positive voltage on the anode they move over to it, but when there is a negative voltage on the anode they are forced back again into the filament.

2. There is a limit to the anode current at any definite filament current. It has been established on sound theoretical and experimental basis that the number of electrons emitted per second from a clean metal surface at a definite temperature is a definite physical property of the metal; it can be put in the form :

$$i = a\sqrt{T}e^{-\frac{b}{T}}$$

where i is the current emitted per unit area, T is the absolute temperature and a and b are physical constants of the metal. It will be seen from the form of

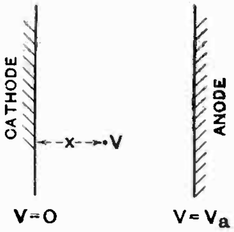


Fig. 2.

this expression that the emission increases very rapidly with T.

3. The third, and perhaps most interesting point, is that to obtain the full emission current a very appreciable positive voltage has to be applied to the anode—for example, returning to Fig. 1, it will be seen that with 0.67 filament current it is

necessary to apply 30 volts in order to obtain an anode current equal to the saturated emission. It might at first be thought that since we are dealing with negatively charged bodies the slightest positive voltage on the anode would cause every electron emitted from the filament to pass over to the anode. The explanation, however, is that the electrons on their way tend to repel those following on.

The following approximate treatment is due to Langmuir.* Consider a simple case in which the cathode and anode are parallel planes a distance d apart, as shown in Fig. 2.

Let V be the voltage at any point distance x from the cathode, V being zero at the cathode and equal to V_a at the anode. Let the number of electrons per sq. cm. per second passing from cathode to anode be n.

Then the current per sq. cm. will be given by $I = ne$, where e is the charge of an electron, and we are taking that I is less than the total emission. If we assume that an electron leaves the cathode with negligible velocity, then when it has got a distance x from the cathode it has reached a velocity and will have gained kinetic energy by an amount equal to $\frac{1}{2} mv^2$ where m is the mass

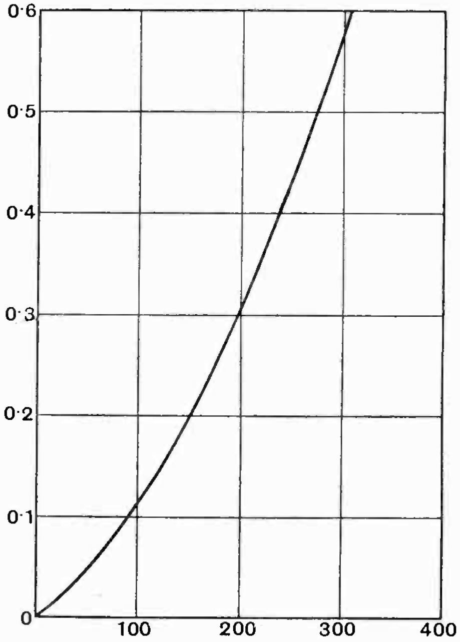


Fig. 4.

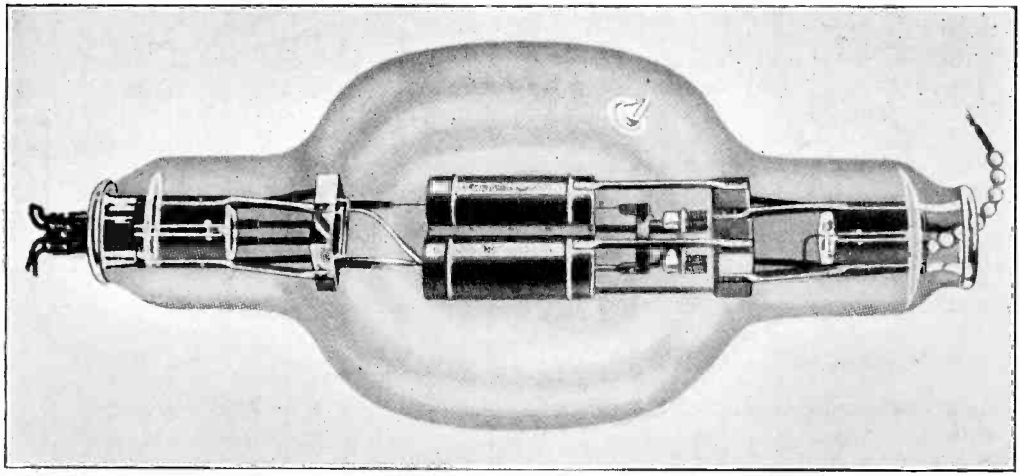


Fig. 3.

of an electron. It will, however, have lost potential energy by an amount V_e and on equating the two, $\frac{1}{2} mv^2 = V_e$.

At the point x, therefore, there are n electrons passing per second per sq. cm. with a velocity v. There will therefore be electrons at the rate of n/v per unit volume at this point, and therefore there will be a volume electrification of $-ne/v$ per unit volume. This is termed the Space Charge.

* Langmuir. *Physical Review*, 1916.

We can apply Poisson's equation and obtain

$$\frac{\partial^2 V}{\partial x^2} = -4\pi\rho$$

$$= .4\pi \frac{ne}{v}$$

$$= \frac{4\pi L}{V}$$

$$= 2\pi i \sqrt{\frac{2m}{eV}}$$

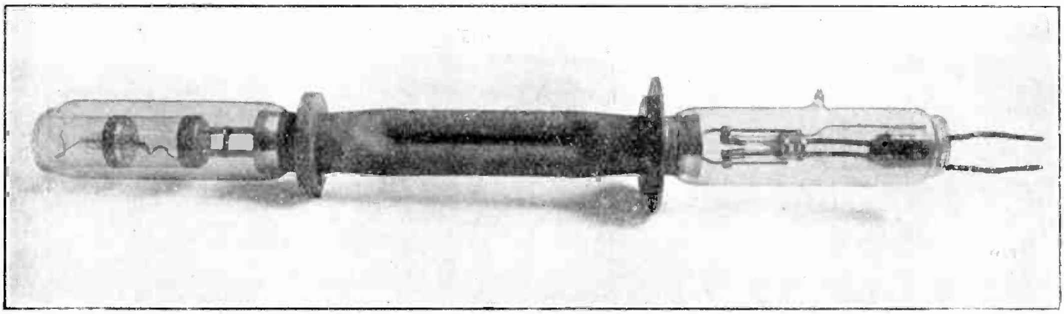


Fig. 5.

We can integrate this equation, obtaining

$$\left(\frac{\partial V}{\partial x}\right)^2 = 8\pi i$$

if we take $\partial V/\partial x = 0$ at the surface. This is fairly obvious, for if $\partial V/\partial x$ were negative no electrons would leave the cathode, and if $\partial V/\partial x$ were positive all electrons would leave the cathode. This equation can again be integrated, giving

$$L = \frac{\sqrt{2}}{9\pi} \quad \sqrt{\frac{e}{m}} \cdot \frac{V^{\frac{3}{2}}}{x^2}$$

and thus

$$i = \frac{\sqrt{2}}{9\pi} \cdot \sqrt{\frac{e}{m}} \cdot \frac{V_a^{\frac{3}{2}}}{d^2}$$

if amps, volts and centimetres are taken it becomes

$$L = 2.33 \times 10^{-5} \frac{V_a^{\frac{3}{2}}}{d^2} \quad \ldots \quad (1)$$

A far more important case is that of the cylindrical rectifier which has also been treated by Langmuir. Without going into details, if d is the anode diameter and d_c the cathode diameter, then the anode current per cm. length of the rectifier is given by

$$i = 2.92 \times 10^{-5} \frac{V^{\frac{3}{2}}}{\beta^2 d} \quad \ldots \quad (2)$$

where β^2 is complicated function of the ratio of cathode and anode diameters, which, however, in most cases is sufficiently near unity to be neglected. This last equation is one of the most important in the whole subject and can be used for actual numerical design—an example will be given later.

The above treatment is, however, only approximate. A more exact but much more complicated treatment has been given by T. C. Fry,* in which the distribution of initial velocities has been taken into account.

Owing to this high speed with which the electrons strike the anode and to their possessing mass they heat it in the same way that a bar of metal becomes heated when hammered, the kinetic energy $\frac{1}{2} mv^2$ of each electron appearing in the form of heat.

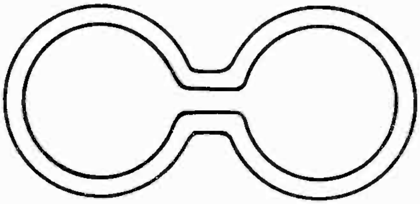


Fig. 6.

From the formulæ given it will be seen that the rate at which energy is liberated at the anode in the form of heat is equal to the product of anode volts and anode current.

* *Physical Review*, Vol. 17, p. 44.

Experiment.

Here the anode of a large glass rectifier of the MR9 type was bombarded to a bright red heat from a 4,000 volt transformer.

To simplify things to-night, only cylindrical type rectifiers and valves will be considered. Although many types of flat valves are on the market the adoption of this form is a concession to manufacturing simplicity and mechanical robustness—were the same length of filament mounted in a cylindrical grid and anode a definite improvement would be obtained.

Fig. 7.

The cylindrical type is not only best form electrically but has the advantage that it is amenable to calculation. In setting about the design of a rectifier the first point to be settled is the emission current required from the filament. From the known physical constants of tungsten * it is possible to design a number of alternative filaments of various temperatures, lengths and diameters that will give the required emission from which a suitable filament can be chosen.

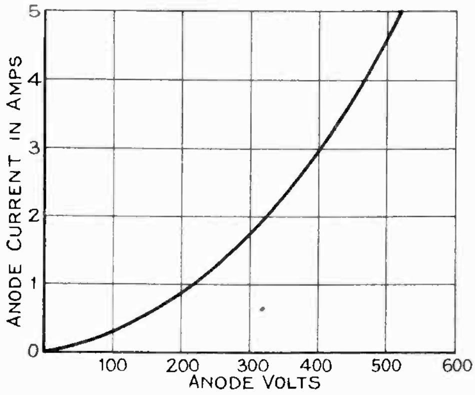


Fig. 8.

The two-electrode rectifier shown in Fig. 3 is an example of a large cylindrical type having two parallel filaments connected in series each in its own cylindrical portion of the anode which is of molybdenum; the filament takes 25 amps at about 20 volts and has an emission of about $1\frac{1}{2}$ amps. This represents almost the largest size made in a glass envelope; a characteristic is shown in Fig. 4.

A larger type of rectifier, having an external water-cooled anode, is the CAR2, shown in Fig. 5 without its water-jacket. The anode is made of one piece of copper tube, of which the central portion is pressed in as shown in Fig. 6 so as to consist of two parallel cylindrical portions.

The filament consists of two parallel portions, as in Fig. 7, each 20 cms. long by 1 mm. diameter connected by molybdenum cross piece. The filament takes 50 amps at 20 volts, giving an emission of 7 amps and in assembly is slid into the anode so that one leg of the filament lies axially in each chamber of the anode.

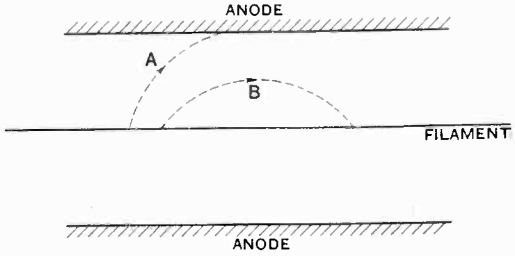


Fig. 9.

An observed characteristic curve is shown in Fig. 8.

I will recall now equation No. 2 for the cylindrical valve. As pointed out, this valve has each filament in a cylinder. The characteristic was calculated from this equation before the valve was actually made. One of the calculated points was 500 volts, giving 4.75 amps, and you will see on the observed curve that it is actually very near to 4.75 amps. The rectifier characteristic came out to its calculated value certainly within 5 per cent. I mention this to show that the formulæ given are really of practical value.

In the making of these larger rectifiers we get no trouble until we get up to this size—of course, there is all the glass work, and the pumping of the valve is difficult, but no new physical effect appears. When we try to make bigger ones difficulties occur at

* Langmuir, *Physical Review*, 1916, Vol. 7, p. 302.
Stead, *J.I.E.E.*, 1920, p. 107.
Worthing, *Jour. Franklin Inst.*, Vol. 194, p. 597.

several points. For instance, suppose we want to increase the emission. In order to do that we have to increase the area of the filament, and we can do that in two ways, either by increasing its length or by increasing its diameter. If we decide to increase the length we run into a difficulty.

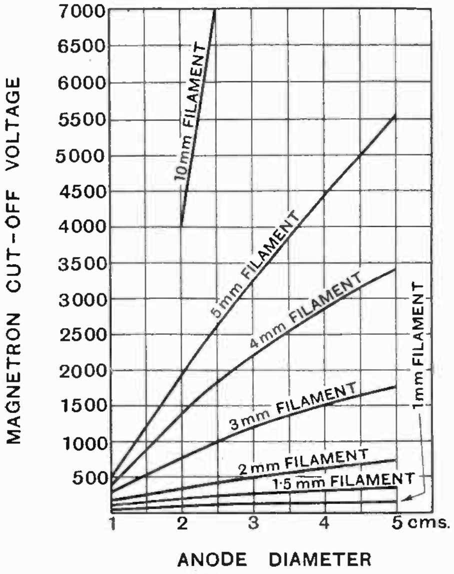


Fig. 10.

When taking anode current from a rectifier the electrons which flow from the filament to the anode have to be replaced by electrons which flow in at the negative end of the filament. That means that if you have a filament normally taking 10 amps, and it is so long that its emission is 10 amps, then at the negative end there is a current of 20 amps, which overheats that end of the filament.

This is shown by this small valve which has a very long fine filament with an emission equal to the normal heating current; the anode is in the form of a grid so that the filament is readily visible. When the H.T. is switched on it is seen that the negative end of the filament is overheated almost to the melting point.

The first limitation, then, is that we cannot lengthen our filaments indefinitely. If we are going to use the same diameter of filament we have to divide the filament into a number of sections, in parallel, but, although that can be done, it is not a very satisfactory arrangement from the manufacturing point of view if carried too far; all the filaments have to be so very well matched.

The other alternative is to increase the diameter of the filament, but there again we run into trouble.

Fig. 9 represents the section of a cylindrical valve, and shows the filament and the anode. The filament heating current has a magnetic field—the lines of force are in the form of circles around the filament. Now a property of an electron in motion is that it tries to bend round lines of magnetic force. In Fig. 9 lines of force are vertical to the plane of the paper, so that the electron, starting from the filament, is deflected round as shown at *A*. With a small filament the effect may be quite negligible, but if we put in a still larger filament, the electrons turn round and come back to the filament without getting to the anode at all, as shown in *B*.

Fig. 10 shows the extent of that effect. For any anode diameter and any diameter of tungsten filament there is a definite cut-off voltage*; if the anode voltage is below that, no electrons whatever can get

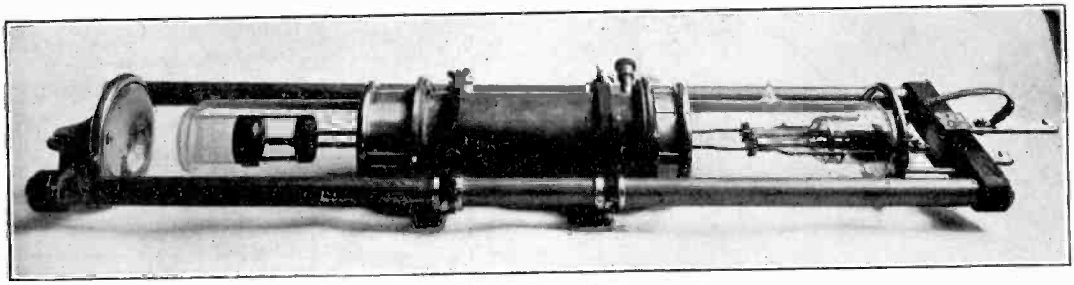


Fig. 11.

* Hull, *Journ. Amer. I.E.E.*, October, 1923, p. 1013.

to the anode. To take an example: If we have an anode of 3 cm. diameter, with a 1 mm. filament this voltage is about 100 volts; but if we put a 4 mm. filament in the same anode the cut-off voltage becomes over 2,000 volts, and that is so serious that the rectifier would be of very little use in practice; if, further, we go to 10 mm.

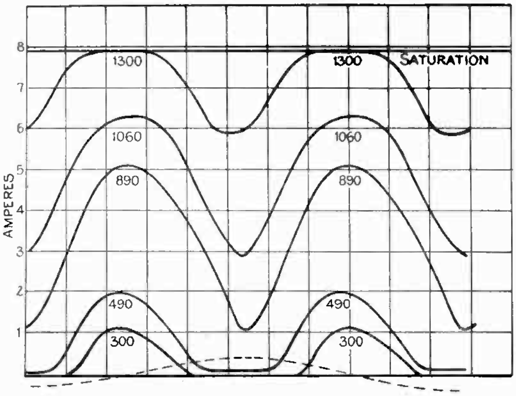


Fig. 12.

filaments, the voltage would get up to 6,000, which makes the use of the rectifier quite impossible.

Fig. 11 shows an example of a valve considerably larger than the previous one, but of the same general design, and in which this effect occurs to a marked extent. It has a filament of about 1.8 mm. diameter and its heating current is about 125 amps; the photograph shows the valve mounted complete with water jacket.

Fig. 12 shows some oscillograms taken of the anode current of this valve with a number of steady D.C. voltages on the anode while the filament was heated by 125 amps A.C.; the small dotted sine curve is the filament current on a reduced scale.

It will be seen that with 300 volts on the anode the anode current is entirely cut off for a large part of the filament current cycle and that even with 1,300 volts on the anode the filament current when passing through its maximum value can appreciably decrease the anode current. Owing to the fact that the anode current depends on the filament current there are a large number of characteristics of this rectifier.

Two of them are shown in Fig. 13; the full line shows the characteristic at the instant of zero filament current—the dotted line at the instant of maximum filament current of

$$125 \times \sqrt{2} = 177 \text{ amps.}$$

That shows that we have, more or less, got up to the limit. The only other possible way is to use numbers of filaments of 50 amps size and perhaps a little bigger connected in parallel.

As we are limited on the filament current types, an alternative method is that of the indirectly-heated cathode.

Fig. 14 is a sketch of two valves which I have here. One valve has a cylindrical anode, with a straight tungsten filament—quite an ordinary valve; the other has an anode of equal size, but, instead of a filament, it has for a cathode a nickel cylinder, which is coated with barium and strontium oxides. It is heated to about 800° C. by thermal radiation from a heavy 40-watt tungsten spiral filament—represented by the wavy line.

Up to the present such a valve is not made in large sizes, because a cathode which will stand high voltages satisfactorily is not at present known. However, this introduces a

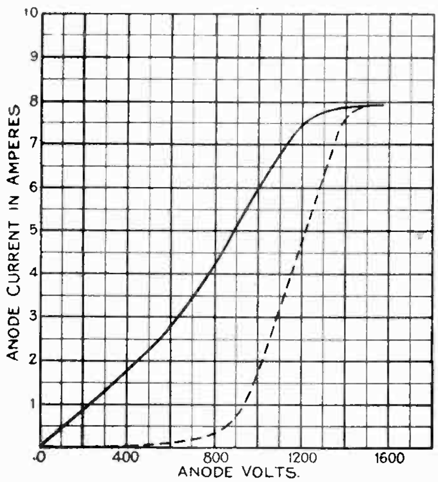


Fig. 13.

very interesting point in the design of valves.

I have mentioned the equation:—

$$I = K \frac{V^{\frac{3}{2}}}{\beta^2 d}$$

where V is the anode volts, and β the anode diameter and have mentioned that β^2

depends on the ratio of anode diameter to cathode diameter.

Fig. 15 shows the value of β^2 plotted against the ratio of anode radius over filament or cathode radius. In all ordinary filament valves this ratio is certainly more than 10, and for most purposes β^2 is near enough to unity, but when we get down to low values, when the ratio of anode to cathode is only slightly greater than unity β^2 becomes very small, which means for the same anode volts a great increase of anode current. In this valve the ratio is about 1.15, and β^2 is about 0.017, so that, since these valves have the same anode and about the same length of cathode, we should expect that the indirectly-heated cathode

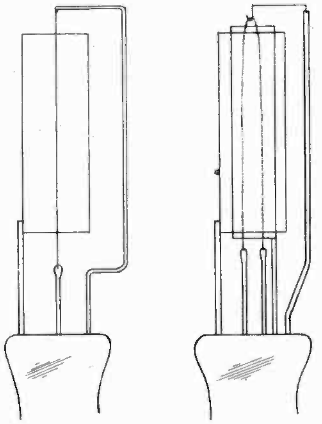


Fig. 14.

valve would give us 1/0.017, which is about 60 times the same anode current as the filament type; and that is so.

Fig. 16 shows the characteristic of these two rectifiers—anode volts against anode current; the lower curve is the filament rectifier, so small that it can hardly be put on the same scale, and the upper curve is the indirectly-heated cathode rectifier. We are getting 0.5 amp at 24 volts, which is quite unheard of in any ordinary rectifier, and the ratio of 60 to 1 for the two valves is attained. Unfortunately, up to the present, this principle has not been applied to very large valves.

So far I have been speaking chiefly about two-electrode valves. Not only the theory, but the actual numerical design, of the two-electrode valve is perfectly well established, and the next step is the consideration of anode current control. The usual form of control is the grid control; there is another form, which is not much used, although it is extremely interesting, and that is magnetic control. It has already been pointed out

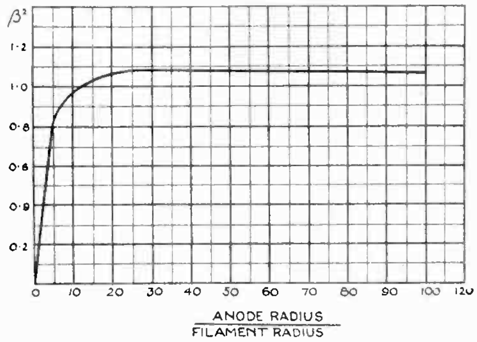


FIG. 186.—Values of β^2.

Fig. 15.

that the field due to the filament current has an effect upon the paths of the electrons.

Take a cylindrical valve as shown in section in Fig. 17 and surround it by a cylindrical coil and suppose that its filament is so small that the magnetic field of the

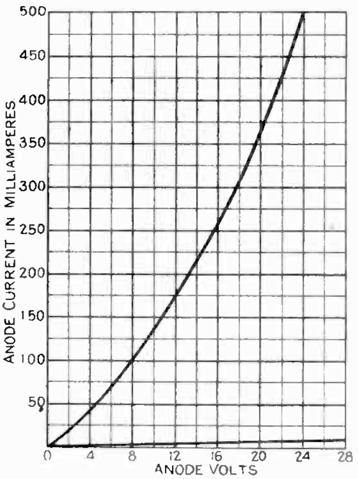


Fig. 16.

filament is negligible; then an electron leaving the filament will go straight to the anode as shown by the dotted lines A. If now a current is passed through the coil a magnetic field is set up of which the lines of force are parallel to the filament. With a small current the electrons will be deflected, as shown by the dotted line B, while with still larger currents the electron may be turned completely round as shown by the dotted line C, in which case, of course, there is no anode current. The magnetic field

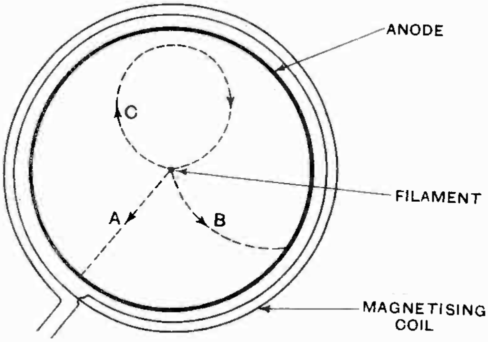


Fig. 17.

necessary to cause the electrons just to miss the anode is given by

$$H = \frac{6.72\sqrt{V}}{R}$$

where R is the anode radius.*

Fig. 18 shows the curves from a small valve at anode voltages of 40, 30, 20 and 10 volts. The sloping parts of the curves can be used in exactly the same way as the curves of the ordinary three-electrode valve, a steady current being used in an analogous way to a grid bias battery to bring the anode current to the centre part of its operating characteristic while on it can be superposed any A.C. current.

The practical drawback to this method of control is the large number of ampere turns required which make a large heavy coil with currents of the order of an ampere necessary for even small anode voltages.

We will now go back to the three-electrode valve. I have already pointed out that, as regards the simple two-electrode valve, we can design to an accuracy equal to that obtained in any ordinary engineering calculation. From this it is possible to go over to the three-electrode valve, and I will now deal briefly with the principles of that valve, showing how its theory can be derived from the two-electrode valve.

The left-hand side of Fig. 19 represents a section of a cylindrical three-electrode valve, the dotted lines showing roughly the lines of force when voltages V and v are applied to the anode and grid. It follows from previous results that the space charge due to the electrons traversing the space between filament and anode, is inversely proportional to the velocity of the electrons and is small between grid and anode where the electrons are moving quickly. Consequently the field of force, except in the immediate neighbourhood of the filament, can be treated approximately as a simple electrostatic problem. It can be shown that if a companion rectifier is made, such as is shown in the right-hand side of Fig. 19, having its anode equal in diameter to the grid diameter of the three-electrode valve and if to anode a voltage

$$\left(\frac{V}{m} + v\right)$$

where "m" is the amplification factor of the valve, is applied, then the field inside the anode of this valve is approximately the same as inside the grid of the three-electrode valve.

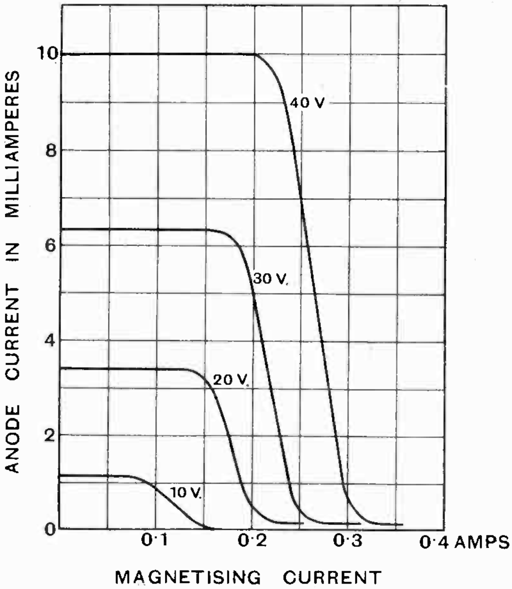


Fig. 18.

The amplification factor "m" of the valve can be calculated by the following approximate formula due to Sir J. J. Thomson.

$$m = \frac{\pi d'n \log \frac{d_a}{d'}}{\log 1/\pi n d_g}$$

* Hull, *J.A.E.E.*, September, 1921.

where n is the number of turns per cm. in the grid

d_a is the anode diameter.
d' is the grid diameter.
d_g is the grid wire diameter.

Since in the two valves the field in the neighbourhood of the filament is the same the space currents will be the same.

Hence, using the ordinary formula for a two-electrode valve, we have the space current of a three-electrode valve per unit length given by

$$I = 2.92 \times 10^{-5} \frac{\left(\frac{V}{m} + v\right)^{\frac{3}{2}}}{d' \beta^2}$$

If v the grid voltage is negative all the space current goes to the anode and the above formula then gives the anode current. Thus the design of the cylindrical three-electrode valve is on a firm theoretical basis.

Fig. 20 shows the characteristic of a valve having an m value of about 7; for if V and v are changed so that the anode current does not change, then

$$\frac{V}{m} + v$$

must remain constant, so that any change in v must be accompanied by a corresponding change "m" times as large in the opposite direction in V. Thus for this particular valve anode current of 15mA is obtained with V—80

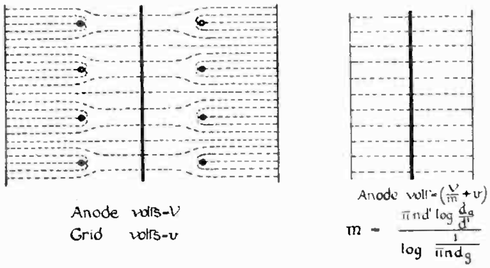


Fig. 19.

and $v = -3$, also the same anode current is obtained with $V = 100$ and $v = -6$, so that if V is increased by 20 volts v has to be decreased by 3 volts.

Hence for this valve "m"$=20/3=7$ approximately.

This account of some of the principles of the design of thermionic valves has necessarily had to be very brief and many points have had to be omitted altogether, but my chief endeavour has been to show that the design of thermionic valves is developing into an important branch of electrical engineering and in many ways has already been reduced to as accurate a numerical basis as most other branches.

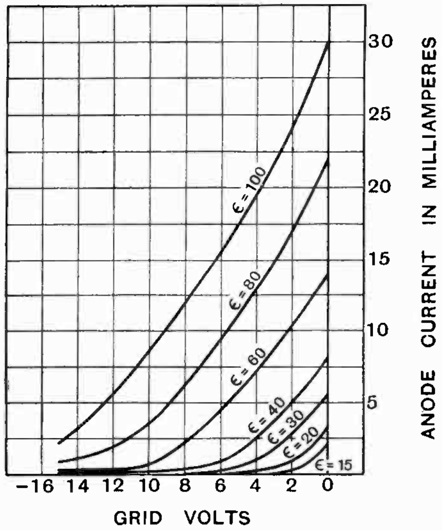


Fig. 20.

DISCUSSION.

Mr. M. Kirk: I was particularly interested in the indirectly-heated cathode valves, because I think it is a very important thing, in the working of small receiving sets, to be able to light the valves directly off A.C. mains. I have tried one or two of the indirectly-heated cathode valves, and they are very efficient as regards the ratio of magnification to plate resistance, but we have a certain amount of trouble because they lose their emission. It seems that in nearly all new types of valves the first trouble is that they lose their emission. This trouble is usually rectified after the valves have been on the market for some time. I should like Mr. Bartlett to say something about loss of emission and its cause. Apparently it is not due entirely to the actual value of anode current, but it is largely due to the actual anode voltage, irrespective of the amount of anode current. There is another point I should like to raise. Mr. Bartlett did not mention the effect of the difference of potential across the filament of the valve on the characteristics of the valve. This effect, I believe, is very interesting, particularly on the curved portion of the bottom of the valve characteristic, and, as this portion is used largely nowadays for rectifying purposes, it is very important to get that curved portion as sharp as possible. I should like to know what hope there is of getting valves with a sharper curved portion. I have noticed particularly that in the separately heated cathode valves it is considerably sharper than in the ordinary valves, and there is no difference of potential across the filament.

Mr. W. K. Alford: I also have been most interested in Mr. Bartlett's excellent lecture. I am glad Mr. Kirk has raised the question of the indirectly-heated cathode valve. I have done a considerable amount of work with these valves lately, and the first thing I did with one of them was to give it a life test. It lasted five days. The circuit on which the valve was put allowed it to draw an anode current of 4 milliamps continuously. After four days the emission of the valve had fallen off so that the anode current dropped to below 3 milliamps. I do not say that that is very serious, but the test gives a fair indication of its use in a broadcast receiver. It is interesting to note that another of these valves, which had evidently been produced at the factory about a month later than the other one, when tested under the same conditions, had not dropped its emission at all after a similar test. I tried one in the West of London, where there is a curious alternating current supply, with a periodicity, I think, of 83 cycles per second. The indirectly-heated cathode valve on that supply is indistinguishable from an ordinary type of valve with accumulator-heated cathode. If one takes the indirectly-heated cathode valve to a supply with a more usual periodicity, say 50 cycles, there is quite a distinct amount of residual hum left in the reproduction. The amount of hum, although hardly audible on an unmodulated carrier wave, is sufficient to break bottom frequencies distinctly and I should like Mr. Bartlett's observations in this connection.

Captain H. de A. Donisthorpe: In connection with the magnetron, it will be interesting to learn whether Mr. Bartlett has carried out any experiments with this device when the valve used is a soft one. In about 1921 I carried out some experiments with magnetic fields around thermionic valves, and found some very interesting differences between soft and hard valves. With a hard valve the effect was a dropping off of the anode current, but with a soft valve there was an increase for certain values of the magnetic field as against a valve operating under normal conditions.

The President (Brig.-General Sir Capel Holden): Mr. Bartlett hinted that there was some difficulty about making the indirectly-heated cathode valves in larger sizes. Is that a mechanical difficulty, is it simply that there would be trouble due to the extraordinary amount of heat in the valve, or is it that the manufacturers have not progressed sufficiently far with this particular type of valve to enable them to say exactly what would happen ?

Mr. Bartlett, replying to the discussion, said: One of the most important things I have to do is to answer for the faults of the indirectly-heated cathode valve. I think that possibly some of the earlier products were not quite so good as can be obtained now, but that is often the case. Mr. Kirk mentioned that the plate resistance is low. That is wrapped up entirely in the effect which is shown in the two valves of Fig. 14. In the indirectly-heated cathode valve the ratio of the cathode diameter to the grid diameter is much nearer unity than is the case in a filament valve, so that, although this valve has a very short, stumpy cathode, its characteristics are extremely good. The β^2 comes in the bottom of the equation. Mr. Kirk also mentioned the curved bottom of the valve, but I will deal with that later, as it is connected with the point raised by Mr. Henderson. Mr. Alford mentioned residual hum, and I must say that I am surprised that he obtained good results on an 83-cycle supply, but not very good results on a 50-cycle supply. Our experience is that a periodicity of 50 cycles is usually quite satisfactory, and anything higher—83 or 133—is apt to give hum.

The question of the lack of voltage drop across the cathode is very important and is shown up in a remarkable way by indirectly-heated cathode valves. Thus in an ordinary high "m" valve—take for example the DE5B, the effect is very noticeable; the characteristic curves instead of being simply displaced to the left by increasing anode volts as shown in Fig. 20 spread out from a point and it is impossible to get a definite figure for the "m" value in the usual way.

This is due to the fact that with small anode currents in a high "m" valve—often only a small fraction of the filament length is actually being used. Thus consider a valve having 100 volts on the anode, grid bias of 1 volt and an m of 40.

At the negative end of the filament

$$\frac{V}{m} + v$$

is thus equal to

$$\left(\frac{100}{40} - 1\right) = 1.5\,;$$

at a point along the filament 1 volt above the negative end the effective anode volts is 99 and the grid is —2 volts below this point on the filament; hence here

$$\left(\frac{V}{m} + v\right) = \left(\frac{99}{40} - 2\right) = .5 \text{ approx.}$$

But at a point 2 volts above the negative end

$$\left(\frac{V}{m} + v\right)$$

is a negative and there is no anode current from this point of the filament or any point at higher voltage.

Some experimental valves similar to the KL1 but with higher "m," which I believe are not yet on the market, show an accurate lateral displacement of characteristic together with a very low impedance such as cannot be approached by a filament valve.

The increase of anode current in a soft valve when a magnetic field is applied, mentioned by Captain Donisthorpe, is doubtless explained by the increased ionisation of the gas due to the longer curved paths of the electrons; the extra positive ions decrease the Space Charge effect and give a larger anode current.

In answer to the President there would probably be little difficulty in making larger size indirectly-heated cathode valves for fairly low voltages—the difficulty is to get coatings which will run satisfactorily with higher anode voltages.

Abstracts and References.

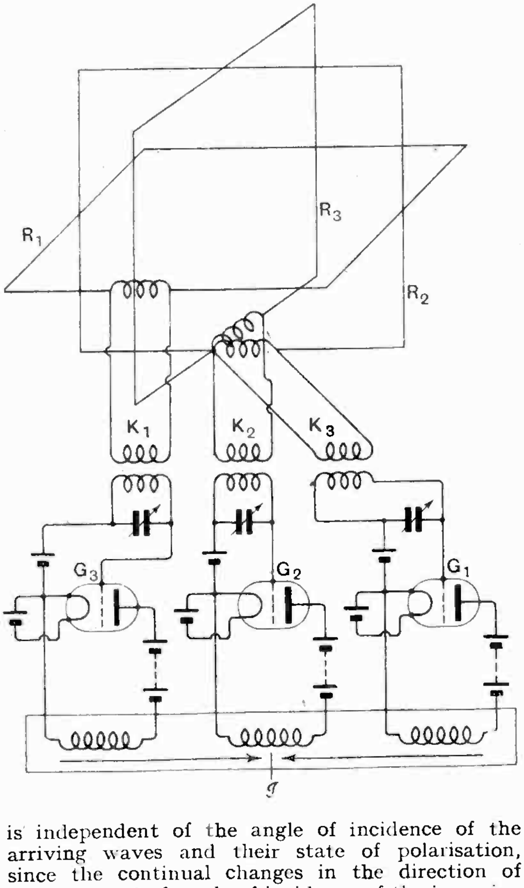
Compiled by the Radio Research Board and reproduced by arrangement with the Department of Scientific and Industrial Research.

PROPAGATION OF WAVES.

UNGERICHTETEN EMPFANG (Undirectional reception) —N. v. Korshenewsky. (*Zeitschr. f. Hochfrequenz*, 29, 3, March, 1927, pp. 78-80.)

It is shown mathematically that, with appropriate orientation of the incoming radiation field and receiving antenna, the frame and the linear antenna are equivalent as concerns directional reception, and that there are no undirectional antennæ.

For wireless short wave reception, however, a nondirectional means of receiving is required, that



is independent of the angle of incidence of the arriving waves and their state of polarisation, since the continual changes in the direction of polarisation and angle of incidence of the incoming waves can cause marked variation of the signals being transmitted.

The alterations of the direction of polarisation are attributed principally to the unhomogeneousness of the atmospheric layers and the action of the earth's magnetic field. The causes for the alteration of the angle of incidence are naturally also to be looked for in the changing condition of the atmospheric layers, largely in the variation of the electronic density of the Heaviside layer in a vertical direction: according as to whether the density of the electrons becomes greater or less with the height, the electro-magnetic wave undergoes greater or less bending. The continual fluctuation of the ionic density is thus responsible for the variation of the angle of incidence of the ray arriving at the receiver as a result of atmospheric refraction. For the ray arriving after reflection at surfaces of different refracting power, the angle of incidence changes with alteration in the height or inclination of the reflecting layer, which alteration is always taking place. Thus whether the ray arrives after refraction or reflection, its inclination to the earth's surface must be continually changing, producing corresponding variations in the antenna current, quite independently of which type of aerial is employed. These variations of the intensity received can produce serious distortion in the transmission of speech or music also, particularly in picture telegraphy.

The necessity therefore arises for the production of a receiving system that will eliminate unintentional variations in the intensity received. Such a system is shown to be obtained by means of three equal aerials (either linear or frame) at right angles to one another, whose oscillations affect a common indicating instrument after passing through separate rectifiers. The figure opposite shows how three frame antennæ are arranged for undirectional reception.

The frames R_1, R_2 and R_3 are connected through the leads K_1, K_2 and K_3 to the rectifiers G_1, G_2 and G_3, the anode circuits of which act on a common instrument $\mathfrak{J}$, whose indications are independent of the angle of incidence and direction of polarisation of the incoming wave.

EXPÉRIENCES SUR LA PROPAGATION DES ONDES COURTES (Experiments on the propagation of short waves).—A. Colmant. (*L'Onde Electrique*, 6, 62, February, 1927, pp. 82-91.)

Lecture given to the Société des Amis de la T.S.F., 16th January, 1926, describing the continuation of the tests between Paris and Algiers made during 1924 (*L'Onde Electrique*, January, 1925).

From the results, which are tabulated and discussed in detail, it is concluded that it is not possible definitely to enunciate hypotheses on propagation, owing to the sudden occurrence of peculiar unexpected facts that do not fit in with the law which otherwise appeared to be satisfactory, also because secondary causes doubtless enter in that mask the true laws of propagation.

The principal difficulty met with in this investigation is expressed as follows: the flat-top of a transmitting antenna can no longer be regarded as a simple capacity with short waves, but behaves like a horizontal antenna ; in what proportion is the energy divided between the flat-top and the vertical wire and how does it vary with the wavelength ? Also what is the relation between the energy of the space wave and that of the ground wave ?

A second difficulty is stated to be the impossibility of separating the direct from the indirect wave in the majority of cases. Complete absorption of the ground wave was only found for waves of the order of 25 metres, and nothing definite could be arrived at for waves of 50 metres or longer.

The experiments, however, appear to confirm the opinion previously formed that the trajectory of a ray resulting from successive refractions in upper strata is *unsymmetrical* with reference to the perpendicular erected midway between the point of departure of the ray and its point of arrival.

SHORT WAVE RECEIVING TESTS ACROSS THE PACIFIC.—T. Nakagami. (*Journ. Inst. Elect. Eng., Japan*, March, 1927, pp. 249-255.)

The transmission from KEL, Bolinas, California, U.S.A., on a wavelength of 29.3 metres, was received at Iwatsuki on 21st October, 1926, for 24 hours. The audibility curve and recording tape are reproduced showing the conditions under which reception took place at different hours. The signals were strong and steady throughout the tests and could be received for 19 hours any day and easily recorded at moderately high speeds after dark. The transmitter worked on the power amplifier system exciting a non-directional aerial with the rated output of 20kW, and the receiver consisted of an autodyne detector, six-stage audio amplifier and rectifier.

DISCUSSION ON RADIO BROADCAST COVERAGE OF CITY AREAS (Espenschied).—(*Journ. A.I.E.E.*, April, 1927, pp. 377-378.)

Discussion of the paper that appeared in *Journ. A.I.E.E.* for January, 1927, p. 25.

LES LIMITES DE MA THÉORIE DE PROPAGATION (The limits of my theory of propagation).—F. Kiebitz. (*L'Onde Electrique*, 6, 63, March, 1927, pp. 127-131.)

In *L'Onde Electrique* for December, 1926 (these abstracts *E.W. & W.E.*, March, 1927, p. 175), Mesny expresses his disagreement with Kiebitz's new propagation formula (*Ann. d. Phys.* 80, 1926, 728; these abstracts, January, 1927, p. 49). In the present note Kiebitz replies to Mesny's objection by showing that it refers to terms inversely proportional, not to the distance for which his solution is strict, but the second power of the distance—terms which are neglected in his theory.

A reply from Mesny follows, indicating that even with the order of approximation adopted, Kiebitz's formula cannot represent the law of wave propagation around the earth.

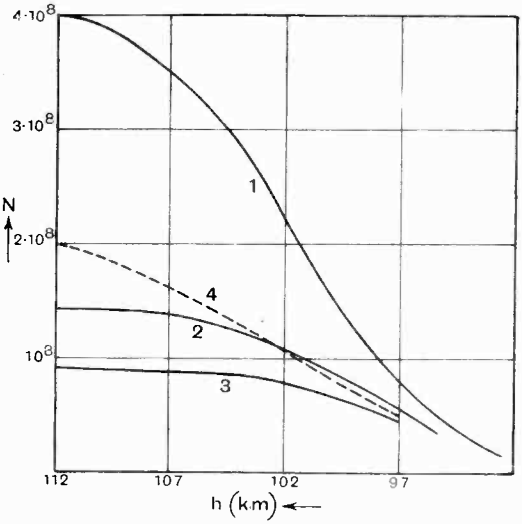
ON THE RADIO FIELD INTENSITY OF TIME SIGNALS SENT OUT BY THE PEARL HARBOUR STATION, OBSERVED AT TOKIO.—T. Minohara. (*Journ. Inst. Elect. Eng., Japan*, No. 464, March, 1927, pp. 225-232.)

The results are given of a series of measurements made at the Naval Experimental and Research Establishment, Tokio, on the signals from Pearl Harbour, covering the period September, 1925, to October, 1926.

Comparing the variations of intensity observed with those of the atmospheric conditions including temperature, humidity and pressure, it is remarked that they are synchronous. The interesting fact is found that the variations are in the same sense during a certain interval and in the opposite sense during another interval, just as often happens with meteorological phenomena. It is observed that perhaps the distance 6,400 kilometres is too long to draw this conclusion, but that the results are very similar to Dr. Austin's made at a distance of 200 kilometres. The field intensity curves are shown and compared with those recorded simultaneously for the temperature, pressure and vapour tension of the atmosphere.

DIE TÄGLICHEN SCHWANKUNGEN DES IONISATIONSZUSTANDES DER HEAVISIDE-SCHICHT (Daily variations of the state of ionisation of the Heaviside layer).—H. Lassen. (*Elekt. Nachr. Technik*, 4, 4, April, 1927, pp. 174-179.)

From previous experiments with short waves (less than 1 kilometre) it is concluded that the



ionisation of the Heaviside layer by day is relatively constant, but that during the night the ionic concentration steadily decreases down to about the fourth or fifth part of the day value. This variation can be directly explained on the assumption that hydrogen ions and not free electrons are mainly operative. By day free electrons are also present, but their action on electric waves is unimportant compared with that of the ions. The ionising agent that is principally effective is the ultra violet light from the sun, the decrease in ionic concentration during the night being due to the reunion of positive and negative charges.

The preceding graph is given to show the concentration of the ions at different times of the day in relation to the height.

Curve 1 represents the number of ions in the daytime.

Curve 2 six hours after the sun has ceased to shine.

Curve 3 twelve hours after the sun has ceased to shine.

Curve 4 one hour after recommencement of sun's radiation.

ATMOSPHERICS AND ATMOSPHERIC ELECTRICITY.

THE RANGE OF ATMOSPHERICS.—(*Nature*, 7th May, 1927, p. 689.)

Brief account of the report of the Committee on Atmospherics and Weather presented by Mr. Watson Watt at a meeting of the Royal Meteorological Society, on 20th March.

LIGHTNING SURVEY IN JAPAN.—R. Mitsuda. (*General Electric Review*, 30, 3, pp. 124-128.)

Report on the lightning strokes observed in Japan between 1921 and 1924, leading to the following conclusions :—

1. Lightning storms generally have definite courses of progress, depending on the local topographic and atmospheric conditions. They almost always originate in high mountainous regions and gradually descend to the flat fields along valleys.

2. More than 40 per cent. of the total lightning flashes occur in August and the least number in winter. This seasonal change resembles that of humidity and the temperature of the atmosphere.

3. Lightning occurs mostly in the evening, especially (40 per cent.) between 3 and 6, and almost never around midnight.

4. The nature of the soil has some bearing on the frequency of lightning strokes: moist, conductive soils seeming much more liable to lightning than dry soils.

MEASUREMENT OF SURGE VOLTAGES ON TRANSMISSION LINES DUE TO LIGHTNING.—E. Lee and C. Foust. (*General Electric Review*, 30, 3, March, 1927, pp. 135-145.)

In *Journal A.I.E.E.*, October, 1926, McEachron gives the results of a detailed study of the calibration of the photographic Lichtenberg figures using the Dufour Cathode Ray Oscillograph as a means for determining with certainty the wave shape of the impressed voltage. The present article contributes additional data and shows that voltages of the order of 2,000,000 volts may be recorded with a reasonable degree of accuracy.

AU SUJET DE L'AURORE DU 15 OCTOBRE OBSERVÉE EN NORVÈGE (On the subject of the aurora of 15th October observed in Norway).—H. Jelstrup. (*L'Onde Electrique*, 6, 63, March, 1927, pp. 132-134.)

Description of this remarkable aurora, with the soft sibilant sound heard at the same time, whose very distinct modulation seemed to follow exactly the undulations of the aurora.

Further observations by Prof. Carl Störmer are appended.

ELECTRICITY OF DUST CLOUDS (PART I).—G. Deodhar. (*Proc. Physical Society*, 39, 3, April, 1927, pp. 243-249.)

In tropical regions like India, large volumes of dust are blown up into the atmosphere, causing what are called dust storms. Such storms produce a great increase in the potential gradient and are a considerable menace to the wireless operator.

The factors governing the phenomena of electricity of dust storms are given as follows: material of the dust, its size, the gas raising the cloud, its velocity, and the temperature. The present paper examines the first two factors.

It is concluded that the electrification is produced by friction, but that there is no definite rule regarding the nature of the electrification and the material of the dust, also that the voltage developed increases very rapidly as the size of the dust particles diminishes.

PROPERTIES OF CIRCUITS.

PERFECTIONNEMENTS AUX AMPLIFICATEURS À RÉSONANCE (Improvements in resonance amplifiers.)—Blanchard. (*L'Onde Electrique*, 6, 62, February, 1927, pp. 57-70.)

Investigation of two circuit-arrangements for resonance amplifiers in which the amplification is approximately constant in a small band of frequencies and practically nil outside of this band. Thus, while these circuit arrangements are not filters, they have analogous properties which are very advantageous, particularly for the medium frequency amplifiers of superheterodynes for broadcast reception.

RESONANCE IN ALTERNATING CIRCUITS CONTAINING A SINGLE HARMONIC.—F. Miller. (*Physical Review*, 29, 4, April, 1927, pp. 546-553.)

The phenomenon of resonance in a circuit having impressed upon it a sinusoidal E.M.F. is a familiar one, and full discussions of it have been presented by many writers; but the current-frequency relations as affected by the presence of harmonics in the voltage wave, although often met with in practice, are not so well known. This paper investigates some of these relations for the case in which one harmonic, of order n, is present in the applied E.M.F. Methods of analysis are here merely outlined, and the conclusions arrived at stated.

DISCUSSION ON THE OUTPUT CHARACTERISTICS OF AMPLIFIER TUBES (Warner and Loughren).—E. Green. (*Proc. Inst. Radio Engineers*, 15, 4, April, 1927, p. 319.)

Further discussion to that given in the March issue of the *Proceedings* on the paper that appeared in the December number of the *Proceedings* (these Abstracts *E.W. & W.E.*, March, 1927, p. 178.)

ÜBER SCHWINGUNGSKREISE, DIE DURCH EINE EISENKERNSPULE GEKOPPELT SIND (On oscillatory circuits coupled by means of an iron-cored coil). — H. Winter-Günther. (*Zeitschr. f. Hochfrequenz.*, 29, 4, April, 1927, pp. 103-114.)

The behaviour is studied, partly theoretically and partly experimentally, of two oscillatory circuits coupled over a coil with a closed iron core. Distinction is made between the cases where primary and secondary circuits have the same natural frequency and where their natural frequencies are different.

(*a*) Where primary and secondary have the same natural frequency: theory shows and experiment confirms that in this case both free and forced oscillations are composed of two parts, one of which corresponds to the oscillations of an iron free condenser circuit while the other to those of a simple condenser circuit with an iron-cored coil.

(*b*) When the natural frequencies of primary and secondary are different: the investigation here extended only to the current tension characteristics of forced oscillations and was limited to cases of approximately sinusoidal currents.

The problem is treated as one of current division, the experiments yielding three essentially different types. The reactances of the primary and secondary circuits determine the characteristic curves, and not the inductances (as is sometimes assumed).

The characteristics are of special interest when the reactance of the secondary equals the maximum inductance of the iron cored coil. When the tension is continuously regulated in this case, sudden changes in the effective value of the primary current occur which are nearly as great as when there is no secondary. With a view to their applicability to the modulation of high frequency currents, these reversible tilting phenomena are studied in detail.

SLOPE INDUCTANCE.—C. Cosens. (*E.W. & W.E.*, June, 1927, pp. 331-335.)

A note on the effective inductance of iron-cored chokes or transformers.

SELF-INDUCTANCE OF STRAIGHT WIRES.—R. Wilmotte. (*E.W. & W.E.*, June, 1927, pp. 355-358.)

MODELLREGELN FÜR SCHWINGUNGSKREISE MIT EISENKERNSPULEN (Model rules for oscillatory circuits with iron-cored coils).—H. Winter-Günther. (*Zeitschr. f. Hochfrequenz.*, 29, 3, March, 1927, pp. 81-82.)

It is often necessary to transfer the experimental results obtained with an oscillatory circuit with an iron-cored coil to circuits containing iron chokes of other dimensions. Model rules for this purpose are derived in this article. Mathematical investigation is made of:—

(*a*) Simple oscillatory circuits with iron-cored coils and direct current superimposed, and

(*b*) Oscillatory circuits coupled over an iron-cored coil.

ÜBER ANODENGLEICHRICHTUNG (On anode rectification. — M. von Ardenne (*Zeitschr. f. Hochfrequenz.*, 29, 3, March, 1927, pp. 82-88.)

The value of the rectification, produced by the curvature of the anode current characteristic, is investigated in relation to the value and nature of the resistance in the anode circuit. From the viewpoint of practical requirement, particular attention is given to finding when the rectifying effect is specially large (for the construction of sensitive rectifiers) and under which conditions it is small (for the production of amplifiers free from distortion).

SUR LES AMPLIFICATEURS DE PUISSANCE SANS DISTORSION (On distortionless power amplifiers).—A. Clavier and I. Podliasky. (*L'Onde Electrique*, 6, 62, February, 1927, pp. 71-81).

This subject has been treated already by various authors, in particular by B. W. Kellogg (*Journal A.I.E.E.*, May, 1925, and *L'Onde Electrique*, November, 1925). It is taken up again here from a different aspect with a view to bringing to light practical rules for a rapid pre-determination of the working conditions of these amplifiers.

A formula that can be easily applied is given for finding the apparent optimum resistance to introduce into the output circuit of the amplifier in the case where the power to be dissipated on the anode at the moment of static functioning is determined. A classification of amplifying triodes is shown and a means of calculating a modulator for a radiophonic transmitter.

SUR LA DÉTECTION PAR LAMPE (On valve detection). —P. David. (*Comptes Rendus*, 184, 25th April, 1927, pp. 1000-1002.)

When one attempts to go beyond the elementary and qualitative explanation of valve detection in order to analyse the phenomena and verify the theory experimentally, the author states it is only to find the literature on the subject incomplete and sometimes contradictory. The purpose of the present article is to take up the question again as a whole. The result of the mathematical investigation is given as follows:—

For every system the detection output begins to improve when the initial amplitude u_1 of the carrier wave or the local oscillation increases. Then this output becomes independent of u_1: the detection curve presents a rectilinear part in which the detected current is strictly proportional to the amplitude of the small variations Δu. This part must be systematically utilised in order to have maximum sensitivity and minimum distortion. The characteristics are tabulated of various French valves with the different detecting circuit arrangements employed.

Lastly, it is shown that in the normal superheterodyne, detection is not effected by the grid, as is believed and in spite of the presence of the shunted condenser, but by the curvature of the plate characteristic.

L'UTILISATION DES LAMPES À QUATRE ELECTRODES (Employment of four-electrode valves.)—B. Decaux. (*L'Onde Electrique*, 6, 61, January, 1927, pp. 1-18.)

A survey of the different uses to which four-electrode valves can be put. The object usually sought in introducing a fourth electrode is either greater sensitivity, or negative resistance, or a reduction of the plate tension, or a combination of these effects.

Under "Generalities," mention is made of Scott-Taggart's double-plate valve, the negatron, giving rise to a circuit with negative resistance; also of Hull's pliodynatron, a development of his dynatron, with a perforated plate at a high potential and the ordinary plate at a lower potential, where negative resistance effects are obtained from secondary emission. The most useful four-electrode valve is said to be that with two grids, known in France as "bigrille," in which the interior grid serves as an "electron pump," the plate voltage by itself being in general too weak to produce a large enough electron current. The double-grid valves investigated by Barkhausen are based on a quite different principle: here the interior grid serves as grid, while the exterior grid is raised to a positive potential a little below that of the plate. Further, Marconi has employed valves in which the interior grid is used as grid and the exterior grid as plate, the plate itself being kept at a fixed potential.

The second section discusses arrangements with one grid which comprise two principal types corresponding to different purposes. In the one the question of simplicity is overlooked in order to have very high amplification, while in the other one is satisfied with normal amplification but has a very reduced plate battery.

The third section considers arrangements with two grids, nearly all of which operate with reduced plate voltage, discussing in particular valves of multiple function, balanced arrangements, and the utilisation of negative resistance.

TRANSMISSION.

SUR L'ENERGIE RAYONNÉE PAR LES RÉSEAUX ELECTROMAGNÉTIQUES (On the energy radiated by electromagnetic systems).—R. Mesny. (*Comptes Rendus*, 184, 2nd May, 1927, pp. 1047-1050.)

A mathematical discussion in which, in order to express the energy radiated in terms that can be easily handled, the parallel wires traversed by equal currents are replaced by a continuous sheet of metal, resulting in the drawing up of simple formulæ that can be applied to the systems employed in practice with little error.

The expressions obtained show that grouping several antennæ together considerably increases the radiation resistance of each of them taken separately. If, for example, two antennæ are a quarter of a wave apart, the resistance of each becomes multiplied by about 1.5. Physically, this increase is readily seen to be due to the component of the field of the neighbouring antennæ which, on a given antenna, is found in opposition with the current in this antenna (*Brillouin, Radio Electricité*, 3, p. 147, April, 1922).

EIN BEITRAG ZUR BERECHNUNG VON ERDVERLUSTEN BEI ANTENNENANLAGEN (Contribution to the calculation of earth losses with antenna systems.)—R. Mayer. (*Zeitschr. f. Hochfrequenz.*, 29, 3, March, 1927, pp. 71-76.)

Of the total earth loss of large antenna systems for long waves, three kinds of loss are distinguished:—

1. When earth plate and counterpoise are absent and there is only an earth of very limited extent in the vicinity of the source of current, the loss then corresponds to a free alternating current in metal-free earth, the current density increasing towards the earth's surface.

2. When there is a buried metal earth, loss then occurs in the earth near the leads carrying the current over the earth to the current source.

3. Loss in the immediate neighbourhood of the metal earth (electrode or propagation loss), for which the corresponding direct current formulæ hold good with sufficient accuracy.

This paper considers mathematically the first two kinds of loss and formulæ are developed which are tested by the values found experimentally.

TÉLÉGRAPHIE ET TÉLÉPHONIE MULTIPLEX SUR ONDES COURTES (Multiplex telegraphy and telephony on short waves).—M. Veaux. (*L'Onde Electrique*, 6, 63, March, 1927, pp. 120-126.)

Multiple modulation has been the object of certain applications, principally in the domain of telemechanics with a view to securing a certain amount of secrecy in the communications and protection against interference. This article recalls the principle of multiple modulation and shows its use on short waves for multiplex transmission in telegraphy and telephony.

UN CHANGEUR DE FRÉQUENCE À MONTAGE SYMÉTRIQUE ET À LAMPES BIGRILLES (A frequency changer with symmetrical circuit arrangement and four-electrode valves).—A. Cazes. (*Radio-Revue*, May, 1927, pp. 359-360.)

RECEPTION.

DISPOSITIF ATTÉNUANT LES EFFETS DU FADING (Device for mitigating fading effects).—H. de Bellescize. (*L'Onde Electrique*, 6, 63, March, 1927, pp. 110-119.)

Lecture given to the S.A.T.S.F., 11th January, 1927, describing a device for continually adapting the sensitivity of the receiver to the intensity of the signals received by the antenna, so as to obtain faithful reproduction of the modulation and permit the operation of certain circuit arrangements requiring absolute steadiness in the carrier wave.

A PROPOS DES "FILTRES ACOUSTIQUES" (Concerning "acoustic filters").—P. David. (*L'Onde Electrique*, 6, 61, pp. 47-51.)

An article referring to M. Nodon's paper in *L'Onde Electrique* for last December, where the employment of acoustic filters is recommended to completely eliminate disturbances in radio telephony. The author details reasons for considering M. Nodon's optimism excessive and even that these filters are unable to improve radio telephone reception at all.

A "PRESS" RADIO RECEIVER.—(*Electrical Review*, 8th April, 1927, p. 574.)

Particulars are given of a new Marconi instrument guaranteed for aural reception of news bulletins from any long-wave C.W. station at the extreme limit of its range.

DIRECTIONAL WIRELESS.

A PORTABLE RADIO DIRECTION FINDER.—(*Journal of the A.I.E.E.*, February, 1927, p. 131.)

Mention is made of a paper by F. W. Dunmore, just issued by the Bureau of Standards, describing the development of a portable direction finder with but two controls—one for tuning and one for balancing. This direction finder operates over the frequency band from 90 to 7,700 kilocycles (3,300-39 metres). The direction finder is of the simple rotating coil type. The receiving set is of the superheterodyne type, with the controls reduced to one by the use of a cam-operated condenser. The wide frequency range is made possible by a set of seven interchangeable plug-in direction finder coils, each with a corresponding heterodyne generator coil and cam for operating the auxiliary tuning condensers.

This paper is obtainable from the Superintendent of Documents, Government Printing Office, Washington, D.C., for 10 cents.

REMARQUE AU SUJET DES EMISSIONS HERTZIENNES DIRIGÉES (Note on the subject of directional Hertzian transmission). — A. Blondel. (*Comptes Rendus*, 184, 11th April, 1927, pp. 923-925.)

In a preceding article (*Comptes Rendus*, 184, p. 561, these Abstracts, *E.W. & W.E.*, June, 1927, p. 372) the author showed how two curtain antennæ can be excited by an oscillating inductor, alternately or simultaneously, giving emissions constantly opposed in phase. This arrangement is a particular case of the double curtain antenna system previously described and presents the two-fold advantage of an easier realisation of the double curtain and an uninterrupted modification of the alternating induction on each curtain, if all break in the circuits is avoided.

In the present note a further development is described in which the curtain antennæ are replaced by frames, enabling the alternate excitation of each frame to vary between a maximum and absolute zero, whatever the angle between the frames. The adjustment is such that there is no periodic variation of the phase of the exciting currents, but only periodic variation of their relative intensities: any phase displacement would give rise to a rotating field which would render its extinction impossible.

VALVES AND THERMIONICS.

CONTRIBUTION À L'ETUDE DE LA RÉPARTITION DES TEMPÉRATURES LE LONG D'UN FILAMENT INCANDESCENT DE TUNGSTÈNE CHAUFFÉ ELECTRIQUEMENT DANS LE VIDE (Contribution to the study of temperature distribution along a glowing tungsten filament heated electrically in vacuo).—G. Ribaud and S. Nikitine. (*Annales de Physique*, 7, pp. 5-34.)

Two corrections are applied to Worthing's theory of temperature distribution for a long filament, and the distribution in a short filament is investigated. A relation is found for calculating the central temperature of a short filament in terms of its linear dimensions and the current.

WIRELESS TRANSMITTING VALVES.—(*E.W. & W.E.*, June, 1927, pp. 359-367.)

Abstracts of three papers read at the meeting of the I.E.E. Wireless Section on 4th May, dealing respectively with the Holweck demountable type valve, silica valves in wireless telegraphy, and cooled-anode valves.

EQUATIONS FOR THERMIONIC EMISSION.—W. Ham. (*Physical Review*, 29, 4, April, 1927, p. 607.)

Abstract of a paper presented at the New York meeting of the American Physical Society, February, 1927.

It has recently been shown that an equation of the form $i = A\varepsilon^{-b_0/T}$ applies as well as any other to experimental data on thermionic and photo-electric emission. The paper discusses the derivation of this equation from Richardson's general equation.

A TYPE OF OSCILLATION HYSTERESIS.—L. Taylor. (*Physical Review*, 29, 4, April, 1927, p. 617.)

Abstract of a paper presented at the New York meeting of the American Physical Society, February, 1927).

A simple triode oscillator was modified by placing a high resistance (.5—1.0 meg.) shunted by a capacity of 0.1μF in series with the grid. The circuit then oscillated intermittently, the period during which oscillation occurs being called a zule. Over a wide region the zule frequency F is found to obey a simple relation to the constants of the circuit, *i.e.*, $F = A \exp [(L_2 - kC_2)/2L_1]$, where A and k are constants. At the borders of these regions F is extremely sensitive to very small changes in L_2 and C_2. A theory is given for the formation of zules showing how they are related to the state of depression of the grid potential. Their finite length is due to a type of oscillation hysteresis, where oscillation ceases at one value of E_g and is resumed at a higher value. At the end of a zule, the mean of E_g is equal to the dynamic cut-off potential, and at the start of the next zule is several volts higher, increasing exponentially between these values. The variations of E_g were later studied by means of a synchronised oscilloscope, and all points of the theory were checked. Oscillation within the main circuit showed the same formation except that the potential between zules was constant.

ÜBER SCHALTVORGÄNGE BEI ELEKTRONENRÖHREN (On circuit phenomena with valves).—R. Mayer. (*Zeitschr. f. Hochfrequenz.*, 29, 3, March, 1927, pp. 76-78.)

Remark on the paper by Fischer and Pungs "Schnelltelegraphie mit Steuerdrosseln" (*Zeitschr. f. Hochfrequenz.*, 27, p. 51; these Abstracts, *E.W. & W.E.*, June, 1926, p. 385).

The course taken by anode and grid currents when the grid potential is suddenly altered, is shown with the aid of the series of characteristics "anode and grid currents as a function of the anode potential with different grid potentials."

GENERAL PHYSICAL ARTICLES.

PIEZO-ELECTRICITY OF CRYSTAL QUARTZ.—L. Dawson. (*Physical Review*, 29, 4, April, 1927, pp. 532-541.)

Description of an extensive investigation of the piezo-electric effect in crystalline quartz, with the apparatus employed, and the results obtained.

Experimental measurements with the quadrant electrometer of the distribution of the piezo-electric charge over the surface of a quartz crystal in a plane normal to the optic axis were found to vary in such a manner as to produce six regions of charge, three positive areas alternating with three negative. The areas had definite geometrical relations to the electric axes and therefore these facts yielded a new and accurate method of determining the directions of the electric axes in crystal quartz. In planes containing the optic axis there was a region of positive charge separated by a line in the direction of the optic axis from a region of negative charge.

The piezo-electric effect increased by 20 per cent. from room temperature to 60 deg. C., and decreased thereafter, reaching zero at about 573 deg. C. Cooling curves showed a lag.

The piezo-electric charge produced on different specimens, or on different areas of the same specimen, all specimens being optically perfect, varied from large positive values of charge to large negative values. In general, the surface of the crystal quartz produced piezo-electric charges of the same sign, but of varying magnitudes. The charge measured over the entire surface of a crystal appeared to be the average of the effects of the elementary areas. The values found in these experiments with different specimens varied on the negative side of the crystal from 5.8×10^{-8} to 7.1×10^{-8} *e.s.u./cm*^{2} $\times$ dyne, and on the positive side from 4.9×10^{-8} to 6.4×10^{-8} *e.s.u./cm*^{2}, figures which do not differ widely from the accepted value of 6.3×10^{-8} *e.s.u./cm*^{2} $\times$ dyne, the "piezo-electric constant" of P. & J. Curie. Such variations are in keeping with recent X-ray investigations on the imperfections of crystals.

It appears that a complete theory of the piezo-electric effect, capable of coping successfully with all the phenomena now known, must await a more comprehensive understanding of the molecular structure of quartz.

PIEZO-ELECTRIC CRYSTALS AT RADIO FREQUENCIES.—A. Meissner. (*Proc. Inst. Radio Engineers*, April, 1927, pp. 281-296.)

Translation from manuscript received 11th October, 1926, presented at the meeting of the Institute of Radio Engineers, New York, 2nd March, 1927.

THEORY AND APPLICATION OF LOW FREQUENCY PIEZO-ELECTRIC VIBRATIONS IN QUARTZ PLATES.—J. Harrison. (*Physical Review*, 29, 4, April, 1927, p. 617.)

Abstract of a paper presented at the New York meeting of the American Physical Society, February, 1927.

Further study of the phenomena described at the December meeting (*Phys. Rev.* 29, p. 366; these Abstracts, *E.W. & W.E.*, May, 1927, p. 311) indicates that the observed frequencies of vibration are sufficiently in accord with those calculated from the formula for flexural vibrations to make it fairly certain that the vibrations are of this type. In general, agreement between theory and observation is best for relatively long plates as would be expected. With longer rods the second mode of vibration having three nodes has also been observed. These facts are illustrated by numerical data and curves. An empirical formula has been derived which fits the observed data better than the theoretical equation for flexural vibrations. A plate 30 × 10 × 1 mm. vibrating at 60 kilo-cycles was placed in the circuit of a type UX—210 tube as a power oscillator. The observed output power was about ½ watt, which, considering the low frequency, compares favourably with the output from a high frequency quartz oscillator.

A SHEAR MODE OF CRYSTAL VIBRATION.—W. G. Cady. (*Physical Review*, 29, 4, April, 1927, p. 617.)

Abstract of a paper presented at the New York meeting of the American Physical Society, February, 1927.

In the various applications of piezo-electric quartz plates, it has until recently been customary to cut the plates with their faces perpendicular to an electric axis, when the vibrations are longitudinal. Various observers have recently found that plates cut parallel to the electric and optic axes are good oscillators, but hitherto no explanation has been offered. According to Voigt's theory of piezo-electricity, an electric field perpendicular to the electric and optic axes causes a shearing stress about the optic axis: hence the deformation of a plate cut as indicated, when in a field normal to its surface, is a shearing strain, and under an alternating impressed field vibrations are to be expected, whose resonant frequency is determined by the shear-inertia of the plate and by the elastic force of restitution. Computed and observed values of the natural frequency are in satisfactory agreement.

OPTIQUE ET RADIOÉLECTRICITÉ (Optics and wireless).—L. Bouthillon. (*L'Onde Electrique*, 6, 63, March, 1927, pp. 97-109.)

In two preceding papers (*L'Onde Electrique*, July, 1925, and November, 1926; these Abstracts, *E.W. & W.E.*, February, 1927, p. 120), the author showed that the classic problems of optics have their corresponding problems in radio and investigated the wireless equivalents of some simple optical systems.

In this third part of the article, the author sets out mathematically the general rules relating to complex systems; rules of addition, substitution and repetition, either at emission or reception, and shows how these rules become modified for real antennæ in place of the hypothetical elements at first considered.

A DIRECT COMPARISON OF THE LOUDNESS OF PURE TONES.—B. Kingsbury. (*Physical Review*, 29, 4, April, 1927, pp. 588-600.)

An account of tests leading to the following conclusion: When the amplitudes of single frequency tones are increased by equal ratios, high frequency tones increase in loudness more slowly than do low frequency tones; however, for frequencies above 700 cycles, the idea that tones are equally loud when they are an equal number of T.U. above the threshold is a very good approximation.

A Study of the Regular Combination of Acoustic Elements, with Applications to Recurrent Acoustic Filters, Tapered Acoustic Filters, and Horns.—W. Mason. (*Bell System Technical Journal*, April, 1927, pp. 258-294.)

A Generalisation of Electrodynamics, consistent with Restricted Relativity and affording a possible explanation of the Earth's Magnetic and Gravitational Fields, and the Maintenance of the Earth's Charge. — W. Swann. (*Philosophical Magazine*, 3, 18, pp. 1088-1136.)

On the Question of the Existence of Induction Effects from suddenly stopped Electrons, predicted by the Classical Theory.—S. Milner and J. Hawnt. (*Philosophical Magazine*, 3, 18, pp. 1185-1195.)

If the radiation from the moving electrons in a vacuum tube when they are suddenly stopped by the anode consists of the spherical pulses of the classical theory, an E.M.F. should be generated in a metal cylinder surrounding the anode; considerations of the energy of the pulses set a limit to the magnitude of the E.M.F. which is, nevertheless, of such a value that it should be capable of being detected by a suitably arranged galvanometer.

The experiments described show no trace of the existence of such an E.M.F. and add further evidence to the view that pulses of the kind formulated by the classical theory, if they exist, are not absorbed in accordance with classical considerations.

Ionisation by Collision.—H. Huxley. (*Philosophical Magazine*, 3, 18, pp. 1056-1061.)

A note commenting on the theory advanced by Taylor in "On the Sparking Potentials of Discharge Tubes containing carefully Purified Electrodes" (*Proc. Roy. Soc.*, February, 1927).

The Use of Gasfilled Photo-electric Cells. —N. Campbell. (*Philosophical Magazine*, 3, 18, pp. 1041-1051.)

Magnetic Permeability of Iron and Magnetite in High Frequency Alternating Fields. —G. Wait. (*Physical Review*, 29, 4, April, 1927, pp. 566-578.)

Wwedensky and Theodortschik have found the magnetic permeability of iron, steel, and nickel in alternating fields to be abnormally large in certain frequency bands and nearly normal in other regions. The general appearance of the phenomenon suggested the existence, in the material, of resonators corresponding to these frequencies. The phenomenon has been observed also by Kralovec. These results are in disagreement with those of the author, who found no anomalous change in permeability at any frequency, and whose methods of investigation are described in this paper.

Contemporary Advances in Physics—XIII. Ferromagnetism. K. Darrow. (*Bell System Technical Journal*, April, 1927, pp. 295-366.)

Thermal Agitation in Conductors. H. Nyquist. (*Physical Review*, 29, 4, April, 1927, p. 614.)

Abstract of a paper presented at the New York meeting of the American Physical Society, February, 1927.

At the December meeting of the American Physical Society, J. Johnson reported the discovery and measurement of an E.M.F. due to the thermal agitation in conductors (*Nature*, 8th January, 1927, p. 50; these Abstracts, *E.W. & W.E.*, March, 1927, p. 183) The present paper outlines a theoretical derivation of this effect. A non-dissipative transmission line is brought into thermodynamic equilibrium with conductors of a definite temperature. The line is then isolated and its energy investigated statistically. The resultant formula is $E_\nu^2 d\nu = 4kTRd\nu$ for the r.m.s. E.M.F. E_ν contributed in a frequency range one cycle wide by a network whose resistance component at the frequency ν is R, T and k are the absolute temperature and the Boltzmann constant. It will be observed that neither the charge nor mass nor any other property of the carrier of electricity enters the formula explicitly, but indirectly through R.

A New Electronic Rectifier.—L. Grondahl and P. Geiger. (*Journal A.I.E.E.*, March, 1927, pp. 215-222.)

A new rectifier utilising a partially oxidised disc of copper as a rectifier unit is described. The rectification appears to take place at the junction between the copper and the oxide without observable physical or chemical changes, and is similar in character to the hot-cathode type of rectification A method of designing assembled rectifiers for special purposes is outlined and some of the problems are discussed.

The discussion on the paper is given in this Journal for May, pp. 505-507.

STATIONS: OPERATION AND DESIGN.

Wireless Beam Communication. — (*Electrical Review*, 22nd April, 1927, pp. 627-629.)

Details are given of the short-wave stations built for the Imperial Telegraph Service between England and Australia.

India — Beam Radio Telegraphy. — (*Electrical Review*, 22nd April, 1927, p. 643.)

Some particulars of the stations in India linking with the Grimsby transmitter and Skegness receiver in England. The transmitting station is situated about six miles from Poona at an elevation of 2,200 ft. above sea level. Heavy fuel oil is used for power production. The receiving station lies in open country about four miles from the small town of Dhond and fifty from the Poona station.

Portugal.—(*Electrical Review*, 6th May, 1927, p. 723.)

On 30th April services on the beam system were inaugurated between Lisbon and the Portuguese colonies of Cape Verde, Angola, and Mozambique. The opening of these services completes the network of wireless communication which the Marconi Company undertook to construct in accordance with the concession obtained from the Portuguese

Government in 1922. Direct wireless communication is now established between Lisbon and all the principal Portuguese colonies, services to Madeira and the Azores having been opened in December last. Direct services betweeen Lisbon and London, Paris, and Berlin have also been opened during the last few months, and a direct service with Rio de Janeiro is expected to be inaugurated almost immediately.

Une Visite à Radio-Barcelone (Visit to the broadcasting station at Barcelona).—E. Caranove. (*Radio-Revue*, May, 1927, pp. 363-367.)

Account of a visit to this station which in February of last year was removed from the town to the top of Mount Tibidabo (582 metres), ascended by funicular railway. The T-shaped antenna is supported by two lattice masts 50 metres high, so that it is now more than 600 metres above sea level and higher than most aerials in Europe. The station is found six times more effective since its transfer. The energy is obtained from the town mains supplying the low and high tension dynamos, through synchronous motors respectively of 4 and 8 h.p. One low tension dynamo provides current at 22 volts for the filaments and the other at 250 volts for the grids. The two high tension dynamos, which are identical and can be coupled in series, supply current of 1 amp 35 at 2,000 volts. The transmitting apparatus comprises four cylindrical Western Electric valves, type 6A, and the wavelength is 325 metres or 344 with a power of 1kW antenna. The studio remains in the town at the Hotel Tivoli.

Le Poste de Nantes de la Marine Française (The French naval station at Nantes).—(*Radio-Revue*, May, 1927, pp. 360-362.)

Views are shown of the equipment.

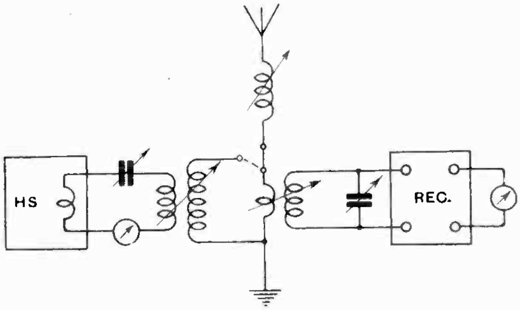
MEASUREMENTS AND STANDARDS.

Quantitative Measurements on Reception in Radio Telegraphy.—G. Anders. (*Proc. Inst. Radio Engineers*, 15, 4, April, 1927, pp. 297-311.)

Abstract of an article that appeared in *Elektrische Nachrichten-Technik*, 12, 2, 1925.

After discussing previous systems of measuring field intensities, their limitations and sources of error, referring particularly to the work of Hollingworth, Vallauri, Guierre and Round in Europe and of Pickard, Austin, England and Früs in America, the author describes the method he has perfected in the German Bureau of Telegraph Engineering. The scheme employs the usual elements in signal strength measuring work, viz., wave collector, receiver set with indicator and calibrating apparatus. The basic arrangement is shown below :

The calibrating method is essentially a current-measuring device. Referring to the figure, the secondary receiving circuit is coupled through the mutual inductance to a small coil, which is alternately switched to the ground lead of the antenna circuit and to the ends of a coil of a relatively large number of turns and small effective resistance. This latter circuit is in turn coupled with the calibrating oscillator *H S* by means of a mutual inductance. These two coils may be regarded as a current transformer. The primary current is measured by means of a vacuum barretter (hot-wire resistance) and the secondary current is made equal to the current produced



by the receiving signal, as indicated by the meter in the output of the receiver. Then knowing the ratio of transformation of the current transformer it is possible to determine antenna currents which do not allow of direct measurement.

The details of the construction of the set are discussed at length.

The Frequency Checking Station at Mare Island.—G. Royden. (*Proc. Inst. Radio Engineers*, 15, 4, April, 1927, pp. 313-318.)

This paper describes the frequency checking station at Mare Island Navy Yard for the purpose of measuring the transmitted frequencies of naval radio stations extending from St. Paul, Alaska, to San Diego, California, as far west as Cavite, Philippine Islands, and as far south as Tutuila, Samoa. The intention, of course, is to secure that each station maintains its assigned frequency and thus prevent interference.

The standard frequency meter consists of two variable air condensers and a set of ten inductance coils, wound with finely divided and insulated radio-frequency cable on bakelite tubes. The calibration of the meter depends primarily on the accuracy of a steel tuning fork, carefully adjusted to 1,000 cycles in comparison with the standard clock at Paris, and kept at a constant temperature. The tuning fork and frequency meter are compared in a screened room by means of a multivibrator together with an amplifier and a heterodyne oscillator. The method is discussed in detail.

The Exact and Precise Measurement of Wavelength in Radio Transmitting Stations — (R. Braillard and El Divoire). (*E.W. & W.E.*, June, 1927, pp. 322-330.)

Parts A and B: General consideration of the broadcast problem and description of wavemeter.

Symposium on High Frequency Measurements.—A. Knowlton. (*Journal A.I.E.E.*, May, 1927, pp. 487-491.)

Résumé of a series of 15 papers dealing with measurements at high frequencies, the preparation of which constituted the major activity of the

Committee on Instruments and Measurements during the year 1926-27. Copies of the papers can be obtained from the Institute Headquarters.

ANALYSER FOR COMPLEX ELECTRIC WAVES.—A. Landeen. (*Bell System Technical Journal*, April, 1927, pp. 230-247.)

For several years there has been in use in the Bell Telephone Laboratories special apparatus by means of which a single component of a complex periodic current wave may be selected from the remaining components and its amplitude determined. The sensitivity and selectivity of this apparatus are such that components of small amplitude may be accurately measured even in the presence of other components of several hundred times the amplitude and differing but little in frequency. With the latest improved form it is now possible to measure current components having amplitudes as low as 10^{-7} amperes with a possible error of 10 per cent. For such minute currents this is within the error that might be introduced by the external apparatus such as attenuators and thermocouples together with their calibration charts.

Though the apparatus described, which can work over the range from about 3,000 to 100,000 cycles was primarily designed for use in current wave analysis work, it may be readily adapted to voltage analysis. Suitably calibrated it can also be used as a frequency meter of extremely high precision.

The third chapter is concerned with the selection of the wavelength on which it is necessary to work for measurements made at high frequency to give the same figure as those carried out electrostatically. A wavelength of 1,000 metres was found suitable for the circuits employed. The last chapter gives the circuit-arrangement and results.

DISCUSSION ON IMPORTANCE OF LABORATORY MEASUREMENTS IN THE DESIGN OF RADIO RECEIVERS.—W. Macdonald. (*Proc. Inst. Radio Engineers*, 15, 4, April, 1927, pp. 329-340.)

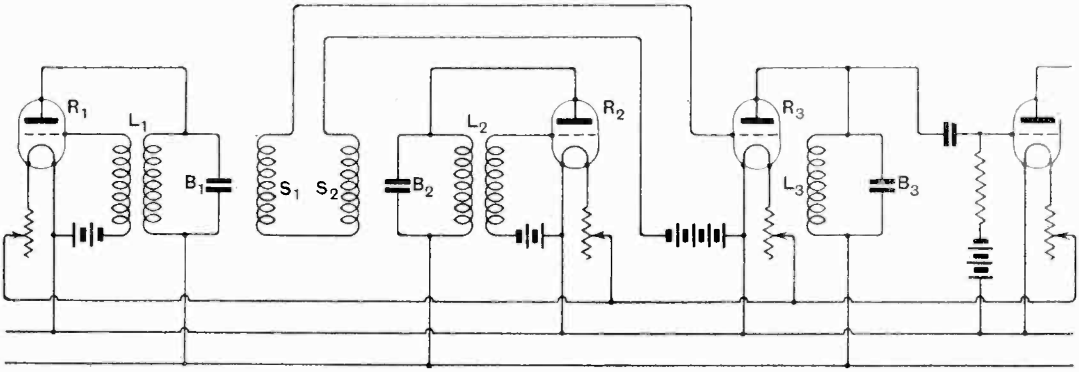
Discussion of the paper that appeared in *Proc. Inst. Radio Engineers*, of last February, pp. 99-111 (these Abstracts, *E.W. & W.E.*, May, 1927, p. 310).

DISCUSSION ON SIMPLIFIED S.L.F. AND S.L.W. DESIGN.—O. Roos. (*Proc. Inst. Radio Engineers*, 15, 4, April, 1927, pp. 319-326.)

Discussion on the paper that appeared in *Proc. Inst. Radio Engineers*, of December, 1926, pp. 773-780.

SUBSIDIARY APPARATUS AND MATERIALS.

TON FREQUENZ-WECHSELSTROMGENERATOR (Audio frequency alternating current generator.—G. Lubszynski. (*Telefunken Zeitung*, 8, 44, pp. 57-60.)



ÜBER MESSUNGEN AU PIEZO-ELEKTRISCHEN KRISTALLEN (Measurements with piezo-electric crystals).—K. Heegner (*Telefunken Zeitung*, 8, 44, pp. 60-63.)

Discussion of the measurement of the damping of an oscillating crystal.

CONTRIBUTION À LA REALISATION D'UN ETALON DE FAIBLE CAPACITÉ (Contribution to the production of a standard of small capacity.)—F. Bedeau (*L'Onde Electrique*, 6, January, 1927, pp. 19-46.)

Second part of an article begun in the December number of *L'Onde Electrique* (these Abstracts, *E.W. & W.E.*, March, 1927, p. 181), containing the third and last chapters on the cylindrical air condenser.

By superimposing two high frequencies and then rectifying, a note frequency is obtained equalling the difference of the high frequencies. In order to prevent these frequencies as well as the low frequency passing beyond the rectifier, a low frequency oscillatory circuit is inserted in the rectifier anode lead. The circuit arrangement is shown above :

LES HAUT-PARLEURS À GRANDE PUISSANCE DE L'EXPOSITION DE BERLIN (Powerful loud-speakers at the Berlin Exhibition.—(*Radio Revue*, May, 1927, p. 370.)

The most powerful of the German loud-speakers are the "Falz" and the "Blatthaller" types. The "Falz" is an electro-dynamic instrument in which the amplified microphonic currents traverse a thin strip of aluminium about 50 cm. long under the influence of a very powerful magnetic field. The strip thus becomes the seat of energetic vibrations, reproducing those of the speech or music, and communicating them directly to the surrounding air. The Blatthaller works on a similar principle: strips of copper which are traversed by the amplified currents and immersed in the field of a very powerful electro-magnet, are fixed to a membrane of "Pertinax," transmitting the vibrations to the surrounding air.

These loud-speakers are controlled by microphones which are in reality microphonic condensers. The condensers consist of a fixed plate pierced with holes, at a very small distance behind which there is an extremely thin sheet of aluminium. Vibrations of the voice cause the distance between the plates to vary and thus the capacity of the condenser. The condenser forms part of a high frequency circuit connected to the grid of a valve: the variations of capacity bring about variation of the high frequency current which is then detected by a second valve and subsequently amplified by a low frequency amplifier with seven valves, of which the last is a power valve.

COIL-DRIVEN LOUD-SPEAKER WITH PERMANENT MAGNETS. — H. Lloyd (*Wireless World*, 1st June, 1927, pp. 689-692.)

UN NOUVEL ISOLANT: "LA THIOLITE" (A new insulator: thiolite). — *Radio-Revue*, May, 1927, p. 376.)

Description of the properties of this new insulator, giving the following numerical data: resistivity 300×10^8 megohms/cm.; specific inductive power 4.5; dielectric loss at high frequency $C = 54 \times 10^{-6}$; dielectric rigidity—the true breakdown voltage for disc electrodes 1 mm. apart is given as 34 kilovolts.

THE LOGARITHMIC CONDENSER.—F. Haynes. (*Wireless World*, 18th May, 1927, pp. 621-626.)

L.T. AND H.T. SUPPLY FROM D.C. MAIN.—A. Robertson. (*E.W. & W.E.*, June, 1927, pp. 336-338.)

MISCELLANEOUS.

U.S.A. FEWER STATIONS ADVOCATED.—*Electrical Review*, 29th April, 1927, p. 683.)

According to *World Radio* a plan for the reduction of the number of broadcasting stations in the United States from 733 to 364 has been submitted by the American Engineering Council to the Federal Radio Commission. Under the scheme there would be 64 national stations and 300 local stations, the former operating in the band between 550 and 1,250 kilocycles, *i.e.*, from 240 to 545 metres, while the local stations would be confined to the range of from 1,250 to 1,500 kilocycles, or from 240 down to 200 metres.

BOLIVIAN TELEGRAPHS.—(*Electrician*, 6th May, 1927, p. 503.)

A contract has been made between Marconi's Wireless Telegraph Co., Ltd., and the Government of Bolivia, by which the company will undertake the control and operation of the postal, telegraph, and wireless services of Bolivia for twenty years. This is the second contract of this kind which the Marconi Company hold in South America, the first being with the Peruvian Government in 1921, since when the annual deficits have been converted into a substantial profit to the National Exchequer, amounting for the years 1924-1925 to 239,968 Peruvian pounds. Particular attention is to be paid to the development of wireless communication.

WIRELESS TELEGRAPH COMMUNICATION.—Lieut. Col. Chetwode Crawley. (*Electrical Review*, 15th and 29th April, and 13th May, 1927.)

A review of the present position of maritime safety services, commercial communication, and point-to-point telegraphy in view of the proposed modified requirements and regulations to be discussed at the International Conference to be held in the United States next autumn.

TRANSATLANTIC RADIO TELEPHONY.—R. Bown. (*Bell System Technical Journal*, April, 1927, pp. 248-257.)

An attempt to provide a *connected* story of how the final result was built up through several years of continued effort.

A NEW TALKING FILM SYSTEM.—A. Dinsdale. (*Wireless World*, 25th May, 1927, pp. 645-647.)

Description of a new system, with cinematograph and sound records on the same film, which has just been developed by a group of engineers belonging to the General Electric Company.

A SUCCESSFUL PUBLIC DEMONSTRATION OF TELEVISION BETWEEN WASHINGTON AND NEW YORK.—A. Dinsdale. (*Wireless World*, 1st June, 1927, pp. 680-686.)

AN ANALYSER FOR THE VOICE FREQUENCY RANGE. —C. Moore and A. Curtis. (*Bell System Technical Journal*, April, 1927, pp. 217-229.)

NOTE SUR UN SYSTÈME DE COMMUNICATIONS ELECTRIQUES SECRÈTES (Note on a system of secret electric communication).—J. Jammet. (*L'Onde Electrique*, 6, 63, March,, 1927, pp. 135-136.)

Reply to the criticism by M. Vincent, published in *L'Onde Electrique*, of November, 1926, of the secret system put forward by M. Jammet in *L'Onde Electrique*, of August, 1926.

Esperanto Section.

Abstracts of the Technical Articles in our last Issue.

Esperanto - Sekcio.

Resumoj de la Teknikaj Artikoloj en nia lasta Numero.

PROPAGADO DE ONDOJ.

RADIO-ESPLORADO DUM LA EKLIPSO.

Noto pri la observadoj farotaj dum la suna eklipso je 29a Junio.

PROPRECOJ DE CIRKVITOJ.

KLINA INDUKTECO.—C. R. Cosens.

Noto pri la efektiva indukteco de ferkernaj ŝokbobenoj aŭ transformatoj. La aŭtoro difinas *Klinan Induktecon* kiel la kvanton $\frac{\text{Ŝanĝo de Flur Turnoj}}{\text{Ŝanĝo de Kurento}}$ kiam la kurenta ŝanĝo estas malgranda kaj estas surmetita sur relative grandan kontinuan kurenton.

Post diskutado pri la A.K. indukteco de ŝokbobeno, oni montras, ke provoj de ĉi-tio ne montras eĉ proksimume la efektivan induktecon de la ŝokbobeno, kiam uzita je la anoda cirkvito de valvo. Poste estas priskribita metodo mezuri klinan induktecon. Per tiu metodo oni sendas kaj K.K. kaj A.K. tra la ŝokbobenon mezurotan, kaj tra rezistancon seriearanĝitan je ĝi. Kondensatoroj apartigas la A.K. fonton for de la bateria fonto, dum ŝokbobenoj en la lasta tenas malalte la alternan kurenton tra la baterio kaj miliampermetro. La A.K. voltkvantoj trans la ŝokbobeno kaj trans la rezistanco estas mezuritaj per valva voltmetro.

Diskutitaj estas metodoj fari la provon, rezultoj, k.t.p., dum aldonaĵo diskutas la eraron kaŭzitan pro malzorgo pri la efektiva bobena rezisteco.

MEM-INDUKTECO DE REKTAJ FADENOJ.—R. M. Wilmotte.

Oni montras, ke la desegno de ŝokbobeno por tre altaj frekvencoj (ekz., 10^7 aŭ 10^8 cikloj) fariĝas pli kaj pli grava. Por malgrandigi la efekton de memkapacito, la fadenoj devas esti spacigitaj, tiel ke la distanco inter fadenoj estas 200-oble pligranda ol la fadena diametro. En ĉi tiu okazo ne gravas, ĉu la fadeno estas streĉita laŭ rekta linio aŭ volvita laŭkutime. La mem-indukteco de cirkvito kaj la komuna indukteco inter ĝiaj partoj estas poste konsideritaj, diversaj esprimoj estante donitaj por L kaj M kaj por kapacito. Tabelo kaj (kurvo montras la induktecon kaj kapaciton dum la proporcia distanco/radiuso estas pligrandigita. Per tio, oni konkludas, ke la distanco de la diversaj partoj de la cirkvito devas esti proksimume 200-oble pli granda ol la diametro, kaj por fari ĉi tion en modera spaco oni devas uzi maldikan fadenon, kiel ekzemple, 47 S.W.G. Je ondolongoj de nur kelkaj metroj oni trovos, ke estas tre oportune uzi nur rektan pecon de fadeno de 47 S.W.G., kiu havas la aldonan avantaĝon, ke ĝi bone apartigas la bornojn.

MEZUROJ KAJ NORMOJ.

LA GÛSTA KAJ PRECIZA MEZURADO DE ONDOLONGO ĈE RADIO-SENDADAJ STACIOJ.—Raymond Braillard and Edmond Divoire.

La aŭtoroj estas respektive Prezidanto kaj Sekretario de la Teknika Komisiono de la *Union Internationale de Radiophonie*.

La artikolo unue diskutas la malfacilecon de komuna interfero de du brodkastaj stacioj kaj la ĝeneralan aferon de altfrekvenca precizeco kaj konstanteco. La ordinara ondometro, oni diras, suferas pro la difektoj de du vastaj ondgrupoj, malkonstanteco de normigado, tro alta amortizo, kaj manko de ŝirmado kontraŭ elektrostatikaj efektoj. La Teknika Komisiono de la U.I.R. do decidis (*a*) studadi novan ondometron, precizan, stabilan, kiu ampleksos tre mallarĝan grupon ĉirkaŭ la funkcia frekvenco, kaj ekipi ĉiun stacion per unu ondometro, (*b*) produkti ĉi tiujn amase, (*c*) normigi ĉiujn ondometrojn en unu laborejo ekipita per unusola frekvenca normo.

La cetero de la nuna parto poste traktas pri priskribo de la ondometro.

La multobla paralela-plata tipo de kondensatoro estis reĵetita, kaj oni decidis adopti kondensatorojn faritajn plejparte el du koncentraj cilindroj. Oni donas matematikan konsideradon pri la evoluigo. La fiksaj kaj varieblaj kondensatoroj estas formitaj en la unu sama organo, la platoj estante koncentraj cilindroj kun la ekstera cilindro kovrita. Oni obtenas kapacitan variadon per movo de du kvadrantoj de cilindroj (apartaj 180°, kaj konektitaj elektre al la ekstera cilindro), kiuj movas rilate al du aliaj kvadrantoj, kiuj estas plilongigaĵoj de la interna cilindro. La induktanco estas bobeno de nuda kupra fadeno, subtenita de ses izolantaj strioj, kiuj formas la facetojn de sesangula prismo. La indikatora cirkvito estas unuobla turno de latuna strio funkciiganta resonancan indikatoron je la formo de inkandeska lampo aŭ termokuplo.

La nuna parto finiĝas per diskutado pri la plej bona proporcio de indukteco je kapacito.

RICEVADO.

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

Daŭrigita el antaŭa numero.

En la nuna parto la aŭtoro daŭrigas konsideradon pri la ekvilibro de la enmeta (detektora oscilatora) cirkvito, kaj pri la ĝenerala aranĝa metodo de ĉi tiu cirkvito. La ĝenerala aranĝo de la kompleta aparato estas poste montrita, inklusive la aranĝon refleksi du el la interaj frekvencaj valvoj, por ke ili ankaŭ funkciu je aŭd-frekvenco. La intera frekvenco uzita estas ĉirkaŭ 100 kilocikloj (3,000 metroj), kun varieblaj kondensatoroj ĉe ĉiuj I.F. transformatoroj, tiel ke, por longaj ondoj, la unua valvo ĉesas oscili, kaj la I.F. amplifikatoro estas uzita senpere kaj agordita al la signalo.

La aŭtoro poste konsideras la diversajn cirkvitojn detale, kun tre kompletaj notoj pri iliaj elektraj dimensioj. Li montras aranĝojn por uzi unuoblan k.k. instrumenton kiel filamentan voltmetron kaj anodan miliampermetron por ĉiu valvo. La detala desegno de la enmeta cirkvito estas diskutita kaj ilustrita, sekvita de simila traktado pri la interfrekvenca amplifikatoro kaj refleksaj cirkvitoj.

La artikolo estas daŭrigota.

MALALT-TENSIA KAJ ALT-TENSIA PROVIZADO PER K. K. ĈEFTUBOJ.—A. Robertson.

La aŭtoro montras tri-valvan ricevilon konektitan al aranĝo por obteni altan tension kaj krad-potencialon pere de 250-volta kontinukurenta provizado, kie la pozitiva flanko de la sistemo estas terigita.

Oni ilustras diversajn alternativajn aranĝojn konektajn, kun rimarkigoj de la aŭtoro pri iliaj respektivaj efikecoj glatigi zumadon.

VALVOJ KAJ TERMIONIKO.

SENFADENAJ SENDAJ VALVOJ.

Resumoj de tri prelegoj legitaj antaŭ la Senfadena Sekcio de la Institucio de Elektraj Inĝenieroj, Londono, je la 4a Majo, kaj de la ĝenerala diskutado, kiu sekvis la legadon de la prelegoj.

La prelegoj estis :—

1. La Demuntebla Valvo "Holweck," de C. F. Elwell, M.I.E.E.

2. Silikaj Valvoj je Senfadena Telegrafio, de H. Morris Airey, C.B.E., M.I.E., G. Shearing, B.Sc., M.I.E.E., kaj H. G. Hughes, M.Sc.

3. Valvoj kun Malvarmigitaj Anodoj, kaj Vivoj de Sendaj Valvoj, de W. J. Picken, A.M.I.E.E.

La unua prelego mallonge priskribas la Holweck Molekula Pumpilo, kaj demuntebla speco de valvo uzita kun ĝi, la vakuo estante konservita per funkciigo de la pumpilo.

La dua prelego priskribas silikajn valvojn, kiel estas uzitaj je Brita Marista Senfadena Telegrafio, ilustrante metodojn por fiksi en elektrodaj konduktoroj, ĝeneralan konstruadon kaj taksadon, kaj lastatempe evoluigitan metodon de anoda malvarmigado per cirkulado.

La tria prelego unue priskribas valvojn kun malvarmigitaj anodoj, fabrikitajn de la Marconi-Osram Valva Kompanio, kun detaloj pri ilia konstruado kaj taksado. La lasta parto de la prelego traktas pri la vivo de sendaj valvoj, la detaloj donitaj estante plejparte por valvoj de la radiada speco.

Presitaj ankaŭ estas la ĝenerala diskutado kaj la respondoj de la aŭtoroj.

DIVERSAĴOJ.

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.

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

Daŭrigita el antaŭaj numeroj. La nuna parto traktas pri la cirkla mezurado de anguloj ; areo (de triangulo, paralelogramo, cirklo, k.t.p.) ; vektoroj ; la adicio de vektoroj ; la multobligo de vektoro per numero ; operatoro kaj operando ; unuo-vektoroj ; la skala produkto de vektoroj, k.t.p.

LIBRA RECENZO.

Oni donas recenzon pri la verko *Wireless Loud Speakers* (Senfadenaj Laŭt-paroliloj), Praktika Manlibro priskribanta la Principojn de Funkciigo, Funkciado, kaj Desegnado. De N. W. McLachlan, D.Sc., M.I.E.E. Eldonita de Illiffe & Sons, Ltd., Londono, eldonistoj de *Experimental Wireless*.

"A Fine British Magazine."

"It is disappointing to note that one of the best British technical journals, EXPERIMENTAL WIRELESS AND THE WIRELESS ENGINEER, published in London by Iliffe & Sons, has been compelled to raise its subscription price to two shillings and sixpence per copy on account of 'lack of support by English advertisers.' Without a doubt if Iliffe & Sons are compelled to pass the hat to keep this magazine going, they will receive strong support from American engineers, for this paper is without a peer as an organ for serious engineers and experimenters. In England a research is undertaken, it seems, with the love of pure science in the investigator's heart and not with one hand tied by production department threats. The English may pursue roundabout methods, but the end point is final and the answer is complete. No American deeply interested in radio science can afford to be without EXPERIMENTAL WIRELESS, even were the price raised to five or six 'bob' per month."—*Radio Broadcast, U.S.A.*

Readers, Please Note.

Our Publishers have asked us to inform readers that arrangements are being made to limit the supply of copies of EXPERIMENTAL WIRELESS to newsagents or bookstalls to those actually ordered, and as a result copies will not in future be available to *occasional* purchasers.

In order therefore to ensure obtaining their copies regularly, will readers please adopt one of the following courses: (1) Give a *definite* order to a newsagent or bookstall for a regular monthly copy, or (2) Send a subscription direct to the Publishers.

Two order forms will be found in this issue, one directed to the Newsagent and the other to the Publishers, and it will be greatly appreciated if readers will make use of whichever of these best suits their requirements.

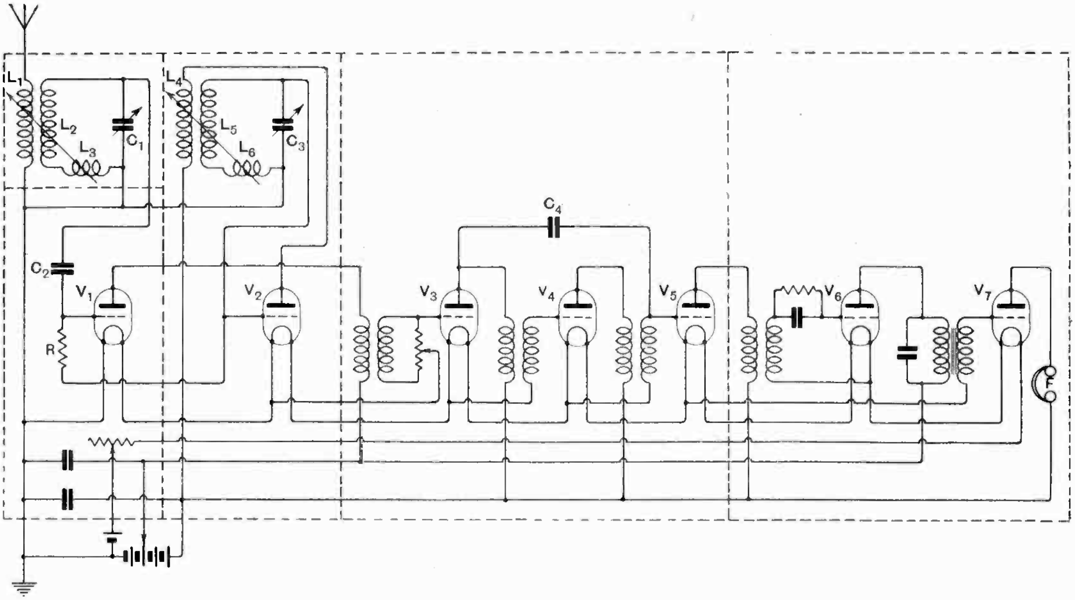
Some Recent Patents.

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 SUPERHETERODYNE RECEIVER.

(*Application date, 18th December*, 1925. *No.* 267,617.)

A superheterodyne receiver utilising a particular form of circuit arrangement and incorporating some rather novel connections is described by Standard Telephones and Cables, Limited, in the above British Patent. The object of the invention is to provide a receiver in which the alteration of the tuning, either of the input circuit or the local oscillator shall have no mutual effect. This is accomplished by using the arrangement shown in the accompanying diagram, the dotted portions representing what may be screened sections. The aerial circuit comprises a variable inductance L_1 coupled to a fixed inductance L_2 and a variable inductance L_3 tuned by a condenser C_1. This is connected to the grid of the first detector valve V_1 through a condenser C_2 in the normal manner. The oscillator valve V_2 is connected in the usual manner, and comprises an inductance L_4 coupled to a grid circuit consisting of a fixed inductance L_5 and a variable inductance L_6 tuned by a condenser C_3. The grid of the oscillator valve V_2 is connected to the grid of the detector valve through a resistance R of about 2 megohms. This resistance R acts partly as a grid-leak to the detector valve, and partly as a means of transferring the oscillations to the detector valve from the oscillator. The remaining portion of the circuit will not be described in detail, as it is more or less normal. The output of the detector valve is coupled through a transformer T_1 to the grid circuit of the first amplifier, the magnitude of the applied potentials being controlled by a potentiometer P in the usual way. The valves V_3, V_4 and V_5 act as intermediate amplifiers, while the valve V_6 is arranged as a second detector. The specification states that the

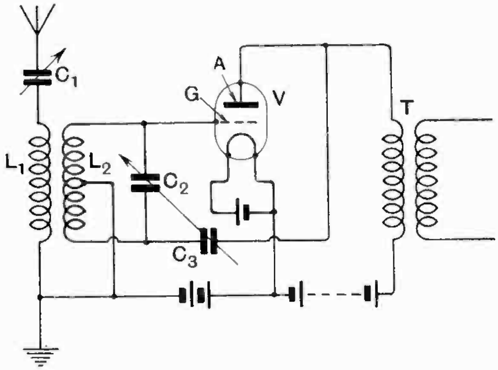


receiver thus arranged gave bad quality, probably due to the fact that certain portions of the intermediate amplifier were resonant. This was overcome by the introduction of a small condenser C_4 between the anode of the valve V_3 and the grid of the valve V_5, thus producing a non-regenerative effect. This condenser, of course, must not be too large, or it will lower the amplification considerably. The output of the second detector is passed through a low frequency transformer to the final valve V_7, the anode circuit of which contains the telephones F.

VARIABLE NEUTRALISATION.

(*Application date, 3rd June*, 1926. *No.* 269,355.)

A circuit for the purpose of varying the amount of neutralisation, and one incorporating a special form of condenser construction is described by Standard Telephones and Cables, Limited, in the above British Patent. It is pointed out that the ordinary neutralising condenser may be adjusted so that exact capacity neutralisation is obtained, or, alternatively, over or under neutralisation. It is further stated that it frequently happens that maximum selectivity and signal strength is obtained

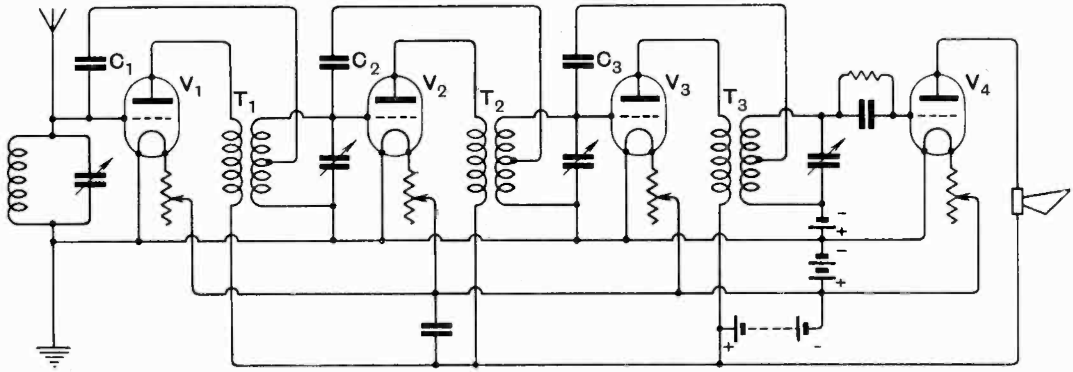


when a slight degree of regeneration is present, that is, the circuit may be over neutralised, or under neutralised, as the case may be. If the circuit is exactly neutralised the value of the neutralising condenser remains substantially constant throughout the whole frequency range of the tuned circuit, whereas, when a certain amount of regeneration is desired, the value of the balancing condenser has to be varied in accordance with the variation of the tuning condenser. According to the invention, however, the two condensers are mechanically combined, and one circuit arrangement adopting this principle is shown in the accompanying diagram. Here the aerial is tuned by a condenser C_1 and an inductance L_1. This is coupled to an inductance L_2 tuned by a condenser C_2. The mid point of the inductance L_2 is connected to the filament and earth, while one end is taken to the grid G of the valve V, and the other end is taken through a variable balancing condenser C_3 to the anode A. The anode circuit is shown to contain the primary of a transformer T. The tuning condenser C_2 and balancing condenser C_3 are nechanically linked so that any variation of the tuning condenser effects a desired change in the balancing condenser. A further feature of the invention is the construction of a variable condenser with a separate insulated plate working in conjunction with another plate on the rotor of the main tuning condenser so that the balancing condenser is constituted by these elements.

CONSTANT AMPLIFICATION.

(*Convention date* (*S.A.*), 10*th October*, 1925. *No.* 259,613.)

Another Hazeltine neutralised circuit is described in the above British Patent Specification by Hazeltine Corporation and W. A. MacDonald. In dealing with neutralised amplifiers the specification mentions that in any particular stage of amplification there is a frequency at which the amplification will be a maximum dependent upon the relation between the inductance and capacity present in the tuned circuit when associated with its particular valve and also the mutual inductance between primary and secondary. In the case of a multi-stage receiver of this type using similar transformers this frequency of optimum amplification is usually the same for each stage. Since the amplification rises in geometric progression it follows that the resultant amplification in a multi-valve amplifier at this optimum frequency will be very much greater than over the whole frequency band for which the amplifier is desired to function. Accordingly, an amplifier is constructed so that the optimum amplification occurs at a different frequency in each stage. This will, therefore, have the effect of levelling the total amplification over the entire band. The accompanying illustration shows a suitable circuit which will be described briefly. Valves V_1, V_2 and V_3 act as radio-frequency amplifiers, while the valve V_4 is used as a detector. The successive stages are coupled respectively by transformers T_1 T_2 and T_3. These are of the tapped secondary neutrodyne type, neutrodyne condensers C_1, C_2 and C_3 respectively being connected between the tapping point on the secondary and the grid of the preceding valve. The three transformers are

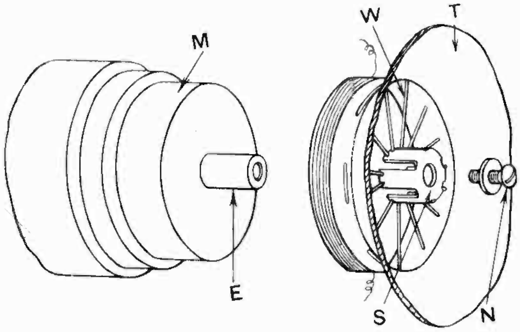


tuned by separate condensers, and the transformers are so constructed that the optimum amplification frequency is different for each stage. Since the remainder of the circuit is normal it will not be described in further detail.

RICE-KELLOGG DETAILS.

(*Convention date (U.S.A.), 9th January,* 1925. *No.* 245,796.)

Some further details of the Rice-Kellogg type of speaker are given in the above Specification by The British Thomson-Houston Company, Limited, C. W. Rice, and E. W. Kellogg. Readers are, no doubt, familiar with the broad principle of the Rice-Kellogg speaker, which has already been given in these columns, but the present invention

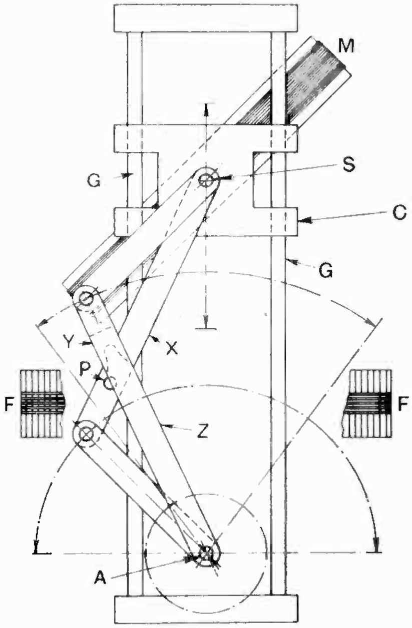


relates to certain modifications which are of considerable importance. As the general principle of the speaker is therefore well known, certain minor points only will be illustrated. The present specification relates chiefly to the method of supporting the cone. The cone *C* is of rigid material, and is fixed to an annular support by means of a ring *R* of some flexible material such as thin rubber or silk. The specification points out that it is necessary that the restoring force on the diaphragm should be such that the natural frequency is very low, and preferably of the order of about 50 cycles, although it is mentioned that satisfactory results can be obtained with a natural frequency as high as 200 cycles. Owing to the very light nature of the flexible suspension of the edge of the diaphragm care has to be taken that the truncated end supporting the coil drive shall not touch the magnetic poles, and a special form of suspension is therefore adopted. The end of the circular magnet pole *M* is provided with an extension *E* to which is fixed a spider *S* by means of a screw and washer *N*. The truncated end *T* of the cone is fixed or laced to the spider by means of wires or strings *W*. This, it is stated, enables the cone to move with a plunger action without any transverse motion occurring. The specification contains a considerable amount of important information regarding sizes and angles of cone, and details of many other interesting points, far too numerous to deal with in a limited space. Readers who are particularly interested in this type of speaker are referred to the specification for greater detail, as it appears to be of very considerable importance. For example, the necessity of not enclosing the air behind the diaphragm is dealt with. If this is done "box resonance" occurs. Another important point is the inclusion of a short circuited turn or ring round the end of the pole piece to act as a "smoothing device" against any fluctuations which may occur in the field winding should it be supplied from rectified alternating current, or be affected by commutator ripple in a D.C. supply.

VARIABLE COUPLING.

(*Application date, 22nd January,* 1926. *No.* 269,668.)

A form of variable coupling particularly suitable for transmitting inductances is described by J. K. im Thurn and G. W. Harris in the above British Patent. The arrangement should be almost self explanatory. The fixed coil is shown at *F*, while the movable coil is shown at *M*. This is mounted on a shaft *S* fixed to a carriage *C* working on vertical guides *G*. The end of the shaft *S* is provided with a link motion actuated by a spindle *A*. It will be seen that rotation of the spindle *A* will cause the link motion to make the coil *M* rotate on the carriage *C*, and simultaneously cause the carriage to move upwards or downwards according to the direction of rotation of the spindle. As the farthest point of travel of the coil *M* is approached a pin *P*



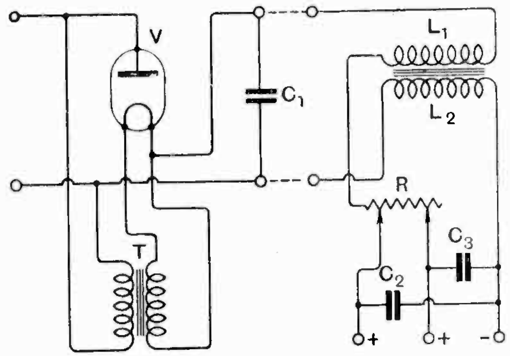
in the link arm *X* engages a guide plate *Y* on the link arm *Z*, and carries it over the top dead centre in a direction depending upon the rotation of the spindle *A*.

A SMOOTHING CIRCUIT.

(*Application date, 2nd March,* 1926. *No.* 267,701.)

A smoothing circuit for use with a valve rectifier, in which the choke elements are arranged in an unusual manner is described in the above

British Patent by W. Diggle in the above specification. The filament of the rectifying valve V is heated from the secondary winding of a transformer T connected with the main A.C. supply. The supply is connected to the rectifier in the usual

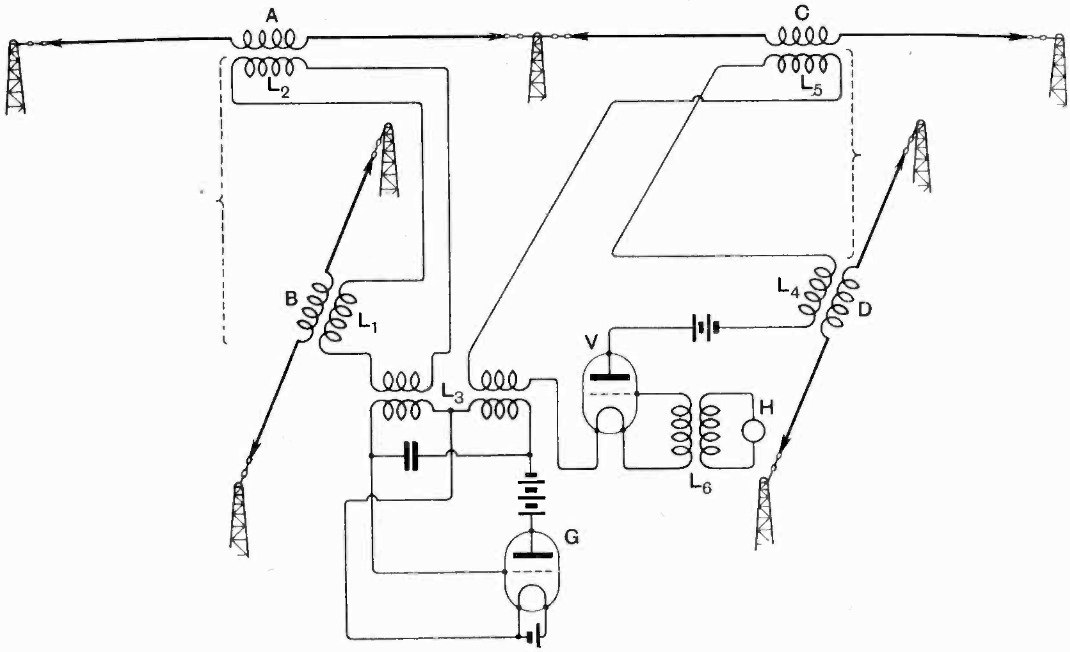


manner, and an integrating condenser C_1 is connected before the chokes. The remainder of the filter circuit is constituted by another condenser C_2 across two chokes L_1 and L_2 in each lead respectively. These two chokes are coupled together and are wound on the same core. An intermediate voltage is derived through a series resistance R and a shunt condenser C_3.

SHORT WAVE TRANSMISSION.

(*Convention date (Germany), 1st October*, 1925. *No.* 259,226.)

A system of short wave transmission designed to overcome fading, skipped distance, and similar troubles is described in the above British Patent by Telefunken Gesellschaft für Drahtlose Telegraphie, M.B.H. The invention consists essentially in the superimposition of two circularly polarised waves whose mutual phase relationship is periodically changed. A very detailed explanation of what probably happens in the case of these undesired effects, and the manner in which the present invention functions is given in the specification. Essentially the arrangement shown in the invention shows four aerials, A, B, C and D. Aerials A, B and C, D are respectively arranged a quarter of a wavelength apart. These are fed by a short wave generator G connected in the normal manner. Aerials A and B are fed through a series link arrangement L_1, L_2 and L_3, while aerials C and D are fed through another link arrangement, L_4, L_5 and L_6, the inductances being respectively coupled to appropriate aerial coils and coils in the generator circuit. In series with the link feed L_4, L_5, L_6 is a valve V. The grid circuit of this is energised by a source of oscillation H which periodically interrupts the feeds to the aerials C and D.



Such an arrangement results in periodic mutual phase change between the superimposed circularly polarised waves. The specification indicated how the various constants may be calculated.

PREPAID PARAGRAPH ADVERTISEMENTS.

The charges for prepaid advertisements are as follows:—

AUCTIONEERS' & OFFICIAL ANNOUNCEMENTS.—*Advertisements under this heading are inserted at a charge of 11s. per single column inch.*

TRADE & MISCELLANEOUS.—*2s. for 12 words and 2d. for each additional word.*

PRIVATE SALE & EXCHANGE.—*Advertisements are inserted in this section at the rate of* One Penny *per word · minimum charge per advertisement* One Shilling. *All advertisements, without exception, must be prepaid to ensure insertion. Single letters or figures are charged as words, and a compound word as two words. The advertiser's name and address are charged for.*

"Box" replies, *care of these offices, are charged 6d. extra to cover postages. The following words must appear at end of advertisement: "Box——* EXPERIMENTAL WIRELESS *Offices," for which usual rate will be charged. (Advertisers need not include our full address.)* When replying to a "Box No." advt., *address your envelope: Advertiser, Box ——,* EXPERIMENTAL WIRELESS & WIRELESS ENGINEER, *Dorset House, Tudor Street, London, E.C.4.*

Advertisers who wish to separate *their announcements into distinct paragraphs must have not less than 12 words in any one paragraph, followed by the word "Below"—which is charged for.*

Remittances should be made by Postal Order or Stamps, and sent to the Advertisement Manager, EXPERIMENTAL WIRELESS & WIRELESS ENGINEER, *Dorset House, Tudor Street, London, E.C.4.*

PRESS DAY.—EXPERIMENTAL WIRELESS & WIRELESS ENGINEER *is published on the first of each month, and copy for advertisements should reach the Advertisement Manager, Dorset House, Tudor Street, London, E.C.4, not later than first post on the 16th of the month preceding.*

COPY FOR ADVERTISEMENTS *is subject to the approval of the Proprietors, who retain the liberty to withhold any advertisement which they regard as unsuitable for publication in this journal. The Proprietors are not responsible for clerical or printers' errors, although every care is taken to avoid mistakes, nor will they accept responsibility for any blocks left in their possession for a period of more than 12 months.*

ORDERS & CHEQUES *should be made payable to* ILIFFE & SONS, LTD., *and crossed "and Co." Treasury Notes, being untraceable if lost in transit, should not be sent as remittances.*

ALL ADVERTISEMENTS MUST BE PREPAID.

OUR DEPOSIT SYSTEM.

We will receive from intending purchasers the purchase money of any article advertised or sold by our advertisers, and will acknowledge its receipt to both the Depositor and the Vendor, whose full names and addresses must be given. Unless otherwise arranged beforehand between the parties, it is understood that all goods are sent on approval, and that each person pays carriage one way if the goods are returned. The deposit is retained by us until we are advised of the completion of the purchase, or of the articles having been returned and accepted. In addition to the amount of the deposit, a fee of 1s. for the sum of £1 and under, and 1s. 6d. for amounts in excess of £1 to cover postage, etc., must be remitted at the same time, and sent to the Advertisement Manager, EXPERIMENTAL WIRELESS & WIRELESS ENGINEER, *Dorset House, Tudor Street, London, E.C.4. In cases of persons not resident within the United Kingdom, double fees are charged.*

The fee should be sent in Stamps or by Postal Order as a separate amount.

The amount of the deposit must be sent either by Postal Order or Registered Letter. (Cheques cannot be accepted.)

In cases of exchanges, money to the value of the article should be deposited by each party. We cannot receive the articles themselves.

PATENT AGENTS.

A. P. Thurston, D.Sc., M.I.A.E., F.R.Ae.S., 369, High Holborn, W.C.1. Phone: Holborn 2542. Patents, Trade Marks, Designs. [0122

Patents and Trade Marks—British and Foreign—Gee & Co., (H. T. P. Gee, Member R.S.G.B., and A.M.I.R.E.) —51-52, Chancery Lane, London, W.C.2. 'Phone: Holborn 1525. [0139

For Wireless Students and Research Workers!

The following are a few of the books published by the proprietors of "Experimental Wireless," intended for the use of advanced wireless students, wireless engineers and research workers. A complete list will be sent on request.

"Wireless Valve Transmitters." *By W. James.* This is the first and only practical book on Transmitting. It thoroughly covers the subject, and each component is treated in detail.
Price **9/-** net. By post, **9/6.**

"Calculation and Measurement of Inductance and Capacity." *By W. H. Nottage, B.Sc.* The more generally useful formulæ and methods of measurement of inductance and capacity are here brought together in convenient form.
Price **7/6** net. By post, **8/-.**

"The Thermionic Valve and its Development in Radio Telegraphy and Telephony." *By J. A. FLEMING, M.A., D.Sc., F.R.S., etc.* A brilliant exposition of the theory and development of the Thermionic valve by one of the most eminent men in the wireless world.
Price **15/-** net. By post, **15/6.**

"Thermionic Tubes in Radio-Telegraphy and Telephony." *By JOHN SCOTT-TAGGART, F.Inst.P., A.M.I.E.E.* A very full and valuable contribution to wireless literature. Of particular interest to the advanced wireless worker.
Price **15/-** net. By post, **15/9.**

Obtainable from all booksellers, or direct from the publishers:

ILIFFE & SONS LTD., Dorset House, Tudor Street, LONDON, E.C.4.

"Croft"

Q. S. L. CARDS

are in circulation throughout the world, giving to the users just that touch of unobtrusive dignity which is so desirable. Why not engage them to be YOUR emissaries into other climes and situations. The cost of these smart little messengers is negligible.

100 **7/6,** 250 **11/9,** 500 **18/-**

Carriage paid in U.K.

Samples will be immediately forwarded on request.

APPLEBY RADIO ENGINEERS

Postal Section

THE CROFT, Willesden, LONDON, N.W.10

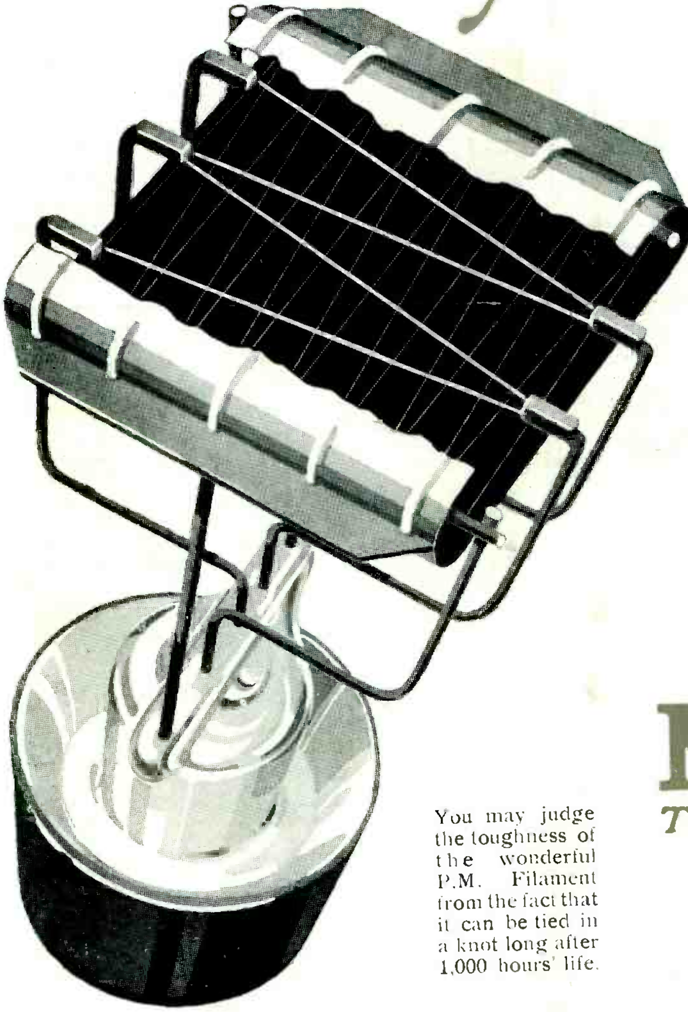
THE ABC OF THE Super-Het 8d POST FREE

88 pages, 17 designs, diagrams or large photographs, including complete schematic and point to point wiring charts of the best Supersonic receiver (cheap to build) yet designed. No guesswork—works well at once. Only book of its kind at present in existence. Described by "Wireless World" as "A fascinating booklet . . . A lucid description of the operation of the Super-Het."
CLAUDE LYONS (G.R. Quality Parts) (Dept. X.), 76, Oldhall St., Liverpool.

INDEX TO ADVERTISERS.

BUYERS' GUIDE.

In any valve it's the FILAMENT *you pay for!*



Remember when you buy radio valves that the life of any valve is not one minute longer than the life of its filament and that upon the performance of the filament depends the results you obtain. Therefore demand :

A LONG FILAMENT . . . a filament with huge proportions, to secure a gigantic emission and the best operating characteristics.

A STRONG FILAMENT . . . a filament that cannot be broken except by the very roughest handling.

A PROVED FILAMENT . . . a filament that has a published National Physical Laboratory Test Report that proves its life and power to be constant and lasting.

Be safe and satisfied. Demand

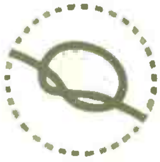
THE WONDERFUL MULLARD P.M. FILAMENT

Obtainable only in Mullard P.M. Valves from all radio dealers.

You may judge the toughness of the wonderful P.M. Filament from the fact that it can be tied in a knot long after 1,000 hours' life.

Mullard

THE · MASTER · VALVE



THE MULLARD WIRELESS SERVICE CO., LTD., MULLARD HOUSE, DENMARK STREET, LONDON, W.C.2

Printed for the Proprietors, ILIFFE & SONS, Limited, Dorset House, Tudor Street, London, E.C.4, by VACHER & SONS, Ltd., Westminster House, Great Smith Street, London, S.W.1.
Sole Agents for Australasia—GORDON & GOTCH (AUSTRALASIA), Ltd.
Sole Agents for South Africa—CENTRAL NEWS AGENCY, Ltd.