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# Editorial

## Some New Methods of Measuring Magnetic Field Strength

THERE are numerous ways of measuring the strength of the magnetic field at any point in air, e.g., the ballistic galvanometer connected to a search coil which can be reversed or withdrawn; the bismuth spiral which undergoes a change of resistance dependent on the strength of the magnetic field; the magnetic balance, in which the force on a current-carrying coil is weighed; the magnetronic diode, in which the field affects the electron current through the bulb: the braking effect due to eddy currents in a rotating disc; and several other methods involving effects which are not much used in practice. After enumerating these various methods in a recent number of the Journal of Scientific Instruments (October, p. 335). Groszkowski points out their disadvantages, especially if it be required to measure relatively weak fields in confined spaces. He then describes a new method, by means of an ingenious device which he calls a vibration magnetometer, in which a rectangular coil 1 cm. wide and about 5 cm. long, wound with, say, 50 turns, is placed with one of its short sides in the field to be measured with the plane of the coil normal to the field. If the coil is now moved rapidly to and fro lengthwise in its own plane, an e.m.f. will be induced in it depending on the value of B, the length of the short side of the coil, the number of turns, and the velocity of movement. If the coil side is 1 cm. and the length of travel 1 cm., the value of B measured will be the mean over this square centimetre to a high degree of approximation. In the actual apparatus described the coil is driven by an eccentric mechanism connected by means of a Bowden wire to a small synchronous motor supplied from the mains. The frequency and travel of the coil are thus maintained constant and the only variable is B in the air space being explored. The small e.m.f. induced is an approximately sinusoidal one of 25 cycles per second, and it is amplified in a two-stage tuned amplifier and then read on a voltmeter of the metal rectifier type. By a series of potential dividers on the input and output of the amplifier, nine ranges can be obtained, the most sensitive being suitable for values of B up to 3 gauss and the other extreme for B up to 30,000 gauss.

To allow for any change in the magnification of the amplifier, due, say, to change of supply voltage, a calibrating permanent magnet is employed and the sensitivity of the amplifier adjusted by means of a variable resistance in one of the anode circuits until the correct reading is obtained.

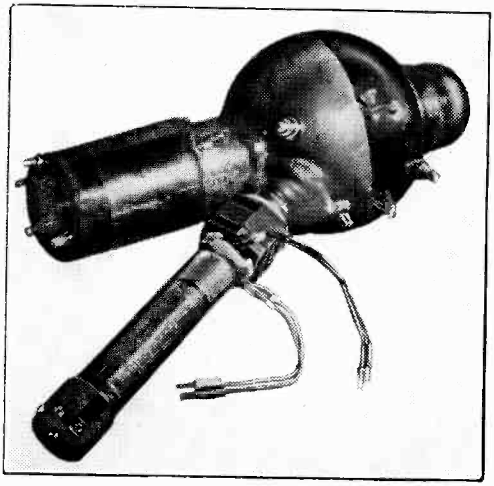
Another method working on an entirely different principle was described by H. Boucke in the June number of the *Archiv* *für Technisches Messen.* If a very small coil is wound on an iron core its self-induction will be affected if it be placed in a steady magnetic field, and the decrease of inductance may be used as a measure of the strength of the magnetic field. Unfortunately the presence of the small iron core distorts the magnetic field which it is desired to measure, and to overcome this to some extent the author proposes the use of iron powder cores which have a permeability of from 10 to 12 when not subjected to a magnetic field; in strong fields the permeability falls to 2 or 3. The coil is necessarily very small and consequently has an inductance of only a few microhenrys. After much experimenting the coils finally adopted were disc-shaped toroids with a thickness of 1.5 mm. and an overall diameter of 6 mm. With such a coil it is, of course, impossible for the steady magnetic field to have the optimum direction for affecting the self-induction, but this disadvantage is counterbalanced by the obvious advantages of a toroidal coil with its absence of stray flux.

An accurate measurement of the very small self-inductance variations is no easy matter. A high-frequency bridge working at a frequency of 6 megacycles per second was not found satisfactory and was discarded in favour of methods depending on the change of frequency in valve oscillators in which the coil was inserted in the oscillatory circuit. Resonance was obtained in a high-quality loosely coupled tuned circuit provided with a valve voltmeter. When the coil was inserted in the magnetic field the frequency of the generated current underwent a change and the departure from resonance was indicated on the valve voltmeter; resonance was then restored by adjustment of the capacitance of the secondary circuit, the amount of this adjustment being a measure of the strength of the field. Want of linearity at low values of B makes the model described unsuitable for values below 100 gauss. The principal disadvantage of the method is the distortion of the field which is being measured, which tests with a coil 1.5 mm. thick and 2 sq. cm. area showed to be sufficient to cause errors of 10 to 20 per cent. The method, as the author admits, is obviously quite unsuitable for absolute measurements, but is an interesting application of incremental permeability.

G. W. O. H.

## New Television Camera at Alexandra Palace

IN the Super-Emitron camera, a description of which appeared in *The Wireless World* for November 18th, 1937, the image is focused upon a photo-emissive screen mounted at one end of the tube. This screen consists of a glass plate coated with a semi-transparent layer of cæsium on silver-oxide on silver. The emitted electrons form an electron-image which is accelerated towards a mosaic screen at the other end of the tube by a positive electrode, and is focused upon it by a magnetic field. Each electron striking an element of the mosaic causes it to emit several secondary electrons. The mosaic is scanned by a cathode-ray beam in the same way as in the older camera. In the latter, however, the mosaic is of photo-emissive material, and the separation of the photo-emissive and mosaic screens in the new camera enables much higher sensitivity to be secured owing to the electron multiplication obtained.



*A view of the tube used in the E.M.I. Super-Emitron camera. The deflecting coils can be seen around the neck of the lower cylinder containing the cathode-ray gun.*

# A Two-Stage Oscillograph Amplifier*

By Christopher Dykes, B.A.

**SUMMARY.**—An inexpensive amplifier is described, to give an amplification of the order of $10^6$, over the frequency range of 10 — $10^4$ c/s. An output of 300V peak swing is available, which may be more than doubled in push-pull working. The amplifier is driven from a mains unit, so arranged that two amplifiers may be worked off the same source without mutual interference.

NOW that cathode-ray equipment forms a part of many laboratories, there is available ample literature dealing with time bases and other apparatus associated with cathode-ray work, but there seems to be little published information on amplifiers with high voltage output. When photographing transient phenomena, the gun voltage is usually increased to the maximum permissible to produce as bright an image as possible, but then the picture is apt to become unreasonably small. An output of 300 volts peak swing may be obtained from one valve, and about 700 volts if push-pull working is resorted to. The smaller figure gives a picture of reasonable size, and the total cost of the apparatus has thus been kept within the nominal figure of £5.

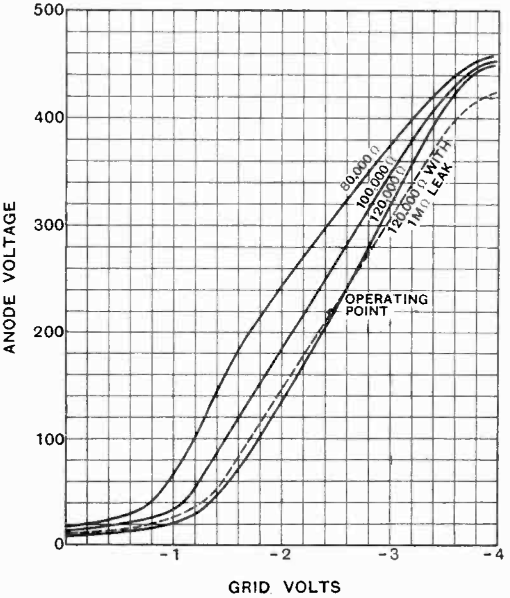


Fig. 1.—*Osram MSP4. Dynamic characteristics for various load resistances. Supply voltage 480 V.*

By experimenting with valve manufacturers' curves it was found that the Osram MSP4 valve could be made to give a very high undistorted voltage output in relation to its anode voltage. The valve is an indirectly heated high frequency pentode, rated at 200 volts maximum anode potential. Provided the anode current is limited, however, the valve is not seriously " over-run " when worked at an anode potential up to 250 volts, which considerably increases the output obtainable. The supply voltage is 480V., derived from a " C " class rectifier, the Osram U14. The value of anode load for maximum output is critical; Fig. 1 gives dynamic characteristics obtained with anode loads of 120,000 ohms, 100,000 ohms, and 80,000 ohms, from which it will be seen that the optimum load value is 100,000 ohms. In practice, however, there is a leak of

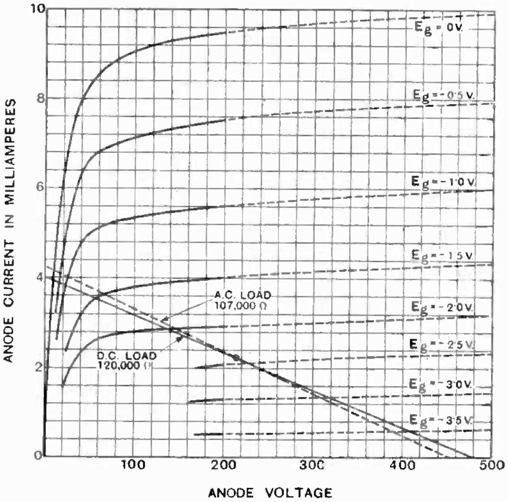


Fig. 2.—*Manufacturer's valve curve for Osram MSP4.*

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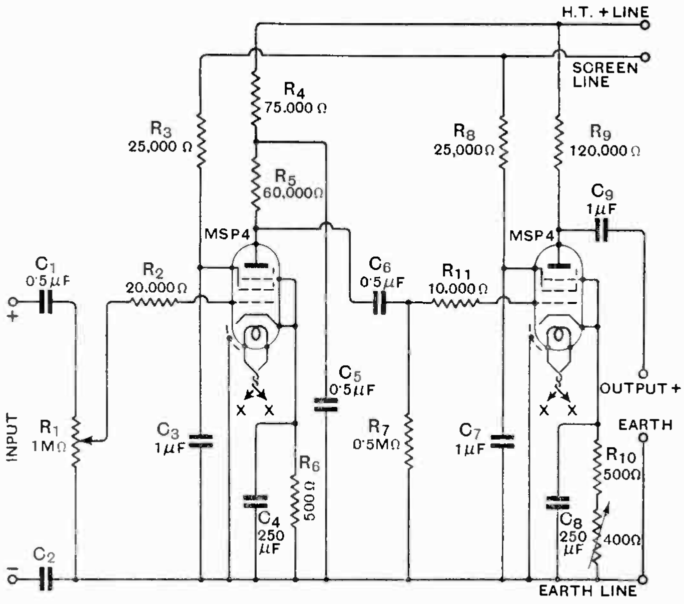
* MS. accepted by the Editor, October, 1936. Delay in publication has been caused by the author's absence abroad.

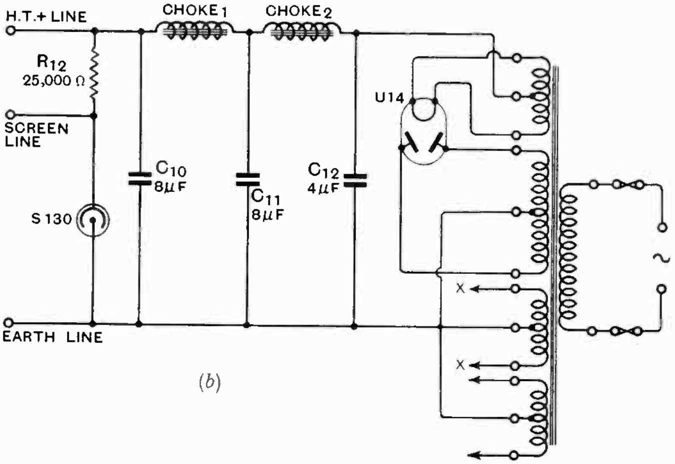
some two megohms between the deflecting plates and the gun of a cathode ray oscillograph, which is effectively in parallel with the anode load. The anode load has therefore been increased to 120,000 ohms, the next standard value; the dynamic characteristic for these conditions is shown by the dotted line in Fig. 1, and the actual operating conditions in Fig. 2. It will be noticed that the output is considerably reduced by the presence of the leak: an output of 320 volts peak swing is available from a grid swing of 2 volts, an amplification of 160 times. In cases where the leakage resistance between the plates and earth is very high, it will be best to reduce the anode load to 100,000 ohms.

The input stage is not at all critical with regard to the choice of valves. Another Osram MSP4 was used at first for convenience; two samples of the valve being available, it was possible to select that valve which gave the higher output. If the apparatus is to be used in positions where there is danger of microphony due to vibration, it is better to use a valve having a domed bulb, giving increased rigidity of electrodes; the valve shown in the photos is a Cossor MVS/PEN. The circuit is straightforward and is shown in Fig. 3. The first stage is decoupled by a resistance $R_4$ of 75,000 ohms; the coupling resistance $R_5$ is 60,000 ohms. With these values, an amplification of 80 times is obtained with an Osram MSP4. There is a potentiometer $R_1$ of one megohm in the input circuit, which serves as a volume control; it is obtained in a logarithmic grading. The value of the decoupling condenser $C_5$ in the anode circuit of the first valve may cause some surprise; it is chosen so that the decoupling of this stage falls off at low frequencies in such a ratio that it compensates for the losses in the coupling condenser $C_6$ and the bias decoupling condensers $C_4$ and $C_8$, at these frequencies. It may be shown by simple, if somewhat strenuous, analysis that it may compensate exactly for the loss in the coupling condenser $C_6$, but that the correction is only approximate if the losses in the other parts of the



(a)

Fig. 3.—*Circuit of the amplifier* (a), *and the supply unit* (b).



(b)

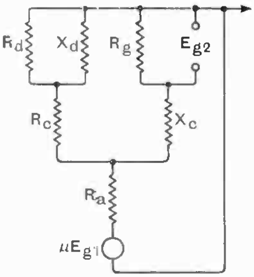


Fig. 4 (a).

circuit are also taken into account: such procedure also reduces the phase shift. In calculating this value, use is made of the equivalent plate circuit theorem: if in Fig. 3,

$X_c$ = The reactance of the coupling condenser $C_6$.
$X_d$ = The reactance of the decoupling condenser $C_5$.
$R_d$ = The resistance of the decoupling resistance $R_4$.
$R_c$ = The resistance of the anode load resistance $R_5$.
$R_g$ = The resistance of the grid leak $R_7$.

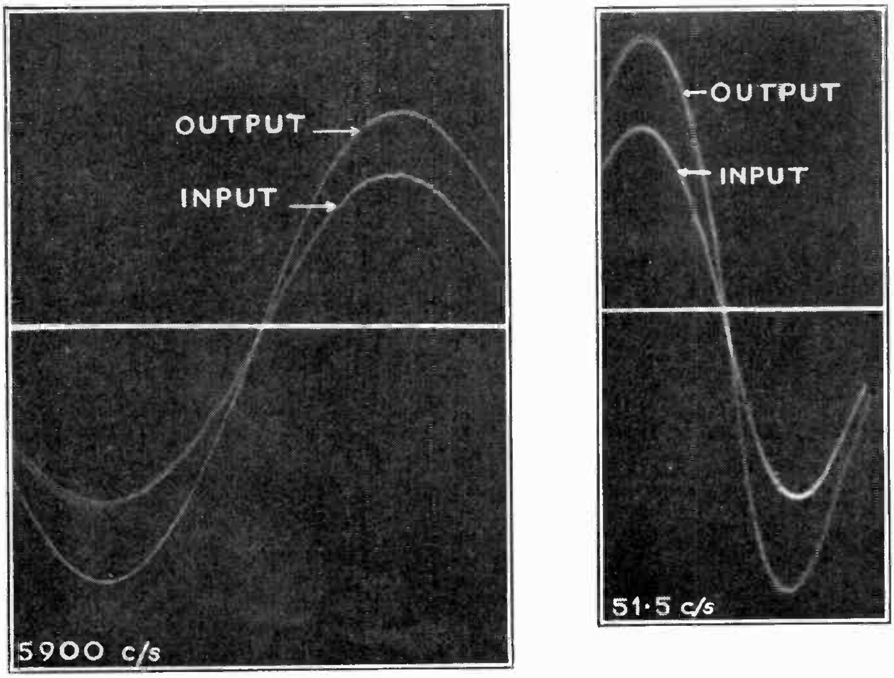


Fig. 4 (b).

$R_a$ = The A.C. resistance of the first valve.
$\mu$ = The amplification factor of the valve.

$X_b$ = The reactance of the bias decoupling condenser $C_4$.

Then at that frequency at which the reactances are calculated, the amplification $m$ of the stage is (assuming no losses in the bias circuit) given by the formula

$$m = \frac{\mu R_g\left(R_c + \dfrac{R_d X_d}{R_d + X_d}\right)}{\left[\left(R_c + \dfrac{R_d X_d}{R_d + X_d}\right)(R_a + R_g + X_c) + R_a(R_g + X_c)\right]}$$

This result follows at once from the equivalent electrical circuit, Fig. 4 (a).

The gain is, however, reduced by the losses in the bias resistance in a ratio approximately

$$\frac{1}{\left[1 + \dfrac{X_b}{R_c} \cdot m\right]}.$$

These expressions are unwieldy, and in practice sufficient accuracy is obtained if the reactances of the condensers are treated as resistances, thus dispensing with imaginary quantities. The actual value of $C_d$ used in this amplifier was calculated in this way, and the correction was designed to be correct for 10 c/s and 1,000 c/s. The low phase shift is shown in the oscillograms of Fig. 4 (b) which were obtained by leading the input and output waves from the amplifier to a special double time base, developed from one described in *Journ. Sci. Inst.*,[1] and completely mains operated. It was impossible to get the figure to stay still long enough at a lower frequency to obtain a satisfactory photograph.

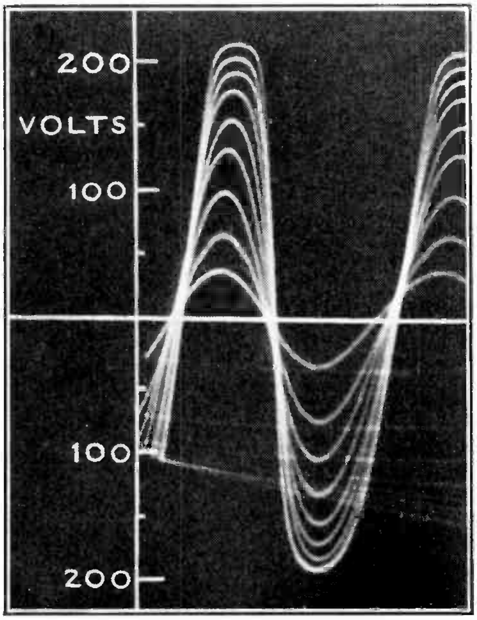
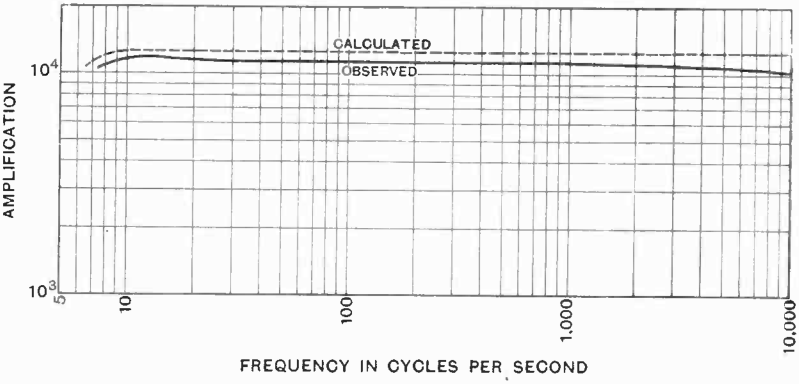


Fig. 5.—*Output of amplifier fed with different values of sinusoidal input. Note distortion when overloaded.*



(*Right*) Fig. 6.—*Amplification frequency curve.*

Up to its full rated output the amplifier is free from harmonic distortion. The oscillograms of Fig. 5 show this well. The superimposed waves represent the output of the amplifier when fed by a series of sinusoidal inputs of gradually increasing amplitude: it will be noticed that both the "tops" and the "bottoms" of the waves flatten out at the same definite level of input to the amplifier. A variable resistance $R_{10}$ ($R_{10}$ actually consists of two parts; one fixed, of 500 ohms, the other variable, of 400 ohms) is included in the cathode circuit of the second valve, by varying which the operating point may be brought to the middle of the straight part of the characteristic. This is realised when the wave begins to flatten out at both ends

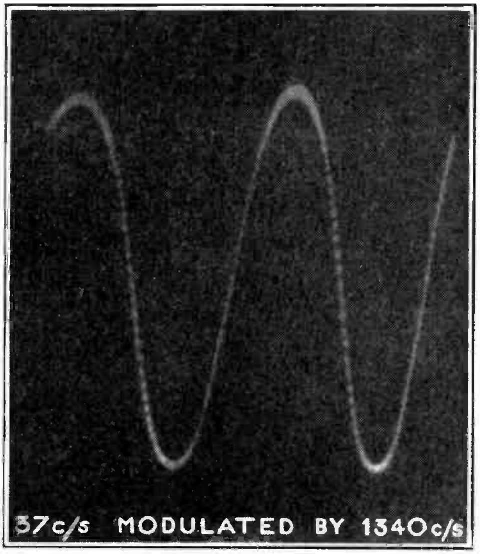


Fig. 7.—*Modulation of one amplifier by another working from same source.*

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[1] I. B. Davidson, *Journ. Sci. Inst.*, November, 1934.

at the same input level; though not, of course, necessarily to the same extent. In practice the bias requires to be lower than that calculated, though the calculated output is obtainable.

It will be noted that no attempt has been made to produce a level response at high frequencies. To achieve this object, it is necessary to employ very low values of coupling resistance; the self capacitance associated with high values defeats the purpose. For special applications it is possible to secure a level high frequency response by careful selection of the cathode by-pass condenser value. Those interested should read von Ardenne's paper.[2] The actual frequency response of the amplifier is shown in Fig. 6. The amplification over the greater part of the frequency range is 11,000 times; the calculated value is 12,500 times. The compensation at the low frequencies holds very well, showing that the simplified method of calculation holds for all practical purposes.

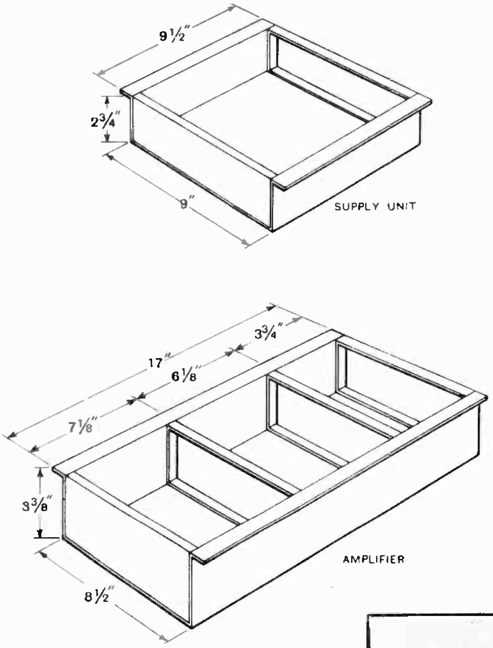
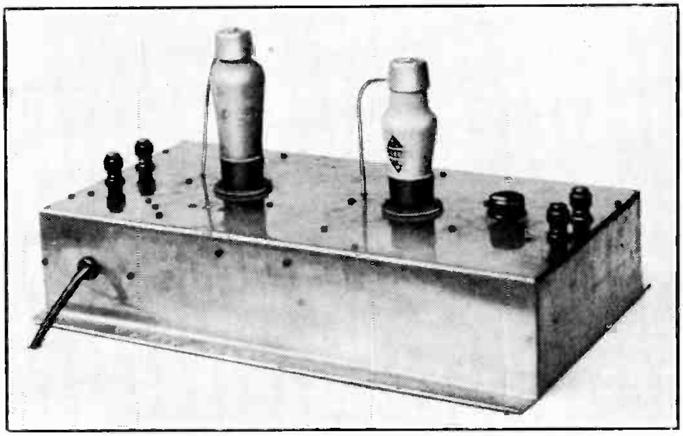


Fig. 8.—*Chassis details. Material 16 S.W.G. aluminium.*



(*Right*) Fig. 9 (a).—*The amplifier.*

The mains unit is entirely straightforward. The rectifier is a directly heated full wave valve (an Osram U14): the H.T. line is smoothed by two chokes $Ch_1$ $Ch_2$, and by two wet electrolytic condensers $C_{10}$ $C_{11}$, which form an invaluable safety device should the rectifier be operated at any time without any load. To keep the screen voltage constant, the screens are fed through two resistances $R_3$, $R_8$, of 25,000 ohms each, from a potentiometer consisting of a 25,000 ohm resistance $R_{12}$ and a Cossor neon voltage stabiliser S 130, in series across the H.T. supply.

For many purposes it is convenient to have two such amplifiers so that voltages of this magnitude may be used on both the X and Y plates of an oscillograph. The supply unit is therefore arranged so that two amplifiers may be connected at once, having separate L.T. supplies, and a common H.T. supply. Due to the high impedance of the valves compared with that of the supply unit, there is a minimum of "pulling" between the two amplifiers. Fig. 7 shows the output wave of one amplifier delivering 300 volts peak swing at 37 c/s, while the other amplifier is delivering 300 volts peak swing at 1,340 c/s. The very small modulation of the wave will be noticed.

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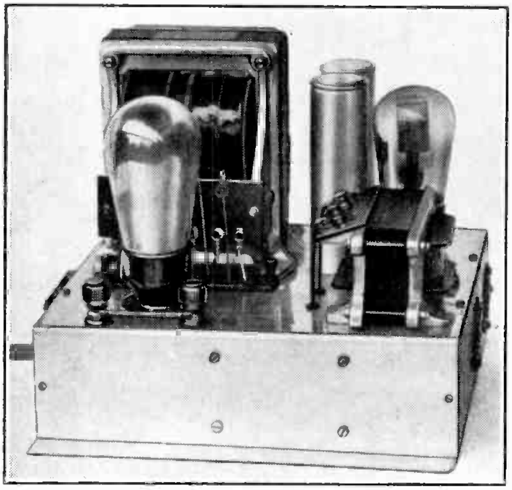
[2] M. von Ardenne. *The Wireless Engineer*, February, 1936.

The construction is essentially simple. An aluminium chassis is cut to the dimensions of Fig. 8; there is no complicated hole to cut, and all the components are mounted with brass B.A. screws. There is a small screen interposed between the two stages in the interests of stability; there is also another between the output terminals and the second valve-holder. The wiring is easy; the heater leads must be twisted together for their whole length, as, owing to the high total magnification, it is very easy to pick up stray A.C. The wires are all short, and the resistances may be suspended without fear by their tag ends. In the original amplifier the choke $Ch_1$ was a Godwinex, type C 80, rated at 12 mA D.C. current; the gap was adjusted experimentally to the optimum for 20 mA, and this should be done to all new chokes. The correct value is ten thousandths of an inch.

A complete list of parts is appended.

(*Right*) Fig. 9 (b).—*Underside view of amplifier with component references as given in Fig. 3.*

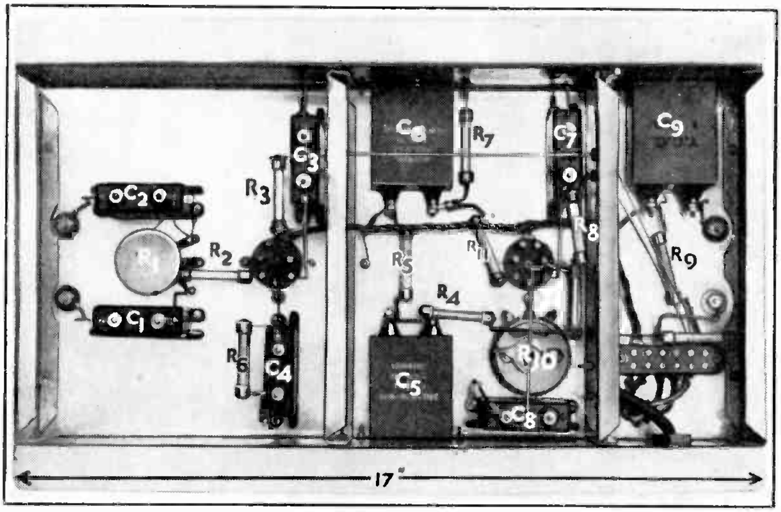
(*Below*) Fig. 10.—*The supply unit.*



**LIST OF PARTS FOR EACH AMPLIFIER.**

CONDENSERS.

1 1 μF. T.C.C., type 111, 1,000V. D.C. working, $C_9$.
1 0.5 μF. T.C.C., type 111, 1,000V. D.C. working, $C_6$.
1 0.5 μF. T.C.C., type 80, 400V. D.C. working, $C_5$.
2 1 μF. T.C.C., type 50, 200V. D.C. working, $C_3$ $C_7$.



2 0.5 μF. T.C.C., type 50, 200V. D.C. working, $C_1$ $C_2$.
2 250 μF. T.C.C., type 501, 12V. D.C. working, $C_4 C_8$.

RESISTANCES.

1 Dubilier Grid Leak, 0.5 Megohm, $R_7$.
1 Dubilier, 120,000 ohms, 1 watt, $R_9$.
1 Dubilier, 75,000 ohms, 1 watt, $R_4$.
1 Dubilier, 60,000 ohms, 1 watt, $R_5$.
2 Dubilier, 25,000 ohms, 1 watt, $R_3$ $R_8$.
1 Dubilier, 20,000 ohms, 1 watt, $R_2$.
1 Dubilier, 10,000 ohms, 1 watt, $R_{11}$.
2 Dubilier, 500 ohms, 1 watt, $R_6$ $R_{10}$.
1 Dubilier Volume Control, 2 Megohms, log wound, type B, $R_1$.
1 Igranic Potentiometer, 400 ohms, porcelain, type 2241/31, $R_{10}$.
2 Marconi-Osram Valves, MSP4, metallised, 7 pin.
2 Clix 7-pin chassis mounting valve holders.
4 Belling-Lee terminals.
2 Anode caps with screened lead, Belling-Lee.
1 Bryce 5-way connector.
2ft. 5-way cable and connector, Bulgin.

*List of Parts for Power Unit.*

1 All Power Mains Transformer, type PT/C, 400-0-400V., 2-0-2V. 2.5A; 2-0-2V. 2A; 2-0-2V. 2A.
1 Godwinex Choke, type C 80, 80H, 12mA., $Ch_1$.
1 Ferranti Choke, type B 10, 40H, 50mA., $Ch_2$.
1 4μF. condenser, T.C.C., type 111, 1,000V. D.C. working, $C_{12}$.
2 8μF. condenser, T.C.C., type 805, 500V. D.C. working, $C_{10}$ $C_{11}$.
1 Dubilier Resistance, 25,000 ohms, 3 watt, $R_{12}$.
1 Marconi-Osram Valve, U14.
1 Cossor Neon Voltage Stabiliser, S 130.
2 Belling-Lee terminals.
4 Clix 5-pin chassis mounting valve holders.
1 Belling-Lee double pole fuse box, with 1A. fuses.

# High-Frequency Power Amplifiers*†

## Calculation of "B" and "C" Types

By F. M. Kósa

MUCH has been already written about high-frequency power amplifiers so that the principle of their operation may be considered as generally known.

In spite of this the planning of such amplifiers is carried out in most cases by the "cut and try" method. The reason of this seems to be that the principles published up to date are either too complicated to be used for engineering calculations, or when simple, the results show a deviation from the measured value greater than allowable. A simple method is shown in the following for the calculation of such amplifiers, by means of which the results will not show in most cases a greater deviation from the actual, measured values, than the deviation existing between individual valves of the same type.

An amplifier is said to be of the class "B" type, when the grid bias is so large that the valve operates in the lower bend of its plate current versus grid tension characteristic. More exactly an amplifier is of the class "B" type when the grid bias is adjusted exactly to the "cut-off" point. An amplifier having a larger grid bias is a class "C" amplifier.

Three different kinds of currents must be clearly distinguished in the plate circuit of such amplifiers, which are important in their operation. We suppose, in the following considerations, that the plate circuit of the amplifier is of such a nature that it has a definite impedance to the first harmonic of the H.F. plate current, but has negligible impedance to all further harmonics. This is the feature of the tank circuits commonly used in H.F. amplifiers.

The current does not flow through the valve during the whole time of the cycle. If we designate the time of one cycle by $2\pi$, then the time during which plate current is flowing through the valve, may be designated by $2\phi$. For example, in an amplifier biased back exactly to cut-off, the time $2\phi$ is half of the time of $2\pi$. The closed circuit excited by the valve during the time $2\phi$, continues to oscillate during the remaining time $2\pi$-$2\phi$ of the whole period. We see from that, that one current flows through the valve, and another current in the outer circuit.

From the point of view of operation, the maximum value of the current flowing through the valve is very important; but the amplitude of the first harmonic current existing in the outer circuit is one factor defining the output power, which is also of prominent importance. In consequence of the beforementioned feature of the tank circuit, the higher harmonics of the tank circuit current play but little role especially concerning the power output. The closed circuit current consists chiefly of the first harmonic and this is even more true of the voltage across the closed circuit.

The D.C. component of the current flowing through the valve is also of great importance. This is the current read on a D.C. ammeter in the plate circuit of the valve. Some relations will be discussed in the following between these three currents.

The actual curved characteristic of the valves is replaced in most of our calculations by a straight line. Thus the calculated value of operating angle (being an auxiliary means for calculation only) characterises the current-flowing-time of a valve having straight line characteristic. This method does not affect considerably the results.

### 1. Relations Between the Different Plate Currents

1.1. *Relation between $I_{\max}$ and $I_m$ (Fig. 1).*

The area between the angles $\alpha_1$ and $\alpha_2$ of a sine function is generally

$$T' = A\int_{\alpha_1}^{\alpha_2} \sin\alpha \, d\alpha = A\Big[-\cos\alpha\Big]_{\alpha_1}^{\alpha_2} = A\Big[\cos\alpha\Big]_{\alpha_2}^{\alpha_1}$$

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* MS. accepted by the Editor, January, 1937.

† For list of symbols employed, see author's Appendix, page 656.

Calculating the area from $\alpha$ to 90° (Fig. 2)

$$T_{\alpha-90^\circ} = A\cos\alpha = A\sin\phi$$

and the useful area is

$$T = A\sin\phi - \phi A\cos\phi = A(\sin\phi - \phi\cos\phi) \quad \ldots \quad \ldots \quad (1)$$

On the other hand, the peak value of the current is

$$I_{\max} = A(1-\cos\phi) \quad \ldots \quad \ldots \quad (2)$$

Replacing this in equation (1)

$$T = I_{\max}\frac{\sin\phi - \phi\cos\phi}{1-\cos\phi}.$$

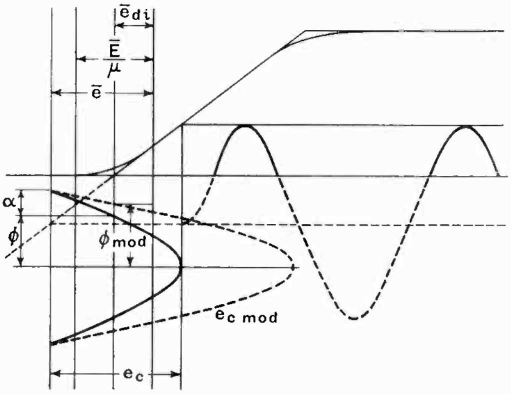

Fig. 1.

Calculating the mean value for a whole period

$$I_m = \frac{2T}{2\pi} = \frac{I_{\max}}{\pi}\,\frac{\sin\phi - \phi\cos\phi}{1-\cos\phi}$$

wherefrom

$$\frac{I_{\max}}{I_m} = \pi\frac{1-\cos\phi}{\sin\phi-\phi\cos\phi} = \pi\frac{s}{r} \quad \ldots \quad (3)$$

The fraction $s/r$ can be brought to a simpler form :

$$r = \sin\phi - \phi\cos\phi = \phi - \frac{\phi^3}{3!} + \frac{\phi^5}{5!} - \frac{\phi^7}{7!} + \ldots$$

$$-\phi + \frac{\phi^3}{2!} - \frac{\phi^5}{4!} + \frac{\phi^7}{6!} - \ldots$$

$$= \frac{\phi^3}{3}\left(1 - \frac{\phi^2}{10} + \frac{\phi^4}{280} - \ldots\right)$$

$$s = 1 - \cos\phi = \frac{\phi^2}{2!} - \frac{\phi^4}{4!} + \ldots = \frac{\phi^2}{2}\left(1 - \frac{\phi^2}{12} + \ldots\right)$$

Taking into account only the first three members of the original infinite series

$$\frac{s}{r} = \frac{3}{2\phi}\cdot\frac{1-\dfrac{\phi^2}{12}}{1-\dfrac{\phi^2}{10}}$$

The second factor of this fraction is

$$\left(1-\frac{\phi^2}{12}\right):\left(1-\frac{\phi^2}{10}\right) = 1 + \frac{\phi^2}{60}, \text{ and thus}$$

$$\frac{I_{\max}}{I_m} = \frac{3\pi}{2\phi}\left(1+\frac{\phi^2}{60}\right) \cong \frac{3\pi}{2\phi\left(1-\dfrac{\phi^2}{60}\right)} \quad \ldots \quad (3a)$$

This is the formula we shall use for further calculations, but in cases requiring less accuracy, the $1 + \frac{\phi^2}{60}$ formula can be made even simpler, if we consider that it can be simply omitted for smaller values of $\phi$ and can be replaced by the value $1.0415 = \pi/3$, for greater values of $\phi$. ($\pi/3$ being the value of the second factor for $\phi = 90^\circ$). Thus for angles between 75° and 90° we can write :

$$\frac{I_{\max}}{I_m} = \frac{\pi^2}{2\phi} \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

and for angles smaller than 75°

$$\frac{I_{\max}}{I_m} = \frac{3\pi}{2\phi} \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

It may be seen from Fig. 1 that $\phi$ varies generally with modulation, except when $\phi = 90^\circ$ (class "B" amp.). It is known that $I_{1\,\mathrm{mod}} = (1+m)I_1$, and with $\phi = 90^\circ$: $I_{\mathrm{maxmod}} = (1+m)I_{\max}$.

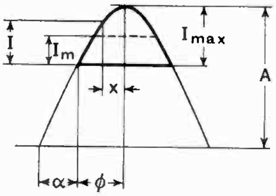

Fig. 2.

For 100% modulation: $I_{\mathrm{maxmod}} = 2I_{\max}$ . . (5)

This holds approximately also for values of $\phi$ not far from 90°. For $\phi$ less than 90°, $I_{\mathrm{maxmod}}$ is also less than $2I_{\max}$.

### 1.2. *Relation between $I_1$ and $I_{\max}$ (Fig. 2).*

The instantaneous value of the current

flowing through the tube

$$I = A\cos x - A\cos\phi \quad \ldots \quad \ldots \quad (6)$$

The peak value of this current is

$$I_{\max} = A(1-\cos\phi).$$

Combining this with (6)

$$I = I_{\max}\frac{\cos x - \cos\phi}{1-\cos\phi}.$$

The constant of the first harmonic in a Fourier series is

$$a_1 = \frac{1}{\pi}\int_0^{2\pi} f(x)\cos x\,dx$$

In our case

$$I_1 = \frac{2}{\pi}\int_0^{\phi} I\cos x\,dx = \frac{2}{\pi}\int_0^{\phi}\frac{I_{\max}}{1-\cos\phi}(\cos^2 x - \cos\phi\cos x)dx$$

$$I_1 = \frac{1}{\pi}\frac{I_{\max}}{1-\cos\phi}[\phi+\sin\phi\cos\phi - 2\sin\phi\cos\phi]$$

and thus

$$\frac{I_1}{I_{\max}} = \frac{1}{\pi}\frac{\phi-\sin\phi\cos\phi}{1-\cos\phi} = \frac{1}{\pi}\frac{s'}{r'} \quad \ldots \quad (7a)$$

Bringing the fraction $s'/r'$ to a simpler form

$$s' = \phi - \frac{\sin 2\phi}{2} = \phi - \phi + \frac{8\phi^3}{2.2.3} - \frac{2^5\phi^5}{2.2.3.4.5} + \frac{2^7\phi^7}{2.2.3.4.5.6.7} = \frac{2\phi^3}{3}\left(1 - 0.2\phi^2 + \frac{12}{630}\phi^4\ldots\right)$$

and

$$r' = 1 - 1 + \frac{\phi^2}{2} - \frac{\phi^4}{2.3.4} + \frac{\phi^6}{2.3.4.5.6} - \ldots = \frac{\phi^2}{2}\left(1 - \frac{\phi^2}{12} + \frac{\phi^4}{360} - \ldots\right).$$

Taking into account again the first three members of the original infinite series

$$\frac{I_1}{I_{\max}} = \frac{4\phi}{3\pi}(1-0.1\phi^2) = \frac{1}{\pi}\frac{\phi - \frac{\sin 2\phi}{2}}{1-\cos\phi} \quad \ldots \quad (7)$$

The fourth member of the original series containing $\phi^4$ has also been taken into account as a correction. The deviation between the two values for $I_1/I_{\max}$ given in (7) does not exceed in the whole range from 0 to 90° one-half per cent.

### 1.3. *Relation between $I_1$ and $I_m$.*

We get an interesting result by combining simply the equations 3 and 7, and that is

$$\frac{I_1}{I_m} = \frac{\phi - \frac{\sin 2\phi}{2}}{\sin\phi - \phi\cos\phi} = 2(1-0.087\phi^2) \quad \ldots \quad (10)$$

## 2. Power and Efficiency

The output power delivered by the valve is

$$W_2 = E_{\text{eff}}\,I_{\text{eff}} = I_m\sqrt{2}(1-0.087\,\phi^2)\frac{E_1}{\sqrt{2}}$$

$$= I_m E_1(1-0.087\phi^2) \quad \ldots \quad \ldots \quad (11)$$

and the input power taken by the valve is

$$W_1 = I_m\overline{E} \quad \ldots \quad \ldots \quad (12)$$

We get the efficiency of the stage from (11) and (12).

$$\eta = \frac{W_2}{W_1} = \frac{1}{2}\frac{\phi - \sin\phi\cos\phi}{\sin\phi - \phi\cos\phi}\cdot\frac{E_1}{\overline{E}}$$

$$= (1-0.087\,\phi^2)\frac{E_1}{\overline{E}} \quad \ldots \quad \ldots \quad (13)$$

and further

$$W_{\text{diss}} = W_1 - W_2 = (1-\eta)W_1 \quad \ldots \quad (13a)$$

$$R_1 = E_1/I_1 \quad \ldots \quad \ldots \quad \ldots \quad (13b)$$

## 3. The Greatest Permissible Value of the Alternating Plate Tension

The amplitude of the alternating plate tension must not exceed a certain value; the instantaneous value of the plate tension equals the difference between the direct plate tension and the instantaneous value of the alternating plate tension. Thus the minimum value of the plate tension is

$$E_{\min} = \overline{E} - E_p$$

If the minimum value of the plate tension is not greater than the maximum value of grid tension—acting simultaneously—the grid current increases suddenly with a consequent decrease in plate current and power. It is obvious that this has a bad effect on both the distortion and the life of the valve. It is therefore necessary that the maximum value of the grid tension multiplied by a value $\kappa$ shall be smaller than the minimum value of the plate tension. I.e.,

$$\kappa(e - \bar{e}) \leq \overline{E} - E_p \quad \ldots \quad \ldots \quad \ldots \quad (8)$$

The following basic relation for the actual valve characteristic is well known :

$$I = g\left[\left(e - \frac{E_p}{\mu}\right)\cos x - \bar{e} + \frac{\bar{E}}{\mu}\right], \quad .. \quad (9)$$

where $\frac{\bar{E}}{\mu}$ should be (see Fig. 1)

replaced by $\bar{e}_{di}$ in the straight line characteristic ; and in the case $x = 0$

$$I_{\max} = g\left[e - \bar{e} + \frac{1}{\mu}(\bar{E} - E_p)\right] \quad .. \quad (9a)$$

From 9 and 8

$$\kappa(e - \bar{e}) = \kappa\left[\frac{I_{\max}}{g} - \frac{1}{\mu}(\bar{E} - E_p)\right] \leq \bar{E} - E_p$$

$$\bar{E}\left(1 + \frac{\kappa}{\mu}\right) \geq E_p\left(1 + \frac{\kappa}{\mu}\right) + \frac{\kappa I_{\max}}{g}$$

or

$$\frac{E_p}{\bar{E}} \leq 1 - \frac{\kappa I_{\max}}{g\bar{E}} \cdot \frac{1}{1 + \frac{\kappa}{\mu}} \cong 1 - \frac{\kappa I_{\max}}{g\bar{E}}.$$

We are however not interested in $E_p/\bar{E}$, but in $E_1/\bar{E}$. The relation $E_1/E_p$ depends on the characteristic of the tank circuit actually used. The tank circuits generally used in transmitters are designed to secure a good stability, frequency response curve, etc., so that with good approximation

$$E_1 = 0.95E_p.$$

Putting this in our previous equation

$$\frac{E_1}{\bar{E}} \leq 0.95\left(1 - \frac{\kappa I_{\max} R_p}{\mu \bar{E}}\right) \quad .. \quad (14)$$

In this equation $I_{\max}$ should be the actual maximum value flowing through the tube. In modulated amplifiers the peak tension and peak current should be taken into account as being present during modulation peaks. We get a suitable value in order to avoid excessive grid currents by taking $\kappa = 1.5$. That means that the minimum plate tension is one and a half times greater than the maximum grid tension. With these considerations

$$\frac{E_{1\mathrm{mod}}}{\bar{E}} = 0.95\left(1 - \frac{1.5 I_{\mathrm{maxmod}} R_p}{\mu \bar{E}}\right) \quad .. \quad (15)$$

This equation gives the maximum permissible value of the amplitude of the A.C. plate tension. The actual value of the A.C. amplitude must be equal to or less than this permitted value.

In case of 100 per cent. modulation the amplitude of the plate tension without modulation is,

$$E_1 = 0.5E_{1\mathrm{mod}}.$$

Calculating the value of equation (15) for the valves at disposal, we shall see that the value $E_{1\mathrm{mod}}/\bar{E}$ will be in most cases very near to the value 0.81. We shall start from this approximation in our calculations and shall see later by means of equation (15) whether this approximation was permissible or not.

We should point out here that although the greatest permissible value of $I_{\mathrm{maxmod}}$ could be theoretically equal to $I_s$, it has to be practically always less than the latter. The following consideration could serve to give an idea of its value.

In modulated amplifiers the upper bend of the valve characteristic cannot be used in consequence of the resulting amplitude distortion. Of course, up to what point we may consider the valve characteristic as a straight line depends on the greatest permissible degree of distortion at modulation peaks. We may take in practice generally

$$I_{\mathrm{maxmod}} = 0.8I_s \quad .. \quad .. \quad (16)$$

without appreciable distortion.

In unmodulated (C.W.) amplifiers $I_{\max}$ represents the largest current flowing through the tube.

The upper limit of this current is limited by the following consideration : It is harmful to the filament of oxide-coated valves to operate continuously in saturation. This condition does not apply to a valve having a Tungsten filament, but this valve has generally a flatter bend in consequence of which the distortion of a sine wave acting on the grid of the valve will badly increase. The output will be but slightly increased by considerably increasing the input power, affecting also unfavourably the life of the tube. It is recommended therefore in unmodulated amplifiers, independently of the construction of the filament, to allow only 5 per cent. more than in the modulated case : so that

$$I_{\max} = 0.84I_s \quad .. \quad .. \quad .. \quad (17)$$

## 4. The Optimum Value of the Angle $\phi$

The question of the angle $\phi$ to be chosen for an amplifier has to be considered not only from a strictly technical, but also from an economical standpoint. The problem arising in practice can be expressed as follows: What is the optimum value of the operating angle $\phi$ by the use of which the greatest output power may be received from a given valve with a greatest possible efficiency. In other words, the maximum value of the function $Z = \eta W_2$ has to be calculated.

The problem has to be divided into two parts according to the construction of the valve. The limit of increasing the load on a valve is determined by one or other of two factors.

The first is that, depending on the construction of the filament, the emission current cannot be increased above a certain limit.

The second is that, depending on the construction of the plate, the dissipated power may not increase above a certain value.

The first condition is the limiting one in practice generally. Let us examine the optimum value of the angle $\phi$ from these two viewpoints.

### 4.1. *The emission of the filament.*

In this case the maximum value of the function

$$Z_1 = \eta W_{2\text{mod}}$$

has to be taken into account. Namely, the filament has to deliver the greatest current during modulation peaks with the permitted distortion, and the efficiency has to reach its greatest value in the unmodulated condition as the amplifiers run for the greatest part of their operating period with low modulation only.

$$W_{2\text{mod}} = \eta_{\text{mod}} W_{1\text{mod}}$$
$$Z = \eta\eta_{\text{mod}} W_{1\text{mod}}$$

taking into account (13) and (3a)

$$Z = \left[ (1 - 0.087\,\phi^2) \,.\, (1 - 0.087\,\phi^2_{\text{mod}})\, \phi_{\text{mod}} \left(1 - \frac{\phi^2_{\text{mod}}}{60}\right)\right] \frac{E_1}{\bar{E}} \frac{E_{1\text{mod}}}{\bar{E}} \bar{E} I_{\text{maxmod}} \cdot \frac{2}{3\pi}.$$

The factors not contained in the brackets [ ] are independent of $\phi$. The value of $\phi_{\text{opt}}$ depends only on the formula contained in these brackets. Little error is introduced if we put in the first factor $\phi_{\text{mod}}$ instead of $\phi$. With this

$$y = \phi_{\text{mod}} - 0.174\,\phi^3_{\text{mod}} + 0.0076\,\phi^5_{\text{mod}} - 0.01665\,\phi^3_{\text{mod}} + 0.0029\phi^5_{\text{mod}}$$

$$y = 0.0105\,\phi^5_{\text{mod}} - 0.1906\,\phi^3_{\text{mod}} + \phi_{\text{mod}}.$$

Putting

$$\frac{dy}{d\phi} = 0.0525\,\phi^4_{\text{mod}} - 0.5718\,\phi^2_{\text{mod}} + 1 = 0$$

we have

$$\phi_{\text{modopt}} = 1.48 = 84^\circ \text{ and } \cos\phi_{\text{modopt}} = 0.1 \quad \ldots \quad (18)$$

The other solutions of the equation being either negative or greater than 90°, may be ignored.

It may be seen from Fig. 1 that

$$\cos\phi = \frac{\bar{e} - \bar{e}_{di}}{e - \dfrac{E_1}{\mu}} \text{ and}$$

$$\cos\phi_{\text{mod}} = \frac{\bar{e} - \bar{e}_{di}}{e_{\text{mod}} - \dfrac{E_{1\text{mod}}}{\mu}}$$

at 100 per cent. modulation

$$e_{\text{mod}} - \frac{E_{1\text{mod}}}{\mu} = 2\left(e - \frac{E_1}{\mu}\right)$$

and thus

$$\cos\phi = 2\cos\phi_{\text{mod}} \quad \ldots \quad \ldots \quad (18a)$$

With this

$$\cos\phi_{\text{opt}} = 0.2, \text{ and } \phi_{\text{opt}} = 78.5^\circ = 1.37 \quad \ldots \quad (19)$$

### 4.2. *Permissible plate dissipation.*

In this case the unmodulated condition may be assumed as a continuous warming up and not an instantaneous peak value has to be taken into consideration. Further, $W_{\text{diss}}$ has to be taken as independent variable instead of $I_{\text{mo lmax}}$.

$$Z_2 = \eta W_2 = \eta^2 W_1$$
$$W_{\text{diss}} = (1 - \eta) W_1 \text{ and}$$

$$Z_2 = \frac{\eta^2}{1 - \eta} W_{\text{diss}} = \frac{(1 - 0.087\,\phi^2)^2 \left(\dfrac{E_1}{\bar{E}}\right)^2}{1 - (1 - 0.087\,\phi^2)\dfrac{E_1}{\bar{E}}} W_{\text{diss}}.$$

It may be seen directly from this function that it has no maximum value between the angles 0 and 90°, but $Z_2$ increases steadily when $\phi$ decreases. On the other hand, $I_{\max}/I_1$ increases also with the decrease of $\phi$ (see 7) and we shall come therefore soon to an angle $\phi$ where the load of the valve will be limited again by the maximum emission current of the filament.

We may see from the above that the best operating angle for a modulated amplifier is 78.5° and for an unmodulated amplifier 84°. This is the angle at which the valve is used in the most economical way.

The greatest efficiency for modulated amplifiers operating with the angle $\phi_{\text{opt}}$ is (see 13)

$$\eta_{\phi\text{opt}} = 0.83 \frac{E_1}{\overline{E}} = 0.83 \frac{0.81}{2} = 33.5\ \% \quad \ldots \quad (20)$$

The same for unmodulated amplifiers

$$\eta_{\phi\ \text{optmod}} = 0.81 \frac{E_1}{\overline{E}} = 0.81\ .\ 0.81 = 66\ \% \quad \ldots \quad (21)$$

## 5. Required Output Power Less than the Maximum Possible Value

The following lines are to give a rough idea for the calculation of amplifiers, when the required output power is less than the maximum possible value. Such amplifiers are frequently used in earlier stages of radio transmitters. With an output power less than the maximum, $I_{\text{max}}$ and $E_1$ may also be decreased relatively, resulting in smaller distortions. Two methods of calculation will be shown.

### 5.1. *$W_2$ should be given.*

Let $E_1 = \delta\overline{E}$ and $I_{\text{max}} = \gamma I_s$

$$2E_{\text{eff}}I_{\text{eff}} = E_1 I_1 = 2W_2 \text{ and } I_1 = \frac{2W_2}{\delta\overline{E}}$$

with 7.

$$\frac{I_1}{I_{\text{max}}} = \left[\frac{2W_2}{\overline{E}I_s}\cdot\frac{1}{\delta\gamma}\right] = \frac{4}{3}\frac{\phi}{\pi}(1 - 0{,}1\phi^2) \quad \ldots \quad (22)$$

All the quantities in the brackets [ ] being either known or assumed $\phi$ may be calculated. With the value of $\phi$ and with the assumed value of $E_1/\overline{E} = \delta$, $\eta$ may also be obtained. In such cases a larger value of $\phi$ may be used and the amplifier is frequently operated as a Class "B" or a Class "A—B" amplifier.

### 5.2. *Let us calculate $E_1$, $I_1$ and $\eta$ with a given value of $\phi$.*

We could start the calculation by taking simply $\eta = 18$–$24$ per cent., which is a convenient value. But in order to have a picture of the factors playing a role in the operation of the amplifier let us consider the following relations:

$$E_1 = \delta\overline{E} \text{ and with 7.}$$

$$I_{\text{max}} = \gamma I_s = \frac{I_1}{\dfrac{1}{\pi}\,\dfrac{\phi - \sin\phi\cos\phi}{1 - \cos\phi}} = \frac{I_1}{f(\phi)}$$

$$E_1 I_1 = \delta\gamma\overline{E}I_s.f(\phi) = 2W_2.$$

At the output of the maximum possible power $E_1$ is approximately 0.4 $\overline{E}$ and $I_{\text{max}}$ is also approximately 0.4 $I_s$ (see par. 3). Thus in this case $\delta = \gamma$. This could be used also with a smaller output power, but we get more favourable conditions generally if $\delta > \gamma$.

Let us put $\delta = r\gamma$, where $r$ varies between 1 and 3. The smaller $W_2$ is required to be, the larger should be the values of $r$. The following advantages accrue from making $\delta$ greater than $\gamma$.

(a) A smaller distortion is generally produced using smaller value of $I_1$ together with a larger value of $E_1$.

(b) We get a better efficiency, less power is required and the valve is less loaded.

(c) A smaller drive is necessary in most cases and so a smaller driving stage may be used.

In such cases generally

$\phi = 90°$ and thus $f(\phi) = 0.5$. With this

$$\delta = \sqrt{\frac{4r\,W_2}{\overline{E}\,I_s}} \quad \ldots \quad \ldots \quad (23)$$

This is of course a formula of approximative nature.

## 6. Calculation of the Drive Necessary

It is known that (see 9).

$$I = g(\bar{e}_c + e_c) = g\left[\left(c - \frac{E_1}{\mu}\right)\cos x - (\bar{e} - \bar{e}_{di}\right]$$

$$\text{but } \bar{e} - \bar{e}_{di} = \left(e - \frac{E_1}{\mu}\right)\cos\phi$$

and thus $I = g\left(c - \dfrac{E_1}{\mu}\right)(\cos x - \cos\phi)$.

We get the maximum value of $I$ at $x = 0$ and in this case $I = I_{\text{max}}$.

$I_{\text{max}} = g\left(e - \dfrac{E_1}{\mu}\right)(1 - \cos\phi)$. But from (7).

$I_{\max} = I_1 \pi \frac{1 - \cos\phi}{\phi - \sin\phi\cos\phi}$. Putting this in the previous equation,

$$I_1 = \frac{\mu e}{R_1 + \frac{\pi}{\phi - \sin\phi\cos\phi} R_p}.$$

The factor $\frac{\pi}{\phi - \sin\phi\cos\phi}$ is designated $\beta$ by Mr. Everitt (*Proceedings of I.R.E.*, 1934, February). Multiplying the equation by $R_1$

$$\frac{E_1}{e} = \mu \frac{R_1}{R_1 + \beta R_p} \quad .. \quad .. \quad (24)$$

$\frac{\mu e}{E_1} = 1 + \beta \frac{R_p}{R_1} = \xi$ which may be called amplification loss factor .. .. (25)

$M = \frac{\mu}{\xi} = \frac{E_1}{e}$ is the amplification of the stage.. .. .. .. .. (25a)

Calculation of $\beta$ and $\xi$ respectively.

(a) $\phi - \sin\phi\cos\phi = \frac{2}{3}\phi^3(1 - 0.2\phi^2 + 0.019\phi^4)$ .. .. (26)

(See function $s'$ in equation (7a).

Hence $$\beta = \frac{3\pi}{2} \cdot \frac{1}{\phi^3(1 - 0.2\phi^2 + 0.019\phi^4)}$$
$$= \frac{4{\cdot}7}{\phi^3(1 - 0.2\phi^2 + 0.019\phi^4)} \quad .. \quad (27)$$

(b) $$\beta = \frac{\pi}{\phi - \sin\phi\cos\phi} = \frac{I_{\max}}{I_1} \frac{1}{1 - \cos\phi} \quad .. \quad .. \quad (28)$$

$$\beta \frac{R_p}{R_1} = \frac{I_{\max} R_p}{E_1} \cdot \frac{1}{1 - \cos\phi}$$
$$= \frac{I_{\max} R_p}{E_1} \cdot \frac{2}{\phi^2\left(1 - \frac{\phi^2}{12}\right)} \quad .. \quad (28a)$$

(c) $\beta \frac{R_p}{R_1}$ may be expressed in several other ways, e.g.

$$\beta \frac{R_p}{R_1} = 3\pi \frac{I_m}{\phi^3} \cdot \frac{R_p}{\bar{E}} \cdot \frac{1}{\eta} = \frac{3\pi}{\phi^3} \frac{R_p W_2}{\eta^2 \bar{E}^2} \quad .. \quad (29)$$

## 7. Calculation of the Grid Bias

Based on the above the grid bias could be calculated from the condition $I = 0$ as follows:

$$\bar{e} = \left(e - \frac{E_1}{\mu}\right)\cos\phi + \frac{\bar{E}}{\mu}$$

At this point however it has to be taken into consideration that $\bar{E}/\mu = \bar{e}_d$ is the grid bias tension corresponding to the cut off point, i.e., to the point where $I = 0$, but in the actual characteristic curve of the valve and not in the straightline, we have taken as basis of calculation. This straight line reaches the grid tension axis at a value $\bar{e}_{di}$, less than $\bar{e}_d$ (see Fig. 3). This $\bar{e}_{di}$ may be drawn from the characteristic curve by drawing a tangent to that point of the curve to which the values $R_p$, $g$, $\mu$ relate. This tangent is the straight line taken as the basis of our calculations and reaches the grid tension axis at the point $\bar{e}_{di}$ (see $t - t$ in Fig. 3).

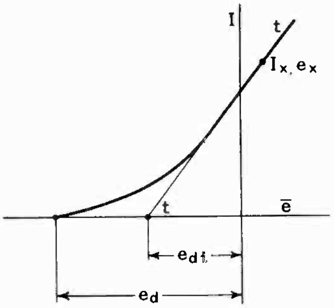

Fig. 3.

The value $\bar{e}_{di}$ however may also be calculated in the following manner:

Knowing the characteristic data $R_p$, $g$ and $\mu$ of the valve and the values $I_x$, $\bar{e}_x$, referring to one point of the characteristic static curve, we may write

$$I - I_x = g(\bar{e} - \bar{e}_x).$$

Setting in the equation $I = 0$, we shall get the value of $\bar{e} = \bar{e}_{di}$:

$$\bar{e}_{di} = -\frac{I_x}{g} + \bar{e}_x \quad .. \quad .. \quad (30)$$

from which the necessary grid bias may easily be calculated as follows:

$$\bar{e} = -\left(e - \frac{E_1}{\mu}\right)\cos\phi + \bar{e}_{di} \quad .. \quad (31)$$

(The value of $\bar{e}_{di}$ is always negative and must be set with this negative sign in the above equation, so that the two members of the right side will be added and not subtracted.)

We may see from the above that all the figures may be calculated of a Class B or

Class C amplifier, which are necessary for adjusting the stage and designing the grid and plate power supplies as well as the driving stage. The amplifier may be set at once for the best operating conditions with $\phi_{\mathrm{opt}}$ and no extensive tests are necessary in order to get the best adjustments. Some measurements will, of course, be necessary, chiefly to get setting, tuning and matching in the high frequency circuits but this is also made easier by knowing in advance the proper values of the high frequency currents and tensions.

The use of above calculations may be best shown in some examples. These examples contain the calculation of actual amplifiers. Tests have shown that the settings given in the examples give in fact the best operating conditions.

## 8. Examples

8.1. *Data :*

Output power required = 30 kW.

Plate tension acting actually on the plate $= \overline{E} = 18{,}600$ V

$g = 1, 9.10^{-2}$ amp./V $W_{\mathrm{diss}} = 80$ kW (permissible)

$I_s = 45$ amp $R_p = 2{,}000$ Ohms

$I_x = 1.85$ amp. $e_x = -235$ Volt.

*Calculation :*

$W_2 = 30{,}000,\ \eta = 33\%$ (assumed value)

$\phi = 1.37$

Putting this value of $\eta$ and $\phi$ in equation 13 we get $\frac{E_1}{\overline{E}} = 0.4$ and for 100 % modulation $\frac{E_{1\mathrm{mod}}}{\overline{E}} = 0.8.$

$$W_1 = \frac{30{,}000}{0.33} = 91{,}000 \text{ w}$$

$$I_m = \frac{91{,}000}{18{,}600} = 4.88 \text{ amp.} \quad \text{from 3 a :}$$

$I_{\mathrm{maxmod}} = 7 \cdot 4.88 = 34.2$ amp., less than $0{,}8.45$, O.K.

The same may also be obtained in another way :

$$E_1 = \frac{0.81}{2} \,.\, 18{,}600 = 7{,}500 \text{ V.}$$

$$I_1 = \frac{2.30000}{7{,}500} = 8 \text{ amp., and from 7 :}$$

$I_{\mathrm{maxmod}} = \frac{8}{0.235} = 34.2$ amp. Permissible max. value of the A.C. plate tension from 15.

$$\frac{E_{1\mathrm{mod}}}{\overline{E}} = 0.95\left(1 - \frac{1.5 \times 34.2 \times 100}{1.9 \times 18600}\right) = 0.81,$$

and thus the assumed values of $\eta$ and $\phi$ may be actually used.

$$R_1 = \frac{7{,}500}{8} = 940 \text{ Ohms}$$

$$\xi = 1 + 2.64\,\frac{2{,}000}{940} = 6.6.$$

$$M = \frac{38}{6.6} = 6$$

$$e = \frac{7{,}500}{6} = 1{,}250 \text{ V.}$$

$e_{\mathrm{eff}} = 890$ V. Grid bias :

$$\bar{e}_{di} = -\frac{1.85}{1.9} \times 10^2 - 235 = -333\ v.$$

$$\bar{e} = -\left(1{,}250 - \frac{7{,}500}{38}\right)0.2 - 333$$
$$= -550 \text{ volt.}$$

$$\bar{e}_d = -\frac{18{,}600}{38} = 490 \text{ volt,}$$

and so we shall operate below the cut off point of the actual characteristic.

$W_{\mathrm{diss}} = 91{,}000 - 30{,}000 = 61{,}000$, less than 80,000 O.K.

We may get an output of $W_2 = 60{,}000$ watts with 2 valves in push-pull, using the same $\bar{e}$, but with twice the value of $e$.

8.2. *Another example.*

*Data :* $W_2 = 350$ w, $\overline{E} = 5{,}000$, $W_{\mathrm{diss}} = 1{,}500$ (permissible)

$\mu = 20,\quad R_p = 8{,}000,\ g = \frac{1}{400}$ amp./v.,

$I_s = 2.5$ amp., $e_x = -55$, $I_x = 0.3$ amp.

*Calculation :*

Let us take $\phi = 1.37$, $\eta = 33\%$ and thus $W_1 = 1{,}060$ w, and $\frac{E_{1\mathrm{mod}}}{\overline{E}} = 0.8.$

$I_m = 1{,}060/5{,}000 = 0.212$ amp.

$I_{\mathrm{maxmod}} = 7 \times 0.212 = 1.48$ amp., less than $0,\ 8 \times 2,\ 5$, O.K.

Permitted value of plate swing:

$$\frac{E_{1\text{mod}}}{E} = 0.95\left(1 - \frac{1.5 \times 1{,}48 \times 400}{5{,}000}\right) = 0.78,$$

that is somewhat less than necessary. Thus we have to reduce the output power in order not to increase the grid current. We shall get in this case a smaller drive and $E_1/E$ may be increased. It could be calculated that the output power must be decreased down to 280 w. We shall choose another way, making a compromise and calculating with an output power of 315 w. and designing a tank circuit in such a way as to have a very low impedance for the higher harmonics of the high frequency voltage (large C/L). So we may put in the above equation 0.98 instead of 0.95. In this case, of course, the closed circuit must actually be adjusted in the said manner.

$W_2 = 315$, $\eta = 33\%$, and thus $W_1 = 950$ w, and $\frac{E_{1\text{mod}}}{E} = 0.8$.

$$I_m = \frac{950}{5{,}000} = 0.19 \text{ amp.}$$

$$I_{\text{maxmod}} = 1.33 \ (= 7 \times 0.19)$$

$$\frac{E_{1\text{mod}}}{E} = 0.98\left(1 - \frac{1.5 \times 1.33 \times 400}{5{,}000}\right) = 0.82$$

$$E_1 = \frac{0.82}{2} \times 5{,}000 = 2{,}050 \text{ V.}$$

$$I_1 = \frac{2 \times 315}{2{,}050} = 0.308 \text{ amp.}$$

$$R_1 = \frac{2{,}050}{0.308} = 6{,}670 \text{ ohm.}$$

$$\xi = 1 + 2.64\,\frac{8{,}000}{6{,}670} = 4.15$$

$$M = \frac{20}{4.15} = 4.8$$

$$e = \frac{2{,}050}{4.8} = 426 \text{ V.}, \ e_{\text{eff}} = 302 \text{ V.}$$

$$\bar{e}_{di} = -0.3 \times 400 - 55 = -175 \text{ V.}$$

$$\bar{e} = -(426 - 102)\,0.2 - 175 = -240 \text{ V.}$$

$W_{\text{diss}} = 950 - 315 = 635$ watt less than 1,500 watt O.K.

8.3. *Let us calculate an amplifier with the same valve, but with an output power of $W_2 = 75$ w. only.*

Let us put $\phi = 90°$, i.e. $\bar{e} = \bar{e}_{di} = -175$ V. $W_2$ being very small, we put $r = 3$. Thus

$$\delta = \sqrt{\frac{3.4 \times 75}{5{,}000 \times 2.5}} = 0.26 = \frac{E_1}{E}$$

$E_1 = 0.26 \times 5{,}000 = 1{,}300$ V., and from (13)

$$\eta = 0.785 \times 0.26 = 20.5\%.$$

$$I_1 = \frac{2 \times 75}{1{,}300} = 0.115 \text{ amp.}$$

$$W_1 = \frac{75}{0.205} = 365 \text{ w.}$$

$I_m = \frac{365}{5{,}000} = 0.073$ amp. $= 73$ mA. From (3) or (3a).

$$I_{\text{max}} = 3.14 \times 0.073 = 0.23 \text{ amp.}$$

$$I_{\text{maxmod}} = 0.46 \text{ amp.}$$

$$R_1 = \frac{1{,}300}{0.115} = 11{,}300 \text{ ohm.}$$

$$\xi = 1 + 2\,\frac{8{,}000}{11{,}300} = 2.42$$

$$M = \frac{20}{2.42} = 8.3$$

$$e = \frac{1{,}300}{8.3} = 156 \text{ V.}$$

It may be seen from the characteristic, that the valve will have a steady plate current (without drive) of approx. 40 mA.

$$W_{\text{diss}} = 365 - 75 = 290 \text{ w.}$$

We give in the table below some numerical

| $\phi$ | $\frac{I_{\text{max}}}{I_m}$ | $\frac{I_1}{I_{\text{max}}}$ | $\frac{I_1}{I_m}$ | $\frac{I_{\text{maxmod}}}{I_m}$ | $\frac{I_1}{I_{\text{maxmod}}}$ | $\beta$ | $\eta$ | cos $\phi$ |
|---|---|---|---|---|---|---|---|---|
| 90° $\pi/2$ | 3.14 | 0.500 | 1.57 | 6.28 | 0.250 | 2.00 | $0.785\frac{E_1}{E}$ | 0 |
| 84° 1.48 | 3.30 | 0.486 | 1.60 | 6.60 | 0.243 | 2.27 | $0.808\frac{E_1}{E}$ | 0.1 |
| 78° 1.37 | 3.50 | 0.470 | 1.66 | 7.00 | 0.235 | 2.64 | $0.830\frac{E_1}{E}$ | 0.2 |

values of the most important relations in order to facilitate calculations :

### Symbols

*General :*

| | |
|---|---|
| Plate tension and current with capital letter. | |
| Grid tension and current with small letter. | |
| D.C. values with a dash over the letter | $(\bar{E}, \bar{I})$ |
| A.C. values without a dash over the letter | $(E, I)$ |
| Modulated values are designed with index mod | $(I_{\max\mathrm{mod}})$ |

*Plate :*

| | |
|---|---|
| Instantaneous value of plate current | $I$ |
| Peak value of plate current through the tube | $I_{\max}$ |
| Amplitude of 1st harmonic of plate current | $I_1$ |
| Average of the D.C. component | $I_m$ |
| Total emission | $I_s$ |
| Steady plate tension | $\bar{E}$ |
| Amplitude of 1st harmonic of A.C. plate tension | $E_1$ |
| Peak value of A.C. plate tension | $E_p$ |

*Grid :*

| | |
|---|---|
| Absolute value of negative grid bias | $\bar{e}$ |
| $\frac{\bar{E}}{\mu}$ (cut-off bias) | $\bar{e}_d$ |
| Amplitude of A.C. grid tension | $e$ |
| Direct current component of the composite voltage $(\bar{e} - \bar{E}/\mu)$ | $\bar{e}_c$ |
| Amplitude of the A.C. comp. of the comp. volt. $e - \frac{E_p}{\mu} \cong e - \frac{E_1}{\mu}$ | $e_c$ |
| Cut-off bias of the straight line characteristic | $\bar{e}_{di}$ |

$\mu$ amplification factor
$R_1$ tank circuit impedance
$R_p$ plate resistance
$g(\mu = R_p g)$ mutual conductivity
$\xi$ amplification loss factor
$M(=\mu/\xi)$ amplification of the stage
$\phi$ operating angle.

# The Industry

TECHNICAL information on interference suppression which has been issued for some time past by Belling & Lee, Ltd. in the form of periodical bulletins, has been reprinted in booklet form under the title of "Radio Interference Bulletins." Those professionally interested in the subject may obtain copies for 1/2 post free from Belling & Lee, Ltd., Cambridge Arterial Road, Enfield, Middlesex.

A cathode-ray oscillograph, a signal generator and a combined resistance-capacity inductance bridge are described in a leaflet issued by The Mullard Wireless Service Co., Ltd., Mullard House, 225, Tottenham Court Road, London, W.1.

Re-designed and improved versions of the Marconi-Ekco Electrolytic Condenser Bridge, Distortion Factor Meter and Output Power Meter are described in leaflets available from Marconi-Ekco Instruments, Ltd., Electra House, Victoria Embankment, London, W.C.2.

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**Television Engineering**

By J. C. Wilson. Pp. 492 + xv. Published by Sir Isaac Pitman and Sons, Ltd., 39, Parker Street, London. Price 30s.

Had this book been entitled "A History of Mechanical Television" it could meet with nothing but praise. Since it bears the title of "Television Engineering," however, one naturally expects it to be up-to-date and to include details of modern television equipment. So far from this being the case, in the chapter headed "Modern Television Equipment," the apparatus most completely described is the long superseded 30-*line gear,* used by the B.B.C. in 1932/35. Truly modern equipment, such as that in regular use for the last year, is dismissed in a few lines.

The major portion of the book is devoted to a description of the eye, optics, scanning systems, and synchronising, stress being laid on mechanical methods. This part of the book is good and an extraordinarily wide range is covered ; while the bibliography is very complete. This material, however, is of more interest to the student, who requires some knowledge of the early stages, than to the engineer, who is concerned primarily with the design of apparatus for present-day use.

The sections of the book which bear more directly upon modern technique are less satisfactory, for the data are very sketchy. In the case of time-bases, for instance, many circuits are given and their mode of operation briefly explained, but few of them are accompanied by any indication of the optimum values of components nor are the data necessary for calculating such values given. It is above all information of this kind that the engineer wants, and he gets it only rarely in the case of the more modern type of apparatus.

The purpose of the book is apparently to provide a source of reference to television engineers. For this, however, it contains far too much of merely historical interest and much too little representative of modern practice.

W. T. C.

# Correspondence

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

## The Use of a Name

*To the Editor, The Wireless Engineer.*

SIR,—When George Thomas John Fitzchumly shows qualities of popular concern, his exploits are not reported as those of George Thomas John. Above all, in scientific writing a name should identify the object. Yet, queerly often, when the behaviour of a thermionic valve is reported, the valve is given only half its name. For instance, in your August issue (page 414), we read of a "V.T.40 valve." A curious valve this, perhaps, which we should like to meet; but the surname is missing. We must search through all directories available, and hope to find George Thomas John.

I ask you, Sir, to use your influence with authors. When a "Mulram P.Q.5" is meant, let it not be called a "P.Q.5." If some obscure objection be felt to naming the maker of a valve, it were better to omit the arbitrary code designation, and to quote the rated amplification and conductance values. But why not the name? L. B. TURNER.

Engineering Laboratory,
Cambridge.

## Novel Method of Coupling.

*To the Editor, The Wireless Engineer.*

SIR,—I have read with interest Mr. Beard's letter in the November issue and patent specification (No. 19369 of 1934) to which he referred.

The trouble about the two arrangements shown in his specification is that they will both produce numerous phantom signals. As an example, his first figure, which shows a receiver designed to cover the normal broadcast band of 550–1,500 kc/s, using a first and second I.F. of 428 and 102 kc/s respectively, will give trouble owing to the following causes amongst others:—

Calling the first oscillator frequency $f_1$
second oscillator frequency $f_2$
first intermediate frequency $f_3$
second intermediate frequency $f_4$
signal frequency $f_5$

$$\begin{aligned} 2f_2 &= 1060 \text{ kc/s} = f_5 \\ f_1 - 2f_2 &= f_3 \quad \text{when } f_1 = 1488 \text{ kc/s.} \\ 3f_2 - f_1 &= f_3 \quad \text{when } f_1 = 1162 \text{ kc/s.} \\ 2f_1 - 3f_2 &= f_3 \quad \text{when } f_1 = 1009 \text{ kc/s.} \end{aligned}$$

etc., etc.

The first of these equations means that the 2nd harmonic of the 2nd oscillator will heterodyne an incoming signal of about 1060 kc/s.

The next three equations show how the first I.F. can be produced by a mixture of the two oscillators or their harmonics, thus producing phantom carriers and consequently whistles. It was to avoid these spurious responses that in the double superhet I described in your July issue I increased my first I.F. to 5155 kc/s; with such a value of I.F., mixture effects can only be produced by fourth or higher harmonics of the two oscillators, which in practice are of low enough amplitudes to prove almost negligible. Mixture effects due to fundamentals, second and third harmonics are by no means negligible even with careful screening and de-coupling. Or does Mr. Beard claim that with divided capacity oscillators this is no longer the case?

As regards Mr. Beard's last question as to whether I have investigated the possibilities of using an intermediate frequency equal to the sum of the beat frequencies instead of the difference in order to minimise phantom signals, my answer is that it makes practically no difference in the case of a high first I.F. and low second I.F.

$$\begin{aligned} \text{Since} \quad f_1 &= f_3 \pm f_5 \\ \text{and} \quad f_2 &= f_3 \pm f_4 \\ \hline f_1 - f_2 &= \pm f_5 \mp f_4 \end{aligned}$$

This shows that the difference in frequency of the two oscillators is almost independent of whether the first I.F. is obtained by sum or difference terms. The second I.F., being low, can only be obtained by difference terms. R. I. KINROSS.

London, W.2.

## Symbols

*To the Editor, The Wireless Engineer.*

SIR,—With reference to the Editorial in your November number, may I suggest that G.W.O.H. would perform a valuable service for wireless engineers and others if he would devote an article to definitions of electric force, electromotive force, potential gradient, and potential difference. I have never yet found definitions of these quantities that would bear close examination. Our standard text books often give one definition of e.m.f. in terms of the chemistry of primary cells, another in terms of magnetic flux, perhaps another in terms of thermo-electric effects, and usually they make no attempt to establish any sort of consistency between them. The terms p.d. and e.m.f. are often used quite indiscriminately, and it is not difficult to understand why so distinguished an author as Mr. Albert Campbell should, in the preface to a book* on electrical measurements, make the somewhat caustic statement "We have avoided the use of misleading terms like electromotive force. . . ."

I would suggest that we badly need sound definitions of the four quantities, suitable symbols, and satisfactory statements of Ohm's Law and of Kirchhof's Laws. It is clear from your November Editorial that G.W.O.H. has a definite use for the four concepts I have mentioned, and knowing from past experience that anything he may write will lack neither precision of statement nor sufficient force of expression to compel immediate attention, I am hopeful that he will soon clear away much of the confusion that undoubtedly exists on this subject. J. HARTSHORN.

Hampton, Middlesex.

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* A. Campbell and E. C. Childs. "The Measurement of Inductance, Capacitance and Frequency." (Macmillan, 1935).

# 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 selection of abstracts from patents issued in the U.S.A. is also included, and these bear a seven-figure serial number.*

## TRANSMISSION CIRCUITS AND APPARATUS

467 840.—High-frequency oscillation-generator of the split-anode " magnetron " type.

*Telefunken Co. Convention date (Germany) 22nd December,* 1934.

468 271.—High-frequency oscillator of the type in which both magnetic and electrostatic control fields are applied to an electron stream.

*Standard Telephones and Cables (assignees of H. J. Scott). Convention date (U.S.A.) 20th May,* 1935.

468 289.—Transmitting system giving a high percentage of modulated carrier from a low-powered signalling current.

*F. G. Frost and Sterling Works (Dagenham). Application date 1st January,* 1936.

468 596.—Magnetron-tube circuit, suitable for the generation, amplification, or reception of ultra-short waves arranged for high sensitivity and requiring low control or modulation power.

*Telefunken Co. Convention date (Germany) 16th October,* 1935.

468 724.—Common-wave broadcasting system in which means are provided to measure and regulate the phase or frequency of the waves radiated from the various stations.

*R. J. Berry (communicated by C. Lorenz, Akt.). Application date 1st May,* 1936.

468 756.—Series-modulated transmitter in which the control-grid voltage includes a rectified component of the modulated energy, for the purpose of regulating the carrier-wave output in accordance with the load.

*Marconi's W.T. Co. and E. Green. Application date 8th January,* 1936.

## RECEPTION CIRCUITS AND APPARATUS

467 335.—Modulating or amplifying circuit in which negative feed-back is used to minimise the effects of frequency distortion.

*J. Hardwick and E. L. C. White. Application date 15th October,* 1935.

467 430.—Method of automatic gain control which depends upon varying the value of a feed-back impedance connected in the cathode circuit of the amplifying valve.

*Marconi's W.T. Co. and N. M. Rust. Application date 16th December,* 1935.

467 573.—Securing negative-resistance and straight-line characteristic effects from valves of the so-called " beam " type.

*Marconi's W.T. Co.; N. M. Rust; and G. F. Brett. Application date 16th December,* 1935.

467 667.—Super-regenerative receiver, particularly for television, designed to give high amplification even with a rapid quenching frequency.

*W. S. Percival. Application date 20th November,* 1935.

467 754.—Superhet receiver in which the operation of tuning is facilitated by the production of an audible warning note.

*E. K. Cole and H. C. Rowe, Jnr. Application date 2nd March,* 1936.

467 833.—Thermionic amplifier with negative feed-back for reducing valve " noise " and eliminating cross-modulation.

*Standard Telephones and Cables and E. K. Sandeman. Application date 23rd December,* 1935.

468 675.—Permeability tuning arrangement designed to give a constant coupling coefficient over a wide band of frequencies.

*Johnson Laboratories Inc. (assignees of W. A. Schaper). Convention date (U.S.A.) 26th June,* 1935.

468 834.—Homodyne receiver in which an isolating " beam valve " precedes the detector.

*Marconi's W.T. Co. and G. M. Wright. Application date 13th December,* 1935.

469 077.—Method of automatically tuning a wireless receiver based on piezo-electric control.

*J. Robinson. Application date 10th January,* 1936.

469 380.—Multi-wave receiver in which the automatic selectivity control is linked up with the wave-change switch.

*E. K. Cole. Convention date (Sweden) 4th July,* 1936.

## VALVES AND THERMIONICS

468 623.—Electron multiplier with external means for controlling the direction of the electron stream through the tube, and thereby the number of targets it impacts against, and the strength of the final output.

*J. E. Keyston. Application date 8th November,* 1935.

469 111.—Electron multiplier in which the first impact electrode or " target " is more highly emissive than subsequent ones.

*W. E. Williams. Application date 18th January,* 1936.

## DIRECTIONAL WIRELESS

467 785.—Directive aerial system in which at least three rotating loops are coupled to a radiogoniometer with the object of eliminating " night effect."

*Telefunken Co. Convention date (Germany) 19th October,* 1935.

470 060.—Direction-finding system in which the pick-up from a pair of fixed frame aerials is passed through an electric "switching" circuit to a direct-reading indicator.

*Soc. Francaise Radio-Electrique. Convention date (France) 30th December,* 1935.

470 596.—Wireless navigational system in which a "guiding-line" or flying course is formed by two overlapping beams of radiated energy.

*Telefunken Co. Convention date (Germany) 25th June,* 1935.

## TELEVISION AND PHOTOTELEGRAPHY

467 366.—Cathode-ray television receiver in which the received picture is reproduced by the incandescence of a screen made of a knitted fabric of refractory wire.

*Farnsworth Television Inc. Convention date (U.S.A.) 7th May,* 1935.

467 838.—Method of producing photo-electric mosaic screens for use in cathode-ray television transmitters.

*Marconi's W.T. Co. Convention date (U.S.A.) 21st December,* 1934.

467 958.—Time-base circuit for television in which the charging current for the condenser varies the bias on all three grids of a pentode valve.

*Standard Telephones and Cables (assignees of F. R. Norton). Convention date (U.S.A.) 25th February,* 1936.

467 995.—Optical system for magnifying the image produced on the fluorescent screen of a cathode-ray television receiver.

*Marconi's W.T. Co. and N. Levin. Application date 27th December,* 1935.

468 294.—Mechanical scanning disc giving a higher degree of definition at the centre of the picture than elsewhere.

*J. G-S. Arathoon. Application date 21st January,* 1936.

468 350.—Means for preventing "flicker" by stabilising the amplifiers in a television receiver.

*Radio-Akt. D. S. Loewe. Convention date (Germany) 25th July,* 1935.

468 394.—Push-pull time-base circuits for generating the scanning voltages used in television.

*The General Electric Co., Ltd., and D. C. Espley. Application date 14th January,* 1936.

468 437.—Arrangement of the control knobs on the panel of a television receiver.

*Radio-Akt. D. S. Loewe. Convention date (Germany) 4th December,* 1934.

468 795.—Cathode-ray television receiver with focusing means designed to produce a clear-cut picture of sufficient intensity to allow it to be optically projected on to an external viewing screen.

*Farnsworth Television Inc. Convention date (U.S.A.) 6th February,* 1935.

468 808.—Time-base circuit for producing saw-toothed oscillations for interlaced scanning.

*Radio-Akt D. S. Loewe. Convention date (Germany) 16th May,* 1935.

468 837.—Television transmitter in which the picture is simultaneously scanned over two mutually-exclusive areas by the ordinary and extraordinary rays from a double-image prism.

*Baird Television and G. E. G. Graham. Application date 13th January,* 1936.

468 891.—Rectifying unit for supplying operating voltages of from 4,000–10,000 volts for a television receiver.

*Radio-Akt. D. S. Loewe. Convention date (Germany) 12th December,* 1934.

469 033.—Cathode-ray tube structure combined with an electron-multiplier for use in television.

*H. G. Lubszynski. Application date 16th January,* 1936.

## SUBSIDIARY APPARATUS AND MATERIALS

467 412.—Meter for continuously indicating the presence of distortion in an amplifier, particularly when the load varies from time to time, as in a broadcast relaying system.

*Rediffusion and P. Adorjan. Application date 11th December,* 1935.

467 435.—Headband for telephone ear-pieces comprising a wire loop the two ends of which are independently and rotatably mounted in the supporting member.

*Standard Telephones and Cables and J. S. P. Roberton. Application date 16th December,* 1935.

469 018.—Means for generating mechanical waves of supersonic frequency by piezo-electric control for application to a light-valve used in television.

*Scophony and J. H. Jeffree. Application date 14th January,* 1936.

469 197.—Loud-speaker movement in which the effective inertia of the moving coil is reduced for the higher frequencies.

*E. K. Cole and A. E. Falkus. Application date 10th March,* 1936.

## MISCELLANEOUS

467 572.—Method of making powdered-iron cores for high-frequency coils.

*G. W. Johnson (communicated by I. G. Farbenindustrie Akt.). Application date 16th December,* 1935.

468 230.—Standby or "watchdog" relay for responding automatically to a definite sequence of signals, such as the emergency call used at sea.

*Y. Watanabe. Convention date (Japan) 2nd June,* 1935.

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## "The Necessary Conditions for Instability (or Self-Oscillation) of Electrical Circuits"

The author of the article under the above heading which appeared in the November issue, regrets that the following errors occurred therein:

Page 591—in lines 36 and 39 of Col. 2 for 15 read 10. Equation 12 should be

$$AI_1 = V_1$$
$$CI_1 + DI_2 = V_2$$

Page 592 (Col. 2) in lines 18, 28 and 31 for 20 read 15; in line 23 for 21 read 16 and in line 45 for 22 read 17.