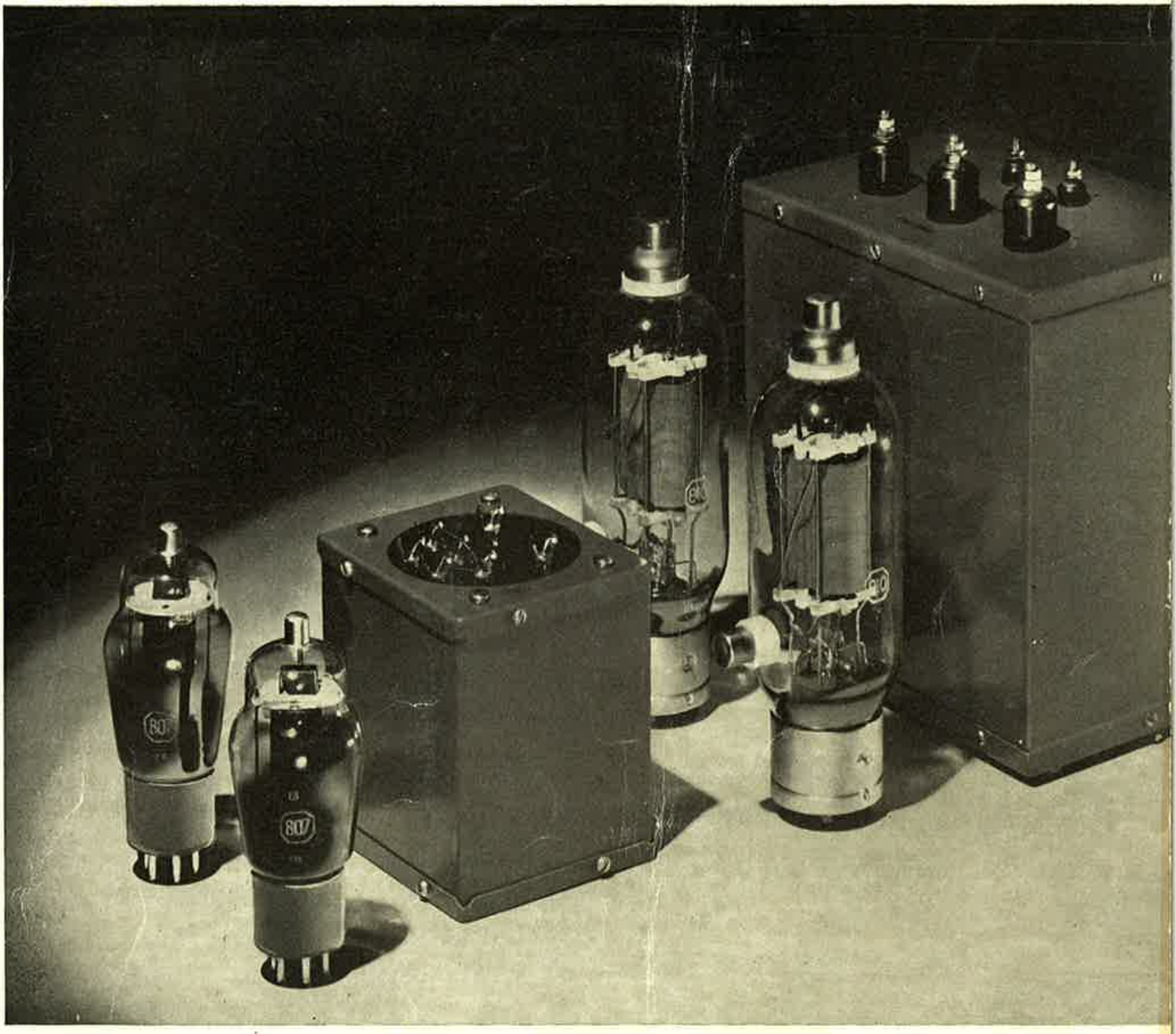
Radiotronics

AN A.W.V. TECHNICAL PUBLICATION DEVOTED TO RADIOTRONS AND THEIR APPLICATION

Number 146
DECEMBER, 1950
Price, 1/-



Nucleus of a high-powered push-pull amplifier.

RESEARCH • DESIGN • MANUFACTURE

Number 146 **December, 1950**

CHRISTMAS ISSUE

RADIOTRONICS

A Radiotron technical release published in Sydney, N.S.W.,
by Amalgamated Wireless Valve Co. Pty. Ltd.

Technical Editor:
F. Langford-Smith, B.Sc., B.E.,
Senior Member I.R.E. (U.S.A.).

Asst. Tech. Editor:
Ian C. Hansen, Member I.R.E. (U.S.A.).

Sub-Editor:
R. Ainsworth, A.S.T.C., A.M.I.R.E. (Aust.).

CONTENTS

IMPORTANT

With the January, 1951, issue of Radiotronics the issue numbering system will be changed from its present consecutive form. Radiotronics has been published for approximately 15 years, and the January, 1951, issue will hence be referred to as Vol. 16, No. 1.

All communications should be directed in Australia to—
Amalgamated Wireless Valve Co. Pty. Ltd.
(Technical Publications Department)
47 York Street, Sydney.

in New Zealand to—
Amalgamated Wireless (Australasia) Ltd., P.O. Box 830, Wellington, C1, N.Z.

Radiotronics is published six times a year, and the subscription for the year 1950 is 5/-

The Design of a Push-Pull Amplifier and Driver Stage

A push-pull circuit is shown in Fig. 1. When a signal e'_g is impressed upon the primary of the input transformer, equal and opposite voltages $+e_g$ and $-e_g$ are impressed upon the grids of the two valves. The plate current of one valve is caused to increase, while that of the other is decreased, and if the grid swing is sufficiently great, one current will increase to a maximum value, while the other will drop to zero. (Cut off.) Design considerations are practically always based on peak grid swing and resultant maximum power, hence in the analysis that follows it will be assumed that either valve's plate current is alternately driven to cutoff.

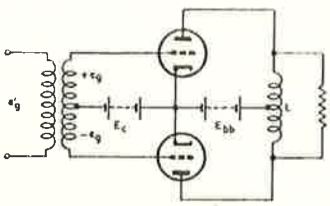


Fig. 1.

Note that the load resistor is represented by R_l, extending from plate to plate; and the output transformer by *L*, a centre tapped choke. In actual practice *L* would be the primary of the output transformer, and the load resistance would be connected to the stepdown secondary of this transformer. This condition can be reduced to the circuit shown in Fig. 1 very simply. Thus, suppose the stepdown ratio of the output transformer is 20:1, and the connected load is 15 ohms, then the equivalent plate to plate resistance shown as R_l in Fig. 1 is $15 \times (20)^2$ which is 6000 ohms. In the method to be described, R_l the plate to plate resistance will be determined, and then the step-down ratio can be calculated that will make the actual given load resistance look like the desired plate to plate resistance. Thus, suppose it is found that a plate to plate resistance of 3800 ohms is optimum for the pair of valves chosen, and the actual load resistance is 500 ohms. The step-down ratio for the output transformer is:—

$$a = \sqrt{\frac{3800}{500}} = 2.76:1$$

The output of each valve in a push-pull stage depends upon the load impedance it faces, just as in any other power circuit. However, the load seen by either valve is not only the reflected value of R_l as it appears across its half of the primary, but the reflected value of the plate resistance of the other valve as well.

The result is that the load seen by either valve is variable or nonlinear over a cycle of signal voltage, and this introduces a major complication. Fortunately this complication can be avoided for the grid swings great enough to bring either valve alternatively to cutoff and beyond, for at cutoff a valve acts as an open circuit, and is therefore temporarily out of the picture. The other valve at this point of the cycle sees an impedance of $R_l/4$ since R_l (Fig. 1) bridges the entire primary, and is stepped down by $(2)^2:1$ to the half primary to which the valve in question is connected. We can now proceed with the design.

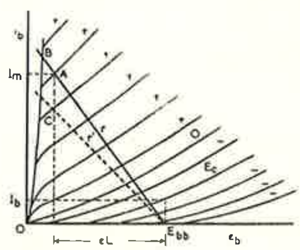


Fig. 2.

In Fig. 2 is shown a valve characteristic set of curves. For the B supply voltage of E_{bb}, a bias voltage E_c must be chosen such that the resultant d.c. plate current I_b does not produce excessive plate dissipation under no-signal conditions. If W_{pd} is the maximum plate dissipation permitted by the manufacturer, then the maximum value of I_b is

$$I_b = W_{pd}/E_{bb}$$

Example

An 812 type valve is to be operated at a plate voltage of 1250 volts, and the maximum plate dissipation is 40 watts. Then the maximum d.c. plate current is

$$I_b = \frac{40}{1250} = .032 \text{ amp. or } 32 \text{ mA}$$

This will require a bias of about –29 volts (found from the valve characteristics). Smaller values of I_b can be employed with a reduction in plate dissipation and an improvement in all-day operating economy. Thus, if the bias is increased to –36 volts the current will be reduced to 24 mA, and the plate dissipation to $.024 \times 1250$ which is 30 watts. The penalty is slightly increased distortion, since the tubes will be operating closer to Class B conditions. This is usually of no consequence. To find the optimum value of R_l, the plate to plate resistance; proceed as follows. Through E_{bb} draw a line r at a slope equal to the average slope of the valve curves themselves in the upper left hand region, above the points where the curves drop abruptly. The slope of this line represents one quarter of the plate to plate resistance, R_l.

To evaluate, choose any point on r, such as A. To this, corresponds a current I_m and a net voltage eL as shown. Then

$$R_l = \frac{4eL}{I_m}$$

In Fig. 2, point A happened to be chosen up on r where a plate current curve just begins to bend down sharply. The next curve for a more positive grid voltage has begun to bend sharply (Point B). The maximum grid swing should not go appreciably beyond A, for otherwise excessive distortion will result, and the grid driving power will be excessive. Thus point A represents the maximum grid swing that can be used. The power output will be

$$P_o = \frac{I_m^2 \ R_l}{8}$$

There remains to be determined, the d.c. power input, P_i. The plate dissipation per valve under full signal conditions will then be

$$W_{pd} = \frac{P_i - P_o}{2}$$

and must not exceed the manufacturer's rating. The plate dissipation at full signal swing is in general, different from that at no signal, and can be excessive under improper design conditions.

As signal is applied to the stage, and power output obtained, the current in either valve changes from a steady d.c. to a distorted combination of d.c. and a.c., and the new average value or d.c. component is greater than its previous steady or no-signal value. This is due to a property of the valve known as self-rectification, and is the mechanism by which the valve draws a greater amount of d.c. input power to cover the a.c. output power plus its losses. (Plate dissipation.) Call the new increased value of the d.c. plate current I'_b. Then P_i equals $I'_b E_{bb}$. It remains to determine I'_b. An approximate formula is as follows:

$$I'_b = \frac{k}{2}\left(\frac{I_m}{2} + I_b\right)$$

where I_m and I_b are defined by Fig. 2. The value of k depends upon the ratio of I_m to I_b. For I_m/I_b equal to 10 or less, k is about 1.05. For I_m/I_b between 50 and 10, k is about 1.12 and for I_m/I_b larger than 50, k is about 1.20. From I'_b, P_i can be found and then W_{pd}, the plate dissipation. Suppose this is excessive. A reduction in grid swing and power output is indicated. But if the grid swing is reduced, the load resistance can be increased, and this counteracts the tendency for the power output to decrease because the plate efficiency is improved. Hence the reduction in power output to keep the plate dissipation within bounds will be appreciable, but not excessive. In Fig. 2 a revised grid swing

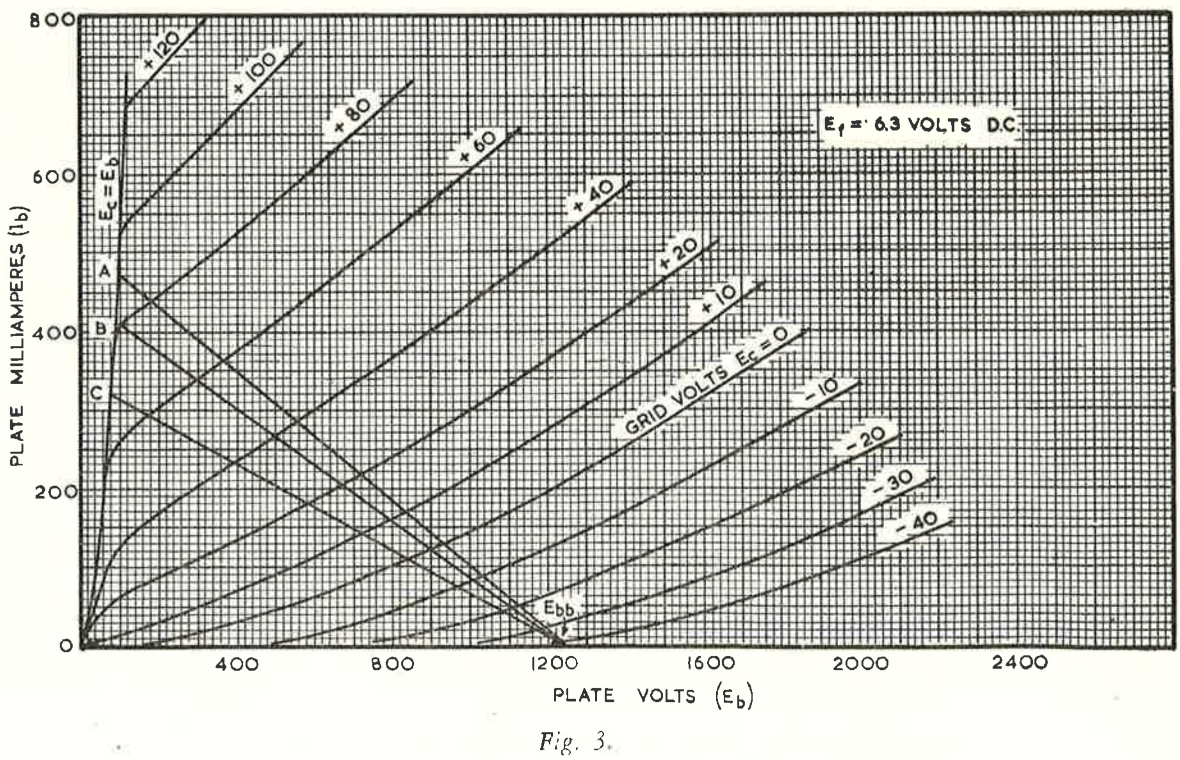


Fig. 3.

corresponding to point C is shown, to which corresponds a higher value r' of $R_l/4$. A few trials will generally yield a value of R_l and peak grid swing that will meet the plate dissipation requirements. The maximum power output can then be found. An example will help explain the method.

In Fig. 3 is shown the plate characteristics for an 812 triode.

A plate voltage of 1250, and an initial (no-signal) plate current of 24 mA, corresponding to a bias of –36 volts, will be employed. The average slope of the valve curves is exemplified by the +80 volt curve. This corresponds to a resistance of

$$\left(\frac{800 - 100}{.695 - .405}\right) = 2410 \text{ ohms.}$$

The procedure involved here is to take any two well separated points on E_c equals +80 volts curve and to divide the difference in the plate voltage values at these points by the difference in the plate current values at the points. Follow the inclined E_c equals +80 volts curve and the vertical line representing plate voltage of 800 volts until they intersect. From the intersection move horizontally to the left and read 695 mils on the vertical (plate mils) scale.

The tentative plate to plate resistance should be 4 × 2410 equals 9640 ohms. The line corresponding to 2410 ohms has been drawn in on Fig. 3. It indicates that a peak grid swing of about +90 volts may be possible. The peak current is 475 mA (point A). To this corresponds a power output of

$$P_o = \frac{(.475)^2\ (9640)}{8} = 272 \text{ watts}$$

The new d.c. component is

$$I'_b = \frac{1.12}{2}\left(\frac{475}{2} + 24\right) = 146 \text{ mA.}$$

The value of k is taken as 1.12 because

$$\frac{475}{24} = 19.8$$

or between 50 and 10. The d.c. power input for both valves is

$$P_i = 2 \times 1250 \times .146 = 366 \text{ watts}$$

The plate dissipation at full signal is

$$W_{pd} = \frac{366 - 272}{2} = 47 \text{ watts per valve}$$

This exceeds the allowable value of 40 watts, hence the grid swing must be reduced.

Let us proceed vertically downward to point B in Fig. 3. This represents a grid swing to +80 volts instead of +90 volts. The peak current I_m is 405 mA. Then the plate to plate resistance is

$$R_l = \frac{4\ (1250 - 100)}{.405} = 11360 \text{ ohms}$$

The rest of the calculations are:—

$$P_o = \frac{(.405)^2\ 11360}{8} = 233 \text{ watts.}$$

$$P_i = 2 \times 1250 \times .127 = 318 \text{ watts.}$$

$$I'_b = \frac{1.12}{2}\left(\frac{405}{2} + 24\right) = 127 \text{ mA.}$$

$$W_{pd} = \frac{318 - 233}{2} = 42.5 \text{ watts.}$$

which is still excessive. Hence try point C on Fig. 3. Then I_m equals 320 mA, and the peak swing is estimated to be about +70 volts.

$$R_l = \frac{4\ (1250 - 80)}{.32} = 14630 \text{ ohms.}$$

$$I'_b = \frac{1.12}{2}\left(\frac{320}{2} + 24\right) = 103 \text{ mA.}$$

$$P_o = \frac{(.32)^2\ 14630}{8} = 187 \text{ watts.}$$

$$P_i = 2 \times 1250 \times .103 = 257.5 \text{ watts.}$$

$$W_{pd} = \frac{257.5 - 187}{2} = 35.3 \text{ watts.}$$

This is an acceptable value, hence the latter calculations can be taken as the final ones. It will be of interest to compare these with those furnished in the valve manual. The values furnished by the manufacturer (RCA) are as follows:—R_l equals 15000 ohms plate to plate. P_o equals 175 watts. I'_b equals 100 mils. W_{pd} equals 37.5 watts. Peak swing +69 volts from an initial bias of –36 volts. The results are fairly close, particularly if it be noted that the values given by the manufacturer include the limitations imposed by a push-pull 6L6 driver stage required to drive the grids of the 812 valves. It is possible to make a more accurate analysis graphically, particularly for the value of I'_b. The labour required is considerable, however, and even where warranted, need be performed only as a check on the final set of values determined by the approximate method just described.

Driver circuit design

In the preceding section, the optimum load impedance, grid drive, power output and plate dissipation for a pair of 812 valves operating in Class AB_2 were discussed. The values found were as follows:—

Optimum load impedance	14630 ohms
Grid drive (per valve)	From –36V to +70V or 106V total
Power output (both valves)	187 watts
Plate dissipation (per valve)	35.3 watts
Plate voltage	1250V
Grid bias	–36V

It was tacitly assumed that the grids could be driven 70 volts positive without the grid current distorting the grid drive voltage, i.e., that the preceding driver stage had zero internal resistance. An actual driver, however, has an appreciable internal resistance, and this in turn produces an internal voltage drop when grid current flows. Since the grid current flows only when the 812 grids are driven positive, the above internal voltage drops occur mainly at the peaks in the grid drive voltage; for the positive peak this is due to one 812 grid drawing current, and for the negative peak this is due to the other 812 grid drawing current, since the centre-tapped secondary of the driver transformer produces voltages of opposite polarity on the two 812 grids, as was indicated in Fig. 1 of the preceding article.

The result of this is that the driver voltage is reduced or flattened on the positive and negative peaks. Such symmetrical distortion of the grid driver voltage indicates the production of odd harmonics. Thus the signal input to the 812 stage is not sinusoidal in shape, as previously assumed, but is itself distorted owing to the flow of grid current. Such distortion is in addition to that produced in the output (plate) circuit of the 812 valves. Since the output is also symmetrical in connection, the distortion there is also of the odd harmonic type. A fair approximation of the distortion both in the grid and plate circuits is to assume that it is mainly third harmonic (although appreciable fifth, and even higher odd harmonics may be present). It may be that the third harmonic produced in the plate circuit is opposite in polarity to that produced in the grid circuit and equal in effect, so that the two cancel. In such an event the driver stage is easier to design. On the other hand, the two harmonics may be additive for certain valves, so that the problem becomes more difficult.

It is proposed to furnish a method here, whereby the driver stage may be designed so that the net third harmonic distortion is a certain permissible percentage of the fundamental current required for a desired fundamental power output. The method, while approximate, gives a fairly good idea of what driver valve or valves are required, what driver input voltage is necessary, and what type of driver transformer is required. It even indicates whether or not it is possible to design the stage, in the event that an unreasonably low distortion is demanded for a required power output.

First the actual grid current flow must be determined. The grid current is a function of the instantaneous (positive) grid voltage and the instantaneous plate voltage. Its plot is most conveniently represented by a grid family of curves as shown in Fig. 4. Each curve is for a different fixed value of positive grid voltage, and shows how the grid current varies with plate voltage. In dynamical operation of the stage, i.e., when a plate-to-plate load is present, the plate voltages as well as the plate currents of the two 812 valves vary with the instantaneous grid voltages. The instantaneous grid current, for every instantaneous value of positive grid voltage and hence plate voltage, can be found as follows:—

The path of operation for the plate current and

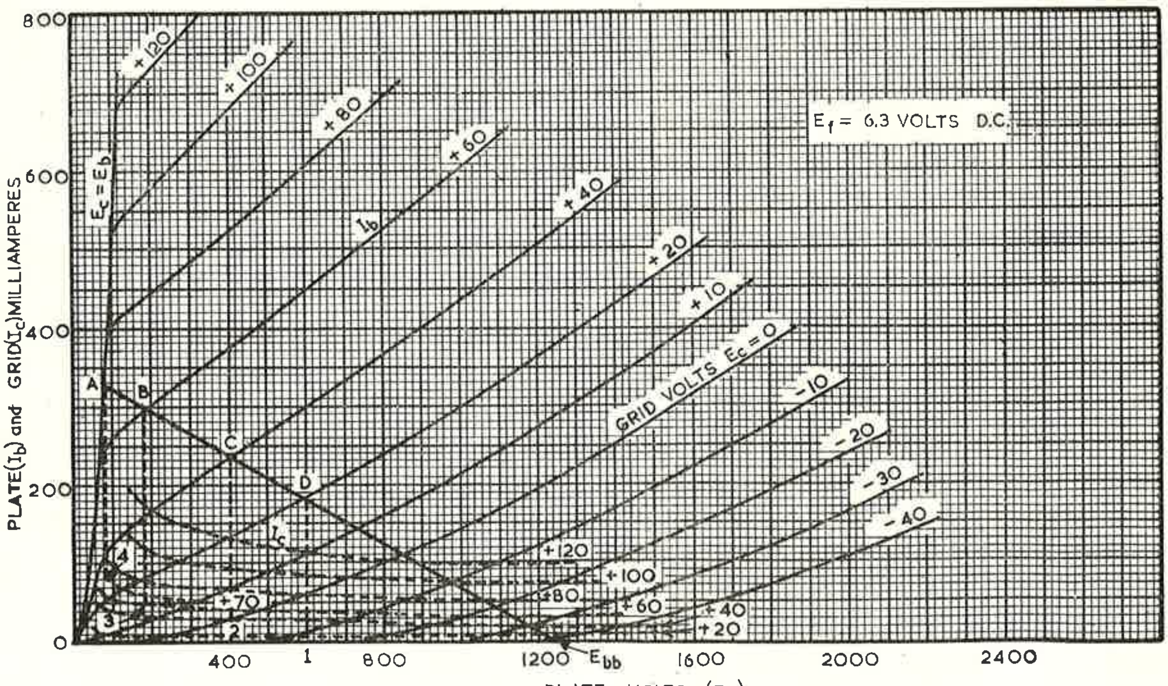


Fig. 4.

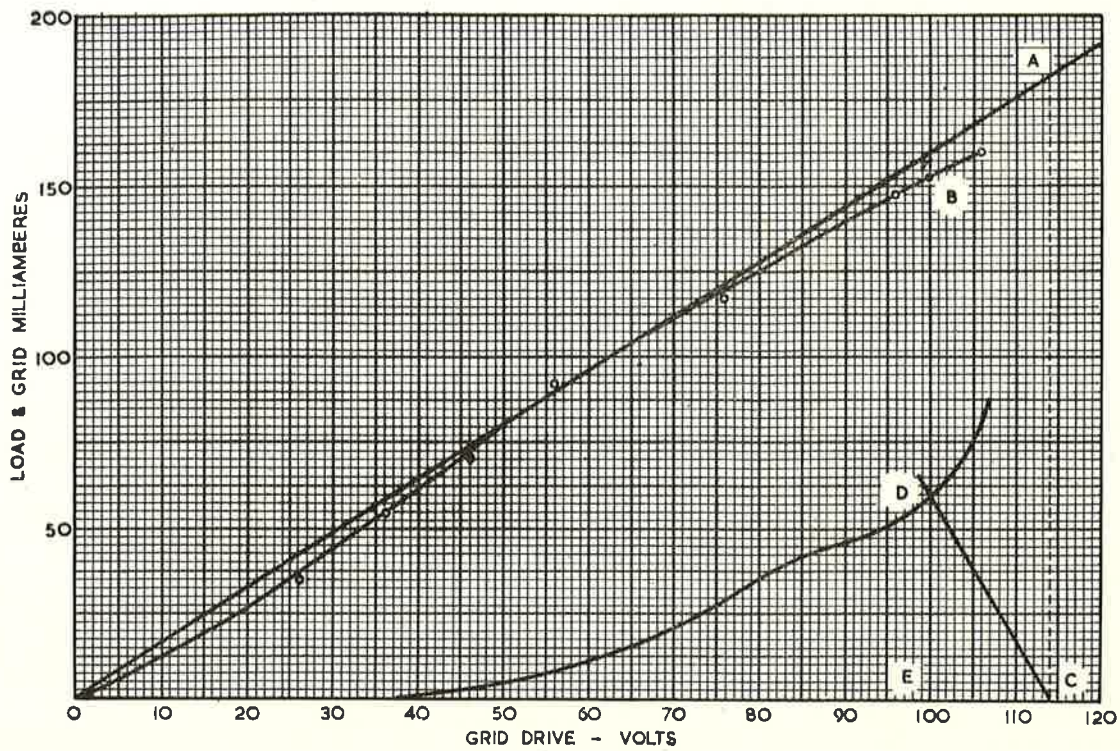


Fig. 5.

plate voltage of each valve is shown in Fig. 4 by the dotted line which blends into the lower part of the straight line ABCD. Our interest lies mainly in the straight line portion that involves the larger grid swings. This line has the slope $R_l/4$ mentioned in the previous section, and when prolonged, intersects the plate voltage axis at a value equal to the plate supply voltage E_{bb}. Consider a grid swing of +20 volts. This intersects the path of operation in point D. The plate current at that instant is 182 mA and the plate voltage is 590 volts. The ordinate through D intersects the +20 grid current curve in point 1. The grid current is then given as 8 mA. This is the instantaneous grid current for that grid swing and the corresponding plate voltage. Furthermore, the load current flowing through the plate-to-plate load resistor is half of the plate current, owing to the 2:1 step down in current from the half winding to the entire output winding, and hence has the value of 182/2 or 91 mA.

Next take point C corresponding to +40 volts grid swing. The plate current is 232 mA, the plate voltage is 400 volts, and the grid current (point 2) is 30 mA. The load current is 232/2 or 116 mA. In a similar manner the load and grid currents for points A and B (and corresponding points 4 and 3) can be found. Other values of load current for grid swings insufficient to draw grid current should be determined as above. In the present example, values down to that for à –10 volt swing will be sufficient. This will embrace the straight line portion ABCD and yet avoid the bottom curved portion, which is more difficult to determine since it represents that part of the cycle where both valves are operative. (Straight line portion ABCD represents the part of the cycle where one valve is beyond cutoff and hence inoperative). The values of load current and grid current are now plotted versus grid swing, as shown in Fig. 5. Note that the grid swing is measured from the bias value. For example, for point D in Fig. 4, the grid voltage is +20, and the grid swing is 20– (–36) = 56 volts. Similarly for the other points. For zero grid swing, the load current is obviously zero, so that the load current plot (upper curve in Fig. 5) passes through the origin. The grid current (lower curve) reaches zero at a 36 volt swing, since this just cancels the –36 volts bias and brings the grid up to zero volts. We are now ready to use these curves in computing the driver design characteristics.

Suppose 187 watts fundamental power output is desired, and the permissible distortion is 5%, a typical value. First determine the peak fundamental current required to give 187 watts in a 14630 ohm plate-to-plate load resistor. This is

$$I_f = \sqrt{\frac{2\,P_o}{R_l}} = \sqrt{\frac{2 \times 187}{14630}} = 159.9 \text{ mA}$$

Now calculate the following two quantities

$$(1 + 3n)\ I_f \quad \text{and} \quad (1 - n)\ I_f$$

where n is the permissible percentage distortion. In the problem at hand these are

$$(1 + 3 \times .05)\ (159.9) = 184 \text{ mA and}$$
$$(1 - .05)\ 159.9 = 152 \text{ mA}$$

Next draw a straight line OA in Fig. 5 so that it coincides most nearly with the lower part of the load current curve. In the case of the 812 valves, this curve appears to have somewhat of a figure S shape, whereas the load current curve for most valves is more nearly straight near the origin, and it is possibly easier to fit a straight line to it. However, the line OA shown in Fig. 5 is a fairly good approximation. **On OA** lay off the value of 184 mA, **point A.** Then locate on **the load current curve** the value of 152 mA. This is **point B.** Project A down to the abscissa axis—point C, and B down to the grid current curve—point D. Then CD is the load line of the driver as it appears to either 812 grid, i.e. it indicates the maximum resistance that the driver can appear to have as seen by either grid, without the distortion exceeding 5% for 187 watts output. The value of this resistance is simply

$$R_D = \frac{CE}{DE} = \frac{114 - 100}{.06} = \frac{14}{.06} = 233 \text{ ohms}$$

The driver circuit must be so designed as to appear as a 233 ohm source to either grid. However, the actual driver is a valve whose internal (plate) resistance is in the order of thousands of ohms. In order for it to appear as only 233 ohms, a stepdown transformer is required between it and the 812 grids. This stepdown transformer is generally called a driver transformer, and it is necessary to determine not only its stepdown ratio, but its winding resistances as well.

First a driver valve or valves must be selected. Suppose we choose a pair of 807 valves, triode-connected, in a push-pull arrangement. The complete circuit is shown in Fig. 6. The resistance of either half of the primary winding of the driver transformer is represented as $R_{pw}/2$, so that of the entire primary is R_{pw}, while that of either half of the secondary winding is denoted by R_{sw}. Let the stepdown ratio of the entire primary to one half of the secondary be denoted by a.

An 807 triode-connected has the following characteristics:

$$R_p = 1700 \text{ ohms} \quad \mu = 8 \quad G_m = 4700$$
$$E_{bb} = 250\text{V} \quad E_c = -20\text{V}$$

From Fig. 5 we find that the peak generated voltage at either 812 grid is 114 volts. Owing to the flow of grid current, the actual grid voltage is only 100 volts, but the driver must be able to develop 114 volts at the 812 socket when the valve is removed, i.e. when no grid current is permitted to flow. Since the 807 valves are in push-pull their resistances appear in series, or 2 × 1700 equals 3400 ohms. To this must be added the total driver transformer winding resistances, as they appear at the primary side, i.e. $R_{pw} + a^2R_{sw}$, since only one half of the secondary is involved at any one time. Assume that $R_{pw} + a^2R_{sw}$ equals 10% of 3400 ohms, or 340 ohms. This is a fair value for the resistance of the winding of a transformer operating from a 3400 ohm source. Then the total resistance on the primary side is 3400 + 340 equals 3740 ohms. This must be stepped down to 233 ohms as determined graphically. Then

$$a = \sqrt{\frac{3740}{233}} = 4:1$$

In the mid-frequency audio range where the driver transformer approaches the ideal transformer in action, the driver stage gain is practically equal to the valve's amplification factor, μ. Since 114 volts must be generated at either grid, the primary voltage must be 4 × 114 equals 456 volts, and across the two grids of the 807's there must appear a voltage of 456/8 or 57 volts. Each grid receives half of this, or 28.5 volts.

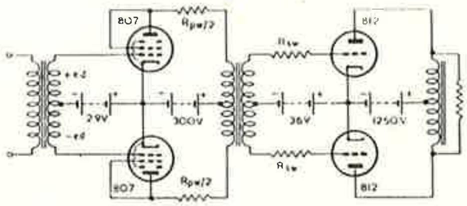


Fig. 6.

However the bias is only 20 volts, so that the grids will be driven 8.5 volts positive. Hence this stage will have to be driven, too. This may be obviated by increasing the plate voltage to 300 volts, and the bias to –29 volts, with a quiescent plate current of about 33 mA. This gives a plate dissipation at no-signal of .033 × 300 or 10 watts, which is within the triode rating. The valves are not operating exactly as a power stage in this type of work. Indeed, such power valves are required only because they can furnish the signal drive required, and present a source of sufficiently low internal resistance, hence low voltage regulation. Their power output is in itself small, since the 812 grids draw current only at the peaks in the voltage cycle.

This concludes the design of the driver stage. The methods derived above can be used in the above example to determine the driver stage when valves other than 807's are employed, as well as for any output stage.

ERRATA RADIOTRONICS 145

We have been advised by RCA that the parts list for figure 6 appearing on page 115 should read as follows: L = 0.5 μH; R_8 = 0.5 MΩ 0.5 watt; R_9 = 7500 Ω 5 watts; R_{10} = 50,000 Ω 5 watts; R_{11} = 35,000 Ω 100 watts. Noted ✓

Universal Coil Winding

By E. WATKINSON, A.S.T.C., A.M.I.E. Aust., M.I.R.E. (Aust.).*

SUMMARY.—A typical coil winding machine and the winding patterns derived from it are described. The various factors which influence the choice of the coil winding gear ratio are explained and analysed. The results are presented in a form suitable for slide rule computation. The detection of faults in winding machines is discussed and the paper includes a bibliography of the existing literature on universal coil winding.

INTRODUCTION

The object of this paper is to present coil winding from a physical rather than a mathematical point of view — to build up a mental picture of the coil winding process and from this picture to deduce the requirements which a coil winding gear ratio must meet. In addition, in the calculation of gear ratios consideration is given to a factor which although not normally taken into account has been found helpful in the mass production of coils. The attached bibliography gives details of universal coil winding literature already in existence.

SYMBOLS

The symbols used in the following treatment with their meanings are set out below for convenience:—

d = coil former diameter (inches).

c = cam throw (inches).

n = nominal number of crossovers in one former revolution.

q = nominal number of crossovers in one winding cycle.

v = number of former revolutions in one winding cycle.

R = gear ratio = $\dfrac{\text{former gear}}{\text{cam gear}}$

w^1 = wire diameter (inches). See text.

w = modified wire diameter (inches). See text.

P = qc/s.

s = $w + x$.

x = smallest amount necessary to make $(qc + s)/vs$ an integer (inches).

T = number of turns in coil.

N = number of spokes on side of coil.

H = winding space.

α = angle between wire and edge of coil.

* Senior engineer, circuit development group, A.W. Valve Co. Pty. Ltd., Ashfield.

Reprinted from Proc. I.R.E. (Aust.) by courtesy of the Institute of Radio Engineers (Aust.).

DESCRIPTION OF MACHINE

The most generally used type of machine is belt driven at a fixed speed, although it is possible for the operator to slip the foot operated clutch to minimize strains on the wire when starting. The drive operates on a shaft directly connected to the former and from this shaft a gear drive to the cam shaft is provided. There is provision for a chain of four gears although the middle pair can be replaced by a single idler if desired. In general the number of teeth on the gears used lies between 20 and 60.

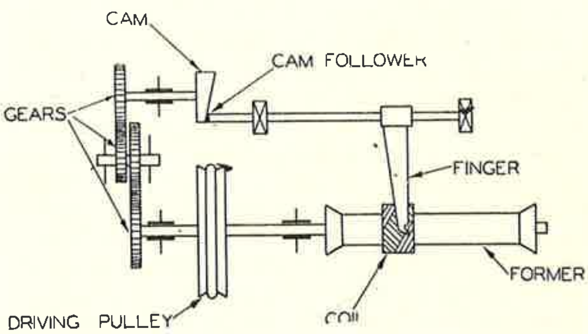


Figure 1. Essential features of a typical coil winding machine.

The shape of the cam is such that the displacement of the cam follower is linear with respect to rotation of the cam. The cam follower is spring loaded against the face of the cam and drives a carriage along guides running parallel with the length of the coil former. On this carriage is mounted the finger which directs the wire on to the former. Figure 1 shows the essential features of such a machine. The wire is fed to the finger over a chain of spring loaded pulleys which, by controlling the pressure on a brake band mounted on the same shaft as the reel of wire, maintain an approximately even tension on the wire, prevent it from snapping when it has to set the reel in rotation and take up the slack wire when the machine is stopped suddenly.

DERIVATION OF PATTERN

While many defects will prevent a coil from winding correctly, the first requirement for a properly wound coil is a suitable gear ratio between former and cam. In considering the effects of different gear ratios it is convenient to use a developed pattern of the coil winding. This is obtained by allowing the coil to proceed for one winding cycle, i.e., for the maximum number of complete turns which can be placed on the former before one turn lies against a previously wound turn. The former is then considered to be split lengthwise and flattened and the pattern results from the excursions of the wire across the former.

Under these conditions Figure 2 shows the pattern obtained with a 1 to 1 gear ratio, giving one cam revolution for each former revolution. Since each cam revolution gives two crossovers, $n = 2$ when the gear ratio is unity. In the list of symbols, n is defined as the nominal number of crossovers per turn and q as the nominal number of crossovers per winding cycle because no account is taken when determining them, of the slight variation in the number of crossovers brought about by the necessity for wire spacing. As a result, n is always an integer or a simple fraction, and q is always an even number. A discussion of wire spacing is given later. Figure 3 shows the pattern when $R = \frac{1}{2}$ and Figure 4 the pattern for $R = \frac{3}{4}$. The method of drawing the pattern in the case of Figure 4, for example, is as follows. Starting at A the wire makes n crossovers by the time the former has travelled πd, finishing the first turn at B. The second turn starts at B^1 and after n more crossovers finishes at C. The third turn starts at C^1 and the pattern continues in this manner until it finishes in the bottom right hand corner at E. Each of the above patterns shows one winding cycle of q crossovers and v turns. In the case of Figure 4 it will be seen that $v = 4$ and $q = 6$.

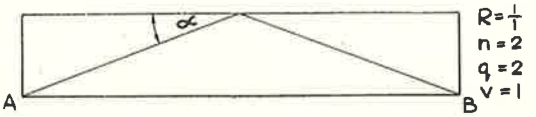


Figure 2. The winding pattern produced with a 1 to 1 gear ratio; $n = 2$, $q = 2$, $v = 1$.

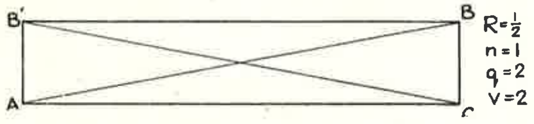


Figure 3. The winding pattern produced with a 1 to 2 gear ratio; $n = 1$, $q = 2$, $v = 2$.

The necessity for making use of patterns other than that obtained from a 1/1 ratio will be appreciated when it is realised that if the angle ∝ at which the wire crosses the former is too great, the wire will slide on the former at the point at which the cam alters its direction of movement. On the other hand the coil gains its mechanical rigidity only from the fact that wires in a layer are held in position by wires in the next layer crossing them at an angle thus holding them down firmly. Because of this ∝ must not be too small. The angle of ∝ is obviously dependent on d and c, and to wind coils with different cams and on formers of different diameters, it is necessary to vary the value of n, with consequent variations in the pattern. Although the maximum angle at which the wire will lie on the former without slipping varies with different wire coverings and different types of former materials, it is found that so long as

$$n \leq \frac{2d}{3c} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

coils with all commonly used wire coverings can be wound on any of the former materials normally encountered without trouble from slipping being experienced. When $n = 2d/3c$, ∝ is approximately 12 degrees. However, as the winding proceeds, the effective diameter of the coil increases and consequently ∝ decreases so that when a coil is required to build up appreciably it is desirable to start the winding with ∝ near its maximum permissible value.

It is found that the simpler the pattern the more mechanically stable will be the resulting coil and mechanical stability is essential if coils are to duplicate electrical properties accurately. Consequently, when deciding the value of n, it is desirable to choose an integer or a simple fraction, to complete the winding cycle after as few former revolutions as possible. Since n must not exceed the maximum obtained from (1) the next smallest convenient value below the maximum must be used. For example, suppose a coil is to be wound on a $\frac{9}{16}$ inch diameter former with a $\frac{1}{4}$ inch cam, $2d/3c = 3/2$ and n can be given this value, in which case the pattern of Figure 4 will result. A simpler pattern and a better coil will result if n is made equal to unity, giving the pattern of Figure 3.

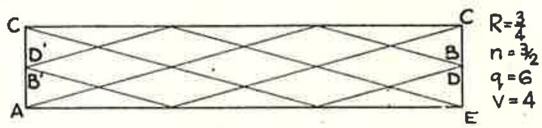


Figure 4. The winding pattern produced with a 3 to 4 gear ratio; $n = 3/2$, $q = 6$, $v = 4$.

Other factors to be borne in mind when determining n are firstly that the maximum speed at which a coil winding machine can be operated is usually the greatest speed at which the cam follower will accurately follow the shape of the cam when its direction of movement is reversed. Consequently the value of n determines the speed at which the machine can be operated and the larger the value chosen for n the slower the machine must run. With normal adjustments a machine will wind a coil using a $\frac{1}{8}$ inch cam and two crossovers per turn at 1400 r.p.m. without the cam follower "hopping", but higher speeds, a larger cam, or more crossovers per turn may give trouble. The lower limit for n seems to be more dependent on cam throw, wire diameter and details of machine adjustment than the upper, but it can usually be assumed that a coil will build up until $n = d/6c$ and it may sometimes be convenient to design so that this limit is approached at the top of the coil.

The second restriction on the choice of n is that if n gives a pattern with crossing wires (Figures 3 and 4, but not Figure 2), i.e. if n has any value other than an even integer, then one or more ridges will appear in each layer of the coil at the point of the cam travel marked by the crossing wires. These ridges are not themselves undesirable, but if the wire used in the winding is insulated only with enamel it is difficult to prevent the finger, as it travels to and fro across the face of the coil, from removing the enamel from the wire forming the ridge.

Despite the apparent complexity of the above considerations, it is found in practice that the majority of coils are wound with two crossovers per turn, this being the correct choice for a $\frac{1}{16}$ inch cam on a former of $\frac{3}{16}$ inch to $\frac{3}{8}$ inch diameter, or for a $\frac{1}{8}$ inch cam on a former of $\frac{3}{8}$ inch to $\frac{3}{4}$ inch diameter.

CHOICE OF CAM

Where the cam is to be chosen before n can be decided, the following points should be remembered.

Q of coil

Maximum Q is usually obtained for a coil in which the diameter of the winding is approximately equal to its length whether or not the coil is wound in sections. This assumes that there is reasonable clearance (about equal to the radius of the coil) between the outside of the coil and any shield that it may have. If the clearance is smaller, a flatter coil will give a better Q.

Ratio of cam to wire diameter

The cam should always be wide enough for at least six and preferably more wires to lie across the face of the coil. If this requirement is not met, difficulty will be experienced in making the coil build up.

Distributed capacitance

The smaller the cam the lower will be the distributed capacitance of the winding for a given inductance and wire size.

Split windings

A coil wound in sections with thin individual windings usually has a smaller distributed capacitance than a solid winding, and thus a better Q since the losses in stray capacitances in coils are high.

Height of coil

The larger the cam the smaller will be the height of the coil for a given inductance and wire size.

WIRE SPACING

Consideration so far has been given only to the angle at which the wire is placed on the former. After the first cycle the patterns described would begin a second cycle on top of the first. This would not give a stable winding and the second purpose of the gear drive is to displace each pattern, or winding cycle, by some convenient amount from the preceding one. Normally the wire in the second cycle is made to lie alongside and as close as possible to the wire in the first cycle, although this slight displacement is not usually taken into account in the drawing of the pattern. This gives two possibilities, as shown in Figures 5 and 6. The dotted line shows the pattern produced by a 1/1 gear ratio, and the

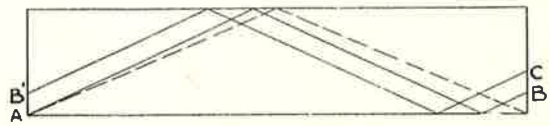


Figure 5. A retrogressive coil winding.

winding, shown in full lines, proceeds from A to B during the first revolution of the former, and from B^1 to C during the second revolution. Figure 5 shows the effect produced when the cam returns, just before the end of the winding cycle, to the side of the coil from which it started; in Figure 6, it returns to the side of the coil just after the end of the winding cycle. Coils wound as shown in Figure 5 are retrogressive coils, and those shown in Figure 6 are progressive coils. In each case the former is rotating towards the left hand side of the figure and the wire is placed on it under tension by a finger located on the right hand side. In

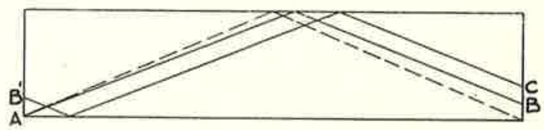


Figure 6. A progressive coil winding.

Figure 5 the tension from the right pulls each turn against the preceding turn, while in Figure 6 the tension pulls the turn away from the preceding ones. The result is that a more solid winding is obtained with retrogressive gears and in practice it is found that with coils that are at all difficult to wind, as for example when very fine wire is being used or if a machine is not in perfect condition, retrogressive coils build up more readily than progressive ones. For this reason the treatment that follows is for retrogressive coils.

The spacing needed between adjacent wires can only be found by experiment and it is not possible to specify any one spacing factor which will give the best results with enamelled wire, litz wire and fabric covered wire. In fact, to obtain the best results, i.e. to wind large coils under difficult conditions, even with fabric covered wire, it is necessary to use different spacing factors depending on the flexibility of the wire and the sponginess of the coverings. However, it is possible to give a rule from which gears can be calculated, resulting in a coil that will build up (other requirements being met satisfactorily) and with a likelihood that they will be the best gears for a given set of conditions. A problem in deciding the spacing to allow for each wire is the determination of the thickness of the wire itself. Even when wire tables are available, many wires do not conform sufficiently accurately with the figures stated for them to be used, and with fabric covered wires the method of measurement has a considerable effect on the result. The method used in work on which this paper is based is to tighten the micrometer until the wire can only just be pulled between the measuring surfaces by a tension similar to that exerted by the tension device on the coil winding machine. An occasional high spot can be ignored and under these conditions the micrometer setting is taken as the wire diameter.

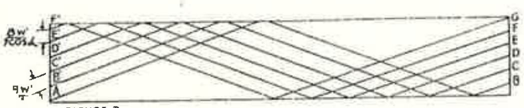


FIGURE 7

Figure 7. The relation between wire spacing and cam movement.

Normally a coil is wound as tightly as possible so that it will be small physically, and a spacing between centres of adjacent wires of approximately $8w^1/7$ is found experimentally to meet this requirement for fabric covered wires. When the wire is enamelled only, the same spacing can be used if the diameter of bare wire is used for w^1. The required spacing factor is governed by the type of finger used and for the spacing mentioned, a finger such as that described in section 13.2 which places the wire in position on a coil is assumed. For cases in which the wire is fed through a groove on top of the finger larger spacing factors are needed, and accurate control of wire position in the coil is not possible. It will often be found that solid wires with fabric covering will give an improved winding with smaller spacing factors, while litz wire windings may improve with more spacing. However, the spacing quoted seems to be the best compromise for the conditions stated and can usually be depended upon to give a winding sufficiently stable for production purposes.

It will be seen from Figure 7 that to give a spacing of $8w^1/7$ between the centres of adjacent wires, it would be necessary for the cam to give a spacing of $8w^1/7 \cos \propto$ at the same point of former rotation in the winding cycle.

However, since $\propto \leqq 12$ degrees, so that $\cos \propto$ lies between unity and 0.978, it is convenient in practice to ignore $\cos \propto$ and to measure $8w^1/7$ in terms of cam displacement across the face of the coil.

SPOKES

Since each cam revolution produces two crossovers of the wire on the former it is necessary when comparing cam travel with former travel to use two crossovers, $2c$ as the unit of cam travel and one former revolution πd, as the unit of former travel. A gear ratio can be expressed as the ratio R of former gear to cam gear, but since a large former gear driving a small cam gear gives a small former movement and a large cam movement,

$$R = \frac{\text{cam travel}}{2c} \div \frac{\text{former travel}}{\pi d}$$

$$= \frac{\text{cam travel}}{\text{former travel}} \cdot \frac{(\pi d)}{(2c)}$$

To produce the patterns of Figures 2, 3 or 4, in which the cam travel is qc, and the former travel πdv,

$$R = \frac{qc\ (\pi d)}{\pi dv\ (2c)}$$

To give the necessary spacing between the wires at the end of one winding cycle and the beginning of the next in a retrogressive coil, the total cam travel must be $qc + 8w^1/7$ for a former travel of πd. For convenience the quantity $8w^1/7$ is termed the modified wire diameter w, and the required gear ratio for a retrogressive coil is

$$R = \frac{qc + w}{\pi dv} \cdot \frac{(\pi d)}{(2c)}$$

$$\therefore R = \frac{qc + w}{2cv} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Since the total cam movement is $qc + w$ while the former completes a winding cycle, the coil former moves through $qc/(qc + w)$ of a winding cycle, while the cam completes q crossovers. Thus towards the end of each winding cycle (after q crossovers) the finger returns to the side of the coil from which it started and reaches the side displaced

$$\left\{ 1 - \frac{qc}{qc + w} \right\}$$

i.e. $w/(qc + w)$ of a winding cycle from its starting point. Since a winding cycle is πdv, the finger returns to the edge of the coil displaced $\pi dv.w/(qc + w)$ from its position at the beginning of the cycle.

The amount $\pi dv.w/(qc + w)$ is a winding space, H, and in terms of the actual winding it represents the distance around the edge of the coil between adjacent wires at the peak of the cam travel. Figure 8 shows the first few turns of a coil in the case where $n = 2$, $q = 2$ and $v = 1$.

When the coil has been wound the winding spaces can be seen on the edge of the coil, and if successive layers have winding spaces directly above each other spokes appear on the side of the coil extending radially outwards from the former as shown in Figure 9. Where there is a slight displacement of the winding cycles in each layer, these spokes become spirals and with large displacements

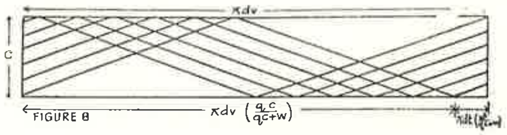


Figure 8. The first few turns of a coil for which $n = 2$, $q = 2$, $v = 1$.

NOTE:—The term at the bottom right hand corner of the diagram should read

$$\pi dv \left\{ \frac{w}{qc + w} \right\}$$

the spokes tend to disappear completely. It is considered desirable to produce straight spokes in production coils because this allows a very easy check on the condition of coil winding machines. A badly adjusted machine, or one with faulty bearings or a worn finger shows up these faults with an indistinct set of spokes, or none at all, before it will give trouble through coils not building up or being rejected electrically. In addition coils wound with straight spokes appear to build up more readily than those with none.

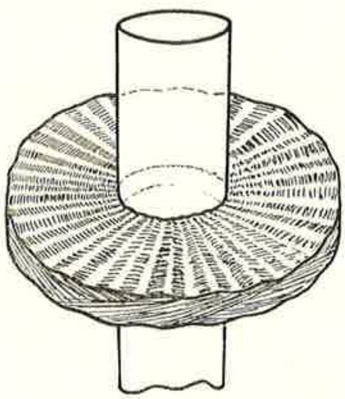


Figure 9. Illustration of side pattern obtained with suitable gear ratio.

To produce coils with straight spokes it is necessary for the number of winding spaces per turn to be an integer. However, one turn of the former is πd and one winding space is $\pi dv.w/(qc + w)$, so that $\pi d \div \pi dv.w/(qc + w)$ i.e. $(qc + w)/vw$ must be an integer. None of these quantities is a variable, so some modification is required. The modification consists of increasing the spacing between adjacent wires by a small amount x, and the required gear ratio (equation 2) can be written as:—

$$R = \frac{qc + s}{2cv} \quad \ldots\ldots\ldots\ldots \quad (3)$$

where $s = w + x$; x is the smallest amount necessary to make $(qc + s)/vs$ an integer N, where N is the number of spokes on the side of the coil. Similarly, the formula for a winding space is modified to

$$H = \pi dv \frac{s}{(qc + s)} \quad \ldots\ldots\ldots \quad (4)$$

CALCULATION OF GEAR RATIO

All the information necessary to determine the gear ratio for a given set of requirements is now available, but the form is unsuitable for manipulation on a slide rule, since it involves adding s, which will be of the order of 0.01 inch and which must be maintained accurately, to qc which may be 0.5 inch or larger. However,

$$R = \frac{qc + s}{2cv};$$

but by definition $q = nv$. Therefore

$$R = \frac{n\,(qc + s)}{2qc}$$

$$= \frac{n}{2} \left\{ 1 + \frac{s}{qc} \right\}$$

$$= \frac{n}{2} \left\{ 1 + \frac{1}{P} \right\} \text{ since } P = qc/s$$

$$\therefore R = \frac{n}{2} \left\{ \frac{P + 1}{P} \right\} \quad \ldots\ldots\ldots \quad (5)$$

Moreover $N = \dfrac{qc + s}{vs} = \dfrac{1}{v} \left\{ \dfrac{qc}{s} + 1 \right\}$

$$\therefore N = \frac{P + 1}{v} \quad \ldots\ldots\ldots\ldots \quad (6)$$

On the basis of the above treatment, a concise instruction for the calculation of gears has been prepared. This instruction is presented in Appendix I.

ESTIMATION OF COIL SIZE

It is often desirable to estimate the size of a coil before actually winding it, and to do this it is necessary to know the number of layers in the coil and the thickness of each layer.

A layer is most conveniently defined as the smallest number of turns that will just cover the area on which the layer is wound. This definition results in a layer with a thickness of two wires, and the number of turns in the layer can be readily determined, since

Turns per layer = (turns per winding cycle) × (winding cycles per winding space) × (winding spaces per layer).

By definition there are v turns per winding cycle. Since there are q crossovers per winding cycle and two crossovers are needed to form one winding space, there are $q/2$ winding spaces per winding cycle, and $2/q$ winding cycles per winding space. In addition from equation 6, the number of winding spaces per ~~winding cycle~~ layer is

$$\frac{P+1}{v}$$

Thus the number of turns per layer is

$$v \times \frac{2}{q} \times \frac{P+1}{v} = \frac{2(P+1)}{q}$$

Now if T is the number of turns in the coil, the height of the coil is $Tq/2(P+1)$ multiplied by the height of one layer which is approximately $2w^1$. Thus the height of a coil of T turns is $Tqw^1/(P+1)$.

Example

A coil is to be wound with 500 turns of 42 S.W.G. enamelled wire;

$$R = \frac{n}{2}\left\{\frac{P+1}{P}\right\} = \frac{44}{43}$$

The diameter of 42 S.W.G. enamelled wire is 0.0044 inch, so the height of the coil will be

$$\frac{500 \times 2 \times 0.0044''}{44} = 0.1 \text{ inch}$$

Practical modifications

In practice it is found that heights calculated as above may vary as much as ± 10 per cent. However, a very close approximation of the final size can be obtained, if the following points are remembered.

1. Coils of large gauge solid wire and coils with ridges, tend to become larger than calculated.
2. Coils of fine enamelled wire without ridges are nearly exact.
3. Coils with fabric covering, particularly if the wire is stranded, tend to be smaller than calculated.

GEAR RATIO BY INSPECTION

If a retrogressive coil has been properly wound so that it is possible to count the winding spaces on the side, the gear ratio with which the coil was wound can be determined by inspection. The number of spokes N is $(P+1)/v$ and the gear ratio is known to be

$$\frac{n}{2}\left\{\frac{P+1}{P}\right\}$$

From an inspection of the top layer of the coil, the number of crossovers per turn, n, may be found and from n the number of turns per winding cycle, v, can be deduced, or obtained from Table I in the Appendix.

Now $Nv = P + 1$ so that

$$\frac{P+1}{P} = \frac{Nv}{Nv-1}$$

Therefore the required gear ratio is

$$R = \frac{n}{2}\left\{\frac{Nv}{Nv-1}\right\} \quad \ldots\ldots\ldots\ldots \quad (7)$$

Example

A coil has seventeen spokes on the side and is wound with two crossovers per turn. Thus $n = 2$, $v = 1$ and

$$R = \frac{n}{2}\left\{\frac{Nv}{Nv-1}\right\} = \frac{17}{16}$$

USE OF SLIDE RULE IN UNUSUAL CASES

It sometimes happens through a required gear being unavailable that it is not possible to set up the coil winding machine with the simple ratio

$$\frac{n}{2}\left\{\frac{P+1}{P}\right\}$$

In such cases a coil cannot usually be wound with straight spokes, but for experimental purposes it may be desirable to ignore this feature to obtain a coil which will approximate a production coil wound with the correct gears. This can be done in the following manner. Reduce R to a single fraction and set this up on the slide rule with the denominator on the C scale and the numerator on the D scale. Choosing two gears known to be available, multiply by the number of teeth in the first, and divide by the number of teeth in the second. Scan the C and D scales for integers exactly opposite each other for which gears are available. If there are none, shift a second number under the cursor and continue in this manner until a matching pair of integers is obtained on the C and D scales. Set up the four integers as gears in the coil winding machine in the order:—

$$R = \frac{\text{D scale number}}{\text{C scale number}} \times \frac{\text{dividing number}}{\text{multiplying number}}$$

The D scale number will be the gear mounted on the same shaft as the former.

Example

A coil is to be wound with $c = 0.125$ inch and $R = 17/16$, but suitable gears with this ratio are not available. Set up 17/16 on the slide rule, multiply by 43 and divide by 44 and it will be found that 26 on C scale coincides with 27 on the D scale. Thus the desired ratio is

$$\frac{27}{26} \times \frac{44}{43}$$

Once the gears have been obtained a simple way of remembering the order in which to use them is that starting with the D scale gear the numbers are written down in the reverse order of their occurrence.

PROGRESSIVE COILS

No attention has been paid in the foregoing to progressive coils because of their undesirable winding characteristic as explained previously. However, for the sake of completeness all formulae which are altered for the use of progressive coils are given below:—

	Retrogressive Coil	*Progressive Coil*
Required gear ratio R:	$\frac{n}{2}\ \frac{(P+1)}{P}$	$\frac{n}{2}\ \frac{(P-1)}{P}$
Winding space H:	$\pi dv \frac{s}{(qc+s)}$	$\pi dv \frac{s}{(qc-s)}$
Number of winding spaces N:	$\frac{P+1}{v}$	$\frac{P-1}{v}$
Number of turns per layer:	$\frac{2(P+1)}{q}$	$\frac{2(P-1)}{q}$
Height of coil:	$\frac{Tqw^1}{P+1}$	$\frac{Tqw^1}{P-1}$
Gear ratio R by inspection:	$\frac{n}{2}\ \frac{Nv}{(Nv-1)}$	$\frac{n}{2}\ \frac{Nv}{(Nv+1)}$

In the case of the formulae for determining gear ratios by inspection, it should be noted that unless a coil is known beforehand to be wound retrogressively it is necessary to determine this point as well as N and n or the wrong gear ratio may result. The type of coil is obvious from an examination of the top layer.

FAULT FINDING

As mentioned previously, it is not possible to wind coils with incorrect gears, but correct gears are only one of the many requirements for a coil to build up correctly. The following points may need investigation if poor results are obtained.

Maintenance

Coil winding machines must be kept in good condition so that excessive play does not develop in bearings. Naturally, the finer the wire being wound, the better must be the machines. If a coil is being wound with 0.004 inch wire, a lateral play of 0.001 inch at the finger is more than 20 per cent. of the required spacing between adjacent wire centres.

Fingers

Probably the most important single part of the machine is the finger. Both the original design and the maintenance are important; the design shown in Figure 10, made in steel with the tip hardened, is satisfactory.

With this finger the tension of the wire pulls the finger on to the coil and the wire leaves the finger after having been placed in the correct position. The carriage holding the finger must be secured by means of the collars on the cam follower shaft so that no side play occurs, but loosely enough to allow the finger to fall on to the coil due to its own weight. Otherwise if the finger is knocked upwards during the winding, it may allow a few turns to take up an incorrect position and so spoil the winding.

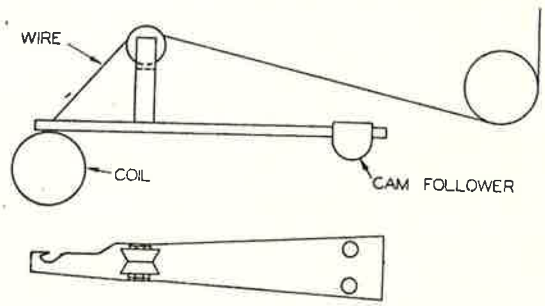


Figure 10. Winding finger.

The shape of the slot in the finger is important, particularly with fine wires. The best shape is a straight V groove with as sharp an apex as possible and with the bottom of the slot rounded only sufficiently to prevent enamel or any other covering from being removed from the wire as it passes through. It is advisable to use a finger made especially for each size of wire to be wound and when the fingers are hardened before use quite satisfactory life can be obtained. As the finger wears, a groove forms underneath it and this groove may not be symmetrical. A coil with good spokes on one side and poorly defined spokes on the other is usually the result of a worn finger.

A convenient method of adjusting the finger to its correct position with respect to the former is to thread the wire through the finger, loosen the finger and pull on the wire. This will pull the finger forwards until the wire passes freely through the groove. If the finger is then pushed backwards just sufficiently to hold the wire between the bottom of the finger and the former, the finger will be correctly located.

Hopping of cam follower

Where a coil does not build up satisfactorily and the spacing between wires is greater on one edge of the coil than elsewhere, it will be found that the cam follower is leaving the face of the cam at the peak of the cycle. A stronger spring may cure the trouble at the expense of additional wear in the machine, but a better remedy is to reduce the cam speed.

Worn cam follower

If one side of a coil continually falls down and the finger is in good condition, it sometimes happens that the cam follower has worn until it will not follow the face of the cam right to the bottom of the cam movement. Sharpening of the follower to a well defined V will remove this trouble.

Excessive tension

Excessive tension, apart from the snapping of wires, often shows up in coils which fall over on either side after winding some few layers with no apparent defects. A more obscure trouble due to too much tension is low Q in litz wire coils. This can be caused by the increased resistance of stretched wire. Excessive tension may also show up by coils being rejected through having too much distributed capacitance in cases where this is important.

Insufficient tension

If not enough tension is used the reel of wire will continue to unwind when the machine is stopped suddenly and the coil will tend to be "spongy" when wound.

APPENDIX I

SYMBOLS

d = coil former diameter (inches).

c = cam throw (inches).

n = nominal number of crossovers in one former revolution.

q = nominal number of crossovers in one winding cycle, i.e. before wire lies alongside preceding wire (See Table I).

v = number of former revolutions in one winding cycle (See Table I).

R = gear ratio = $\dfrac{\text{former gear}}{\text{cam gear}}$

w = modified wire diameter (inches). See note.

$P = \dfrac{qc}{w + x}$ = an integer.

x = the smallest amount necessary to make $(P + 1)/v$ an integer (inches).

NOTE: For fabric covered wire, w = (diameter of covered wire) × 8/7.

If the wire is enamelled only, the same formula is used, but the bare wire diameter is multiplied by 8/7.

PROCEDURE

(a) From $n \leqq 2d/3c$ determine the largest convenient value of n. Do not use values of n less than 2 for bare enamelled wire. Obtain values of q and v from the table below for the value of n chosen.

TABLE I

n	6	4	2	1	2/3	1/2	1/3	1/4
q	6	4	2	2	2	2	2	2
v	1	1	1	2	3	4	6	8

(b) Determine w from information given in the note above.

(c) Calculate P from $P = qc/(w + x)$.

(d) Obtain R from $R = \dfrac{n}{2}\left\{\dfrac{P+1}{P}\right\}$

EXAMPLE 1

Given $d = \frac{1}{2}$ inch and $c = \frac{1}{10}$ inch, determine the gears to wind a coil with 42 S.W.G. enamelled wire.

(a) $2d/3c = 1.0/0.3$. Take $n = 2$, giving $q = 2$ and $v = 1$ from the table.

(b) The diameter of bare 42 S.W.G. wire is 0.004 inch, so $w = 0.00457$ inch.

(c) $P = qc/(w + x)$ and $(P + 1)/v$ must be an integer; thus P must be an integer since $v = 1$. Now $qc/w = 200/4.57 = 43.7$. But $P = qc/(w + x)$ is an integer, so that $P = 43$.

(d) $R = \dfrac{n}{2}\left\{\dfrac{P+1}{P}\right\} =$

EXAMPLE 2

Given $d = \frac{1}{4}$ inch and $c = \frac{1}{4}$ inch, determine the gears to wind a coil with 0.016 inch litz wire.

(a) $\dfrac{2d}{3c} = \dfrac{2}{3}$. Take $n = \dfrac{2}{3}$ giving $q = 2$ and $v = 3$.

(b) $w = 0.016 \text{ inch} \times 8/7 = 0.0183$ inch.

(c) $\dfrac{qc}{w} = \dfrac{500}{18.3} = 27.3$. But $(P+1)/v$ is an integer, so that $P = 26$.

(d) $R = \dfrac{n}{2}\left\{\dfrac{P+1}{P}\right\} = \dfrac{1}{3} \times \dfrac{27}{26}$.

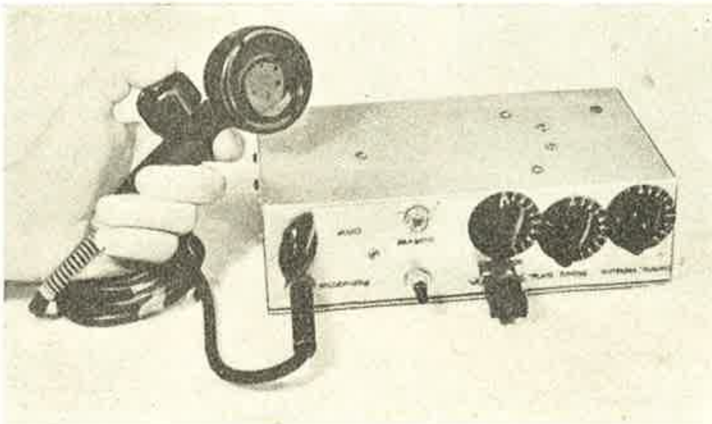
To obtain suitable gears write

$$R = \frac{2}{3} \times \frac{1}{2} \times \frac{27}{26}$$

$$= \frac{28}{42} \times \frac{27}{52}$$

(Continued on page 144)

A New *Miniature* 10-Metre Transmitter



Completely housed in a 5" × 9½" × 2½" chassis, this miniature transmitter is particularly suited for mobile work. It uses the new Radiotron 5763 r-f power pentode as an output valve, and operates with a plate input power to the final of 15 watts at 27 to 30 Mc/s.

By MARTIN GASPIERIK and PAT PATTERSON

RCA Tube Department.

Being avid mobile fans, originally by necessity, later by choice, the possibilities envisioned in the recently announced r-f power pentode, the Radiotron 5763, were intriguing. The result was "Tiny-Tran", a miniature mobile transmitter for 10 and 11 metres. This 5 × 9½ × 2½ inch rig operates with a plate input power to the final of 15 watts at 27 to 30 Mc/s. The heater drain is only 2.7 amperes at 6.0 volts and the plate supply 140 mA at 300 volts.

Let's take a look at the output valve first. The 5763 is a 9-pin miniature transmitting type, capable of 15 watts input up to 175 Mc/s. The high-perveance characteristic is particularly suitable for mobile operation because it considerably reduces power supply problems. Another important feature is the heater rating. The cathode is so constructed as to give full emission with only 6.0 volts applied to the heater. Heater voltage is an important consideration in mobile work since, more often than not, the battery voltage less the line drop approximates this 6-volt figure.

Quite naturally its size, too, is interesting, since the 5763 is only slightly larger in diameter than the 7-pin miniature 6AQ5. When the 5763 is used in the r-f stages, and other miniatures are used in the audio stages, economy of space is at a maximum.

The heater requirements and maximum ratings of the Radiotron 5763 are as follows:

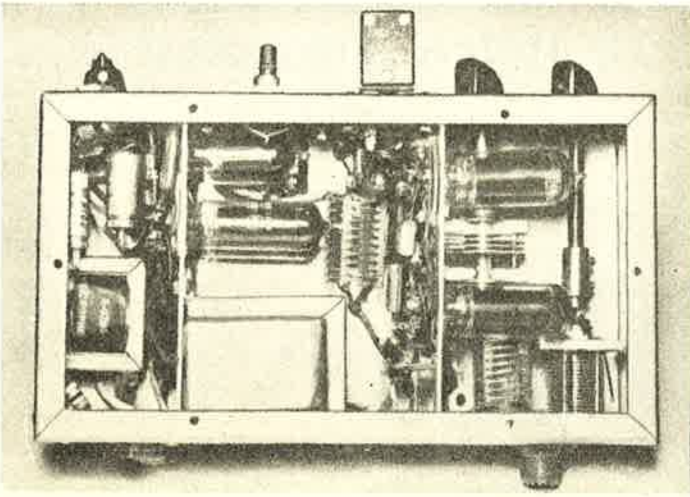
Heater Voltage (a.c. or d.c.) .	6.0 ± 10% volts
Heater Current	0.75 ampere
D.C. Plate Voltage	300 max. volts
D.C. Grid-No. 3 (Suppressor). Voltage	0 max. volts
D.C. Grid-No. 2 (Screen) Voltage	250 max. volts
D.C. Grid-No. 1 (Control-Grid) Voltage	125 max. volts
D.C. Plate Current	50 max. mA
D.C. Grid-No. 2 Current	15 max. mA
D.C. Grid-No. 1 Current	5 max. mA
Plate Input	15 max. watts
Grid-No. 2 Input	2 max. watts
Plate Dissipation	12 max. watts

Design considerations

Because mobile operation can take place anywhere, it seemed advisable to design a unit readily adaptable to a Crosley or a Cadillac, a Piper Cub or a DC-6, a row-boat or the Queen Mary. By employing miniature tubes and small components, it was possible to place the entire circuit inside a small metal chassis 5 × 9½ × 2½ inches. This size and shape lends itself readily to mounting in any number of positions about the panel of a car. Even the glove compartment of most models will accommodate such a box. All controls are brought to the front panel with the exception of the meter jack, which is brought out in the rear.

The bottom plate of the chassis becomes the side panel and gives access to the "innards" of the transmitter by removal of the self-tapping screws. Two

Reprinted from Ham Tips by courtesy of Radio Corporation of America.



An inside view of the transmitter.

sub panels are cut to fit as indicated in the photographs. The lower panel holds the audio stages, while the upper one supports the r-f unit. Some of the components are mounted directly on the chassis, but, despite cramped quarters, all parts and wiring are quite accessible.

Because the 5763 is designed to operate at a high temperature (maximum 250° C) and requires good ventilation, a series of holes is drilled in the top of the case and in the cover plate directly opposite the valves. A similar arrangement is also made for cooling the modulator stage.

R-F section

The r-f section utilizes two of the new Radiotron 5763's, one as tritet oscillator-multiplier, and the other as an r-f final amplifier. When a crystal in the order of 7 Mc/s is used, ample drive to the grid of the final at 28 Mc/s is obtained readily.

An important space-saving feature is the tritet coil which is an r-f choke, the size of a one-watt resistor.

The antenna coupling system is especially interesting because it very effectively discriminates against harmonics. (1) This type of coupling (a modified pi network) compared to the conventional link coupling, provides only $\frac{1}{4}$ of the 2nd-harmonic output, 1/9 of the 3rd-harmonic output, and proportionately smaller amounts of higher-order harmonics.

Maximum loading is obtained by tuning the capacitors in the pi network. In one particular installation the antenna was fed with a 2-foot length of 72-ohm coax line. Placement of the transmitter in the front area of the car, incidentally, allows use of a standard 4-section collapsible receiving antenna capable of being extended to 100 inches or more.

This position eliminates the need for drilling holes in the rear deck of the car for the more costly police-type whips.

Audio section

The audio section is also simple in design. A Radiotron 12AU7 medium mu twin triode is used as the input phase-inverter stage, and is coupled by means of capacitors to a pair of 6AQ5's which function as class AB modulators. All operating conditions are carefully chosen so that clean, crisp speech results. This valve line-up, as in the r-f section, allows either a parallel or series-parallel heater connection for 6- or 12-volt battery operation. (Most personal aircraft and some small cars use 12-volt electrical systems.)

The miniature components given in the parts list are the ones used in this transmitter. Substitutions may be made if they are equivalent in size as well as electrical characteristics.

The antenna transfer relay is mounted at the base of the antenna and is controlled by the circuit that operates the dynamotor relay. Thus, when the microphone push-to-talk switch is pressed, the dynamotor is started, the antenna transferred, and voltage applied to the mike button.

Construction

The chassis, the two shelves, and the cover plate are first drilled and shaped. Next the shelves and major components are mounted inside the chassis to check their fit. The only component which requires any change in adjustments to insure a proper fit is the modulation transformer. Its rear mounting ear is bent down even with the side of the transformer shell, thus making the unit fit snugly against the rear wall of the chassis to which the transformer is bolted.

After all components fit satisfactorily, the r-f and modulator shelves are removed and wiring of the transmitter started. The two shelves should be wired as completely as possible before mounting them inside the chassis. Leads leaving the shelves for connection to other components should be left sufficiently long for easy connection. The r-f shelf, which contains the 5763 oscillator at the left and the 5763 amplifier at the right should be mounted in the chassis first. Wiring for the r-f section of the transmitter can then be completed. The hot heater supply lead for this section goes directly up from the main switch, S_1. The B+ supply lead goes to a 2-terminal lug strip mounted below the shelf on the mounting screw of an r-f amplifier socket. The B+ end of RFC_2 is secured to a 1-terminal lug strip mounted to the right of the r-f amplifier tube above the shelf. This lead is covered with a varnished cambric tubing and passed through a small hole in the r-f shelf in such a manner as to bring the plate lead directly away from the grid connection. The B+ end of L_1 is also connected to a 1-terminal lug strip. All leads are kept short and a common ground point is used for each stage.

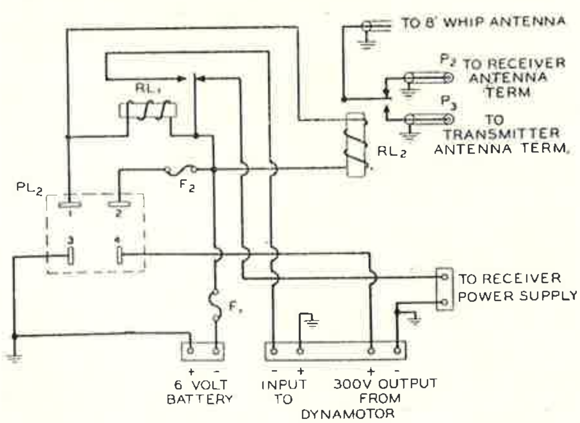
Checking the r-f section

It is suggested that the r-f section be tested before mounting the audio shelf in the chassis.

For preliminary testing in the ham shack a half-wave dipole cut to frequency and centre fed with a section of 72-ohm coax approximately equal in length to that used in the mobile installation should be used. Crystals between 7.125 Mc/s and 7.425 Mc/s should be used for 10-metre phone and between 6.79 Mc/s and 6.857 Mc/s for 11 metres. Insert a 0-100 mA meter in the cathode circuit (*J2*) of the final amplifier, open switch S_2, and tune the oscillator circuit for resonance by adjusting capacitor C_3 for the meter reading. This reading indicates grid current of the final amplifier because S_2 interrupts the screen supply of the final and allows no plate or screen current to flow. When sufficient grid drive is obtained (3 to 5 mA), the r-f amplifier can be operated by releasing S_2 and tuning C_9 in final tank for a dip in the cathode current. The oscillator tube draws approximately 35 mA at 300 volts.

Loading

The antenna should be cut reasonably close to the correct length for the operating frequency to prevent any difficulty in loading the transmitter. Decreasing

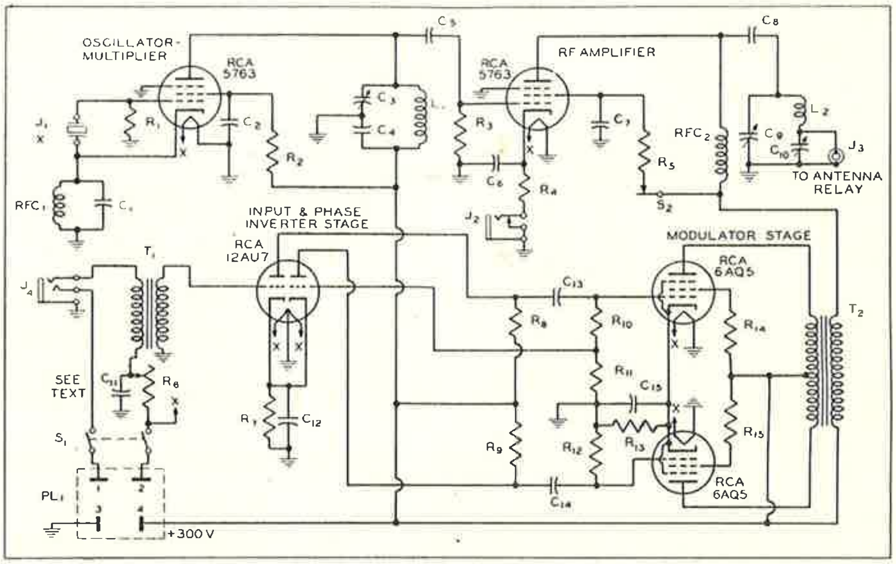


Transmitter power supply and switching arrangement.

the capacitance of C_{10} increases the plate loading but, for efficient transfer of power to the antenna, the capacitive reactance of C_{10} should equal the transmission-line impedance. For 72-ohm coax, C_{10} should be adjusted to approximately 80 $\mu\mu$F and for 52-ohm coax, to about 100 $\mu\mu$F. If this adjustment does not provide a plate current of 45 to 50 mA (measured cathode current less 8 mA screen current and 3- to 5-mA control-grid current), decrease the capacitance of C_{10} until the proper value is obtained. After each change in C_{10}, retune C_9 for maximum dip in cathode current. A further check may be made by means of a neon bulb placed at the ends of the antenna.

Adding modulator section

After checking out the r-f portion of the trans-



Schematic of the transmitter.

mitter, the modulator is completed. Leads on transformer T_1 are left sufficiently long so that the transformer may be fastened to the chassis after the bottom shelf is mounted. The leads to the secondary of the modulation transformer are connected for a plate-to-plate load impedance of 4500 ohms, determined by the chart accompanying the transformer.

The 1000-ohm potentiometer which controls the microphone current must be insulated from the chassis because this miniature style pot is obtainable only with the rotor grounded. The proper connection of C_{11} should be determined before it is installed because its polarity must correspond to the polarity of the car battery. The connections shown in the schematic is for cars having the positive battery terminal grounded.

Checking the modulator

It is a good idea to test the modulator thoroughly before mounting it in the chassis. The best check is to complete the wiring of the transmitter and operate it in the phone band with a temporary antenna. The 3 valves in the modulator should draw approximately 48 mA at 300 volts. If a.c. is used for heater power during the test, use a 6-volt battery for energizing the microphone. Modulation can be checked on a scope by conventional methods or on a good phone monitor. The microphone used with this transmitter is a surplus T-17 single-button carbon unit. The bakelite face plate should be removed and 5 or 6 additional holes drilled in it. These additional air paths increase the output of the T-17 substantially, because its basic design is for close-talking service and low extraneous pickup.

The leads connected to S_1 are passed through the grommet in the lower shelf and then through the grommet in the back of the chassis. Then, the lower shelf is positioned diagonally in the chassis with the modulation transformer against the r-f shelf and the left end of the shelf above R_6. Next, the modulator transformer is pushed down and the shelf fastened in position. T_2, C_{11} and J_2 are then fastened in position.

PARTS LIST

C_1	0.00015 μF
C_2, C_4, C_6, C_7, C_8	0.001 μF
C_3	25 $\mu\mu$F variable
C_5	50 $\mu\mu$F
C_9	50 $\mu\mu$F variable
C_{10}	100 $\mu\mu$F variable
C_{11}	50 μF 6V electrolytic
C_{12}	10 μF 25V electrolytic
C_{13}, C_{14}	0.01 μF 400V paper
C_{15}	20 μF 25V electrolytic
J_1	Crystal socket, 0.487″ spacing
J_2	Closed-circuit jack
J_3	Coax connector, chassis type
J_4	Microphone jack 3 circuit
L_1, L_2	10 turns $\frac{3}{4}$″ dia., $1\frac{1}{4}$″ long
PL_1	4-contact male plug
PL_2	4-contact female socket
RFC_1	1.8 μH r-f choke
RFC_2	21 μH r-f choke
RL_1	6V, SPDT relay, 15A contacts
RL_2	6V, SPDT antenna relay
R_1, R_8, R_9	100,000 Ω $\frac{1}{2}$w carbon
R_2, R_5	6,800 Ω 2w carbon
R_3	20,000 Ω 1w carbon
R_4	68 Ω $\frac{1}{2}$w carbon
R_6	1,000 Ω potentiometer
R_7	3,300 Ω $\frac{1}{2}$w carbon
R_{10}, R_{12}	200,000 Ω $\frac{1}{2}$w carbon
R_{11}	15,000 Ω $\frac{1}{2}$w carbon
R_{13}	390 Ω 2w carbon
R_{14}, R_{15}	33,000 Ω 1w carbon
S_1	DPST toggle switch
S_2	Momentary push switch norm. closed
T_1	Microphone transformer
T_2	Modulation transformer

New RCA Release

Radiotron type 5876 — is a general purpose, high-mu, "pencil type" triode designed for use in grounded-grid circuits. It is particularly useful as an r-f Amplifier, i-f Amplifier or mixer in receivers operating at frequencies up to about 1000 Mc/s; as a frequency multiplier up to about 1500 Mc/s; and as an oscillator up to 1700 Mc/s. As an unmodulated class C r-f Amplifier, the 5876 is capable of giving a useful power output of 5 watts at 500 Mc/s.

The "pencil type" construction of the 5876 meets not only the requirements of a good u-h-f valve as to minimum transit time, low lead inductance, and low interelectrode capacitances, but also provides other desirable features such as small size, light weight, low heater wattage, good thermal stability, and convenience of use in circuits of the coaxial-cylinder, line, or lumped-circuit type. In grounded-grid circuits, the grid flange permits effective isolation of the plate circuit from the cathode circuit.

UNIVERSAL COIL WINDING

(Continued from page 140)

When it is known that n will be 2, as is the case with the majority of coils, the method reduces to dividing the modified wire diameter into twice the cam throw (ignoring any fractions in the answer). This gives P and the required ratio is $(P+1)/P$.

BIBLIOGRAPHY

Simon, A. W.: "Winding the Universal Coil," Electronics, 9.

Joyner, A. A. and Landon, V. D.: "Theory and Design of Progressive Universal Coils," Communications 18, 1938, 5.

Hershey, L. M.: "The Design of the Universal Winding," Proc. I.R.E., 29, 1941, 442.

Simon, A. W.: "On the Winding of the Universal Coil," Proc. I.R.E., 33, 1945, 35.

Simon, A. W.: "Winding Universal Coils — Short cut procedures to obtaining exact self-inductance, mutual inductance and centre-taps," Electronics 18, 1945, 170.

Simon, A. W.: "On the Theory of the Progressive Universal Winding," Proc. I.R.E., 33, part 1, 1945, 868.

Simon, A. W.: "Wire Length of Universal Coils," Electronics 19, 1946, 162.

Simon, A. W.: "Universal Coil Design," Radio 31, 1947, 16.

Kantor, M.: "Theory and Design of Progressive and Ordinary Universal Windings," Proc. I.R.E., 35, 1947, 1563.

Simon, A. W.: "Theory and Design of Progressive and Ordinary Universal Windings," Proc. I.R.E., 37, 1949, 1029.

Arany, D and Macomber, M.: "Universal Coil Winding Graph," Communications, 29, 1949, 28.

International Allocation of Radio Frequencies

By T. L. BARTLETT

Radio stations, unless separated from each other by suitable spacing of their geographic locations and the frequencies on which they operate, create interference which is mutually destructive of their services.

The rapidly continuing growth of radio and the constant increase in the number of stations for which frequency spectrum space must be found requires planned economy in frequency usage and the development of conservation measures through sound frequency allocations and assignment practices. The importance of the subject of allocation of radio frequencies is proportional to the total value of radio.

International agreement, planning and regulation are keys to the frequency utilization problem and to the maintenance and growth of the radio structure. The future course of radio usage, civil and military, is dependent on actions taken at the international level. A review of the background and of current developments in this field has significance to all radio users.

Early Berlin conference

Within a short space of time after the first employment of radio for communication, the necessity for international arrangements on frequency matters became apparent, and as early as 1903 an international radio conference was held in Berlin which dealt with two frequencies, 500 and 1000 kilocycles, used for marine radio telegraphy.

Neither this conference nor that held in London nine years later developed the conflicts of interest which began to emerge when the high frequencies, with their capacity of causing interference over long ranges, came into use as a result of amateur experimentation and the general growth of the radio art stimulated by World War I.

The Washington Conference of 1927 established an allocations table covering the range 10-23000 kilocycles, and the Madrid Conference of 1932, especially significant for the creation of the International Telecommunications Union, increased the scope of the table made subject to world agreement to 30000 kilocycles. At Cairo in 1938 the sphere of international interest was recognized as extending to 200 megacycles; the agreements on the higher bands, however, being made on a regional basis.

Atlantic City conference

The intervening time until the Atlantic City Conference of 1947 saw developments which have led to the present critical stage in international frequency negotiation. The system of random notification by governments of frequency assignments, with no discretion on the part of any international body to adjust interference problems, had already become outmoded before the outbreak of World War II and had given rise to diplomatic exchanges.

The imperfections in frequency utilization disclosed by the lists maintained by the Bureau of the International Telecommunications Union at Berne reached the chaotic stage when war participants ceased notifications for security reasons and occupied frequency space according to military necessity. The situation made of little practical use, after the war, the resumption of the system of notifications to the Berne Bureau. Apart from these factors, the war had greatly extended the scope of radio knowledge and had made useful portions of the spectrum greatly beyond the 200 megacycle limit dealt with by the Cairo Conference.

The rapid growth of international aviation had created new requirements for frequency allocations; the problem being particularly acute in the congested high frequency bands. Governments attached increasing importance to international broadcasting, making further encroachments into this portion of the spectrum.

The Atlantic City Conference was required to deal with these major factors arising during the long gap between conferences. In addition, the detailed provisions of the radio regulations governing operating matters and the use of frequencies needed overhauling. If all nations had approached the conference with the need for satisfying the same basic demands, the task would have been difficult enough, but added to these complexities were fundamental differences in national interests.

For example, the maritime nations, such as United Kingdom and the Scandinavian countries, had requirements for large portions of frequency space for their marine services. Countries whose internal development required large use of radio in areas where wire line construction had not made progress, such as the Soviet Union, Brazil and China, had needs for many fixed point-to-point frequencies.

America protected "hams"

Several countries whose requirements for fixed and maritime service could readily be met desired the allocation of increased space for broadcasting. This was particularly the case in tropical areas where high noise levels limit the usefulness of the standard

Reprinted from Signals (Jan.-Feb., 1950) by courtesy of the Armed Forces Communications Association, U.S.A.

broadcast band, and where, in some instances, a nation-wide coverage is possible only through high frequency broadcasting.

The United States and other countries of the Western Hemisphere endeavoured to protect the allocations to the amateur service and this interest was opposed by other countries who desired to minimize allocations to amateurs in order to provide more space for broadcasting and the fixed and marine services.

The United States had made elaborate preparations, at the Third Inter-American (regional) Radio Communications Conference of 1945, and in a special five-power conference in Moscow in 1946, for the complete revision on a basis of sound engineering practice, of the frequency assignments for the radio stations of the world, realizing that unless improvement could be made, the saturation point in frequency usage would prevent the growth of radio and very possibly restrict current operations. The magnitude of this task became evident in the first two months of the Atlantic City Conference, and the direct approach to it had to be abandoned.

Thereafter the United States effort was directed towards three other objectives, all of which were attained. These were: first, to prepare a new frequency allocations table; second, to establish a Provisional Frequency Board for the purpose of drawing up a master frequency list, as a condition precedent to the implementation of the frequency allocation table; and third, to establish an International Frequency Registration Board having powers substantially beyond those of the Bureau of the Telecommunications Union, to which the master frequency list would be furnished as a point of beginning in its task of maintaining international assignments on an engineered basis.

Allocations table

Through the processes of the previous conferences an allocations table had been developed over the years and the Atlantic City Conference utilized the basic framework of the table, as last approved at Cairo, modifying it so far as could be agreed to meet changes in the world situation.

At Atlantic City, the band 90-110 kilocycles was set aside for the ultimate long distance marine and aeronautical navigation aid, modifying the previous allocation in this part of the spectrum to fixed and maritime mobile services. The current space for standard loran in the band 1800-2000 kilocycles was continued in regions where the system had been installed by the U.S. Air Force, but this allocation was made temporary pending international standardization on the ultimate navigational aid.

The standard broadcast band was widened, making two additional frequencies, 540 and 1600 kilocycles, available for broadcasting. The frequency 2182 kilocycles was designated for world-wide distress and calling purposes in the maritime mobile service. The marine beacon band was widened by approximately one-third.

In the high frequency portion of the spectrum, i.e., from 3 to 30 megacycles, the significant actions were allocation of exclusive bands for the aeronautical mobile service and the widening of the bands for broadcasting, both accomplished by withdrawing spectrum space from the fixed services. Losses in frequency space were also sustained by the amateur service.

Upper limit extended

The conference extended the upper limit of the allocated spectrum to 10,500 megacycles; the agreements in the region above 30 megacycles being chiefly on a regional basis. The reasons for regional agreement at world level on allocations in the upper portions of the spectrum where international interference problems are ordinarily not serious, include provision of means for mobile installations to work in the course of movement between areas, and making possible the standardizing of equipments.

The governmental agencies of the United States concerned, believing that the compromises secured at Atlantic City were the best obtainable, have bent their efforts toward the finalizing of this table which, because of the shifting of station frequencies into new bands which must first be vacated, can be accomplished only through the successful conclusion of the work of the Provisional Frequency Board.

The Provisional Frequency Board has been continuously in session in Geneva since January 8, 1948. Subdivisions of its overall task of formulating a master frequency assignment plan have been undertaken by the International Aeronautical Administrative Radio Conference, the International High Frequency Broadcasting Conference, and by a marine group of the Provisional Frequency Board membership. The board has responsibility for listing all classes of stations on frequencies between 10 and 30,000 kilocycles.

Board directive adopted

A detailed directive governing the actions of the board was adopted at Atlantic City which requires, in summary, compilation of the technical principles to be used in framing the master list, compilation of the requirements filed by the various governments on the basis of the technical principles. Into the eventual list would be integrated the assignment plans prepared by the aeronautical, broadcasting and marine groups. At the conclusion of the work of the board, a special administrative radio conference is to be convened to review the board's actions, finalize them and take action for implementation.

The board has fallen far behind its schedule of completion dates for its tasks. This has been due in part to insistence by the U.S.S.R. that the Berne frequency list of 1939 should be resorted to in determining registration priorities. The U.S.S.R. finally withdrew from the conference the first of November, 1949.

The principal difficulty, however, which has impeded the progress of the board, arises from the filing by all governments of requirements predicated on anticipated rather than actual needs. The result has been a total demand in some parts of the spectrum for several times the amount of space available. There is, of course, no means for any national or international body to conduct an investigation in a particular country to ascertain its true minimum requirements. Therefore, the relinquishment of demands becomes a matter of voluntary co-operative action. Recognizing the vital importance of rights in the radio frequency spectrum, countries have been extremely reluctant to yield concessions.

Progress

Despite the difficulties, the Provisional Frequency Board has made important progress. Agreement has been reached on the technical principles applicable to frequency assignment, and the requirements as filed for the radio stations of the world have been listed. Agreement has also been reached as to the megacycle order of frequencies needed for the service to be rendered by each listed station. Guides for the further work of the board, and which will be of great value for the future in planned frequency utilization, have thus been established.

1950 schedule

In an effort to secure agreement, the United States has recently given consideration to reduction of its requirements or restatement of them on a basis of priorities, with the hope and expectancy that other countries will follow its example. The first priority would consist of those frequency requirements which will be registered and recognized as entitled to international protection from interference. Frequency assignments falling into the second category would constitute "notifications" only, eligible for possible later advancement to registration status with the privilege in the meantime of use on a non-interfering basis.

The date of completion of the work of the board, which has on three occasions been extended by action of the International Telecommunications Union through its administrative council, is now scheduled for February 28, 1950. The date of the holding of the special administrative radio conference, to approve its work, has been set for September 1, 1950.

The administrations now participating as members of the board have indicated with near unanimity co-operative attitudes and desires. Realization now exists by most governments of the necessity for agreement and of the concessions which must be made in order to make agreement possible. It can be said without question that the Board has made substantial progress, and the next few months may very well see the successful termination of its work.

The framing of assignment plans by special conferences covering the aeronautical, international broadcasting and marine services has proceeded concurrently with the work of the Provisional Frequency Board.

Aeronautical

The first session of the International Aeronautical Administrative Conference at Geneva began in April, 1948, and adjourned in September without reaching a result. The conference work has been made difficult by the existence in some European countries of a basis of assigning frequencies for the aeronautical mobile service utilizing CW telegraphy as the exclusive method of working.

A majority of countries, led by the United States, desired to formulate the aeronautical plan utilizing band-widths equivalent to those required for radiotelephony channels where that is necessary for CW working.

In common with all the conferences, the aeronautical group was faced with demands greatly exceeding space available. The first session, however, made progress in establishing technical principles and in working out a formula for assessing load factors to assist in the final task of reducing requirements to the supply level.

Also, the first session of the conference succeeded in developing a plan which was agreed to by the participating governments and which became a final action of the conference, covering the "off-route" aeronautical bands, which are those allocated primarily for military and, secondarily, for itinerant flying.

In the interval between the first and second sessions a number of regional aeronautical meetings were held, including, in particular, a Western Hemisphere conference which began in Washington in March, 1949. Some of the intervening proceedings were conducted by the International Civil Aviation Organization, and a remarkable satisfactory degree of co-operation was developed between the two international agencies.

Aeronautical solution

The world aeronautical conference resumed its sessions at Geneva in August, 1949, and by the middle of October had reached a final result. The voting on the frequency allotment plan, as adopted, was 32 to 10; the principal negative vote having been cast by the U.S.S.R. The scheme finally agreed upon does not allocate specific frequencies to stations, but allots families of frequencies to routes and areas, subdivided into major world air routes and regional and subregional areas.

Under this plan governments having responsibility for particular stations may register assignments within the applicable allotments without the possibility of conflict. The results of the aeronautical conference were important not only in providing the solution of the aeronautical problem, but in demonstrating that agreement can be accomplished in the solution of a complex frequency assignment problem on a basis of sound engineering principles.

International broadcasting

The first session of the International High Frequency Broadcasting Conference was held simultaneously with the other telecommunications conferences at Atlantic City in 1947 and accomplished little more than the laying out of a programme for further work. A planning committee met at Geneva in the spring of 1948, and in the fall of that year the second session of the conference began at Mexico City, and continued its deliberations for the succeeding six months.

It was recognized that in order to make maximum use of the frequencies allocated for the broadcasting service, planning would have to be on a basis which took advantage of time differentials and frequency propagation factors at the various hours of the day and night over the world areas to be served. Even on this basis, the complete loading of the high frequency broadcast bands was found to yield about 6,000 broadcast hours per day as compared to the requirements filed by the various countries totalling approximately 15,000 channel hours.

A plan designated as No. 70, or the June median sunspot phase plan, one of several necessary to take into account propagation variations due to the sunspot cycle and seasonal changes, was finally prepared at Mexico City. Insufficient time remained to prepare the additional plans for the other seasons and phases of the sunspot cycle; and a technical planning committee was established to carry out the principle of the June median plan in working out the total high frequency broadcasting assignments. This committee has held subsequent meetings, and the sessions of the conference as a whole are to be resumed in Florence, Italy, beginning April 1, 1950.

Russian jam

Most of the countries, parties to the Mexico City Conference, signed the resulting partial agreement. Among the countries not signing were the U.S.S.R. and the United States, although each had succeeded in obtaining recognition of all its usage and proposed usage. The refusal of the two governments to sign rested on political grounds. By the time the June median plan was completed, in April, 1949, the Russian programme of jamming international broadcasts was in full swing, and this was one of the matters referred to by the delegate of the United States in his statement supporting our refusal to sign.

In the United States international broadcasting is conducted almost exclusively by the Voice of America, a function of the Department of State. The significance of the programme from cultural and national defence standpoints, its effectiveness in view of the susceptibility of the transmissions to jamming, and measures which can be taken to circumvent jamming operations are factors bearing on our future position with regard to frequency allocations for international broadcasting.

Conclusion

The success of the work of the Provisional Frequency Board and the finalizing of the Atlantic City allocations table are of prime importance to the United States. The military interest is two-fold: direct, in that the positioning in the various parts of the spectrum of civil radio activities permits the marking out of the areas in which development of military equipment and services are carried forward; and indirect, in that the military has an interest in development of civil equipment and the establishment of civil communications facilities available for military use in time of an emergency. Consistent with these interests, the military services have been suitably represented at the international conferences described above.

The United States has taken the lead in the effort to establish allocations and frequency assignments on an engineered and orderly basis. The world-wide importance of the conferences now going on make success and the maintenance of this position of leadership a matter of national concern. The majority of foreign administrations have indicated co-operative attitudes and desires, and there is a basis for expectancy that the next few months will see the successful termination of the present tasks. The fact that certain nations may not subscribe to the final result of these proceedings, does not necessarily mean ultimate failure to achieve an international order in frequency matters. The nations must make provision, in any case, so that services of all countries, participant and non-participant, may be operated so far as possible on a non-interfering basis.

As has been indicated, the task is a continuing one. The seventy-eight governments which are members of the International Telecommunications Union have agreed to meet every five years, to review and adjust their agreements to meet the shifting and changing developments in the art and the uses of radio. The next scheduled general conference is that of Buenos Aires in 1952.

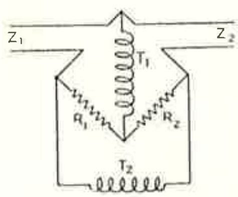
This field is peculiarly one in which international agreement serves the practical interests of all nations, and it is on this basis that we can look forward confidently to the ultimate success of the negotiations.

Switchless Intercommunication Unit

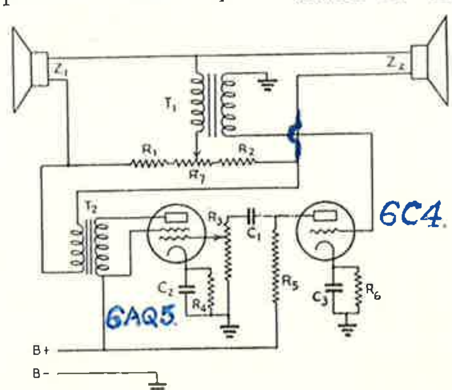
An intercom. unit which requires no switching is shown in Fig. B. It is a circuit commonly used in telephone repeater service and is described by G. Smith of Chicago, Ill. For the benefit of those who are not familiar with the principles involved, a brief explanation is given.

Referring to diagram A, T_1 and T_2 are the input and output respectively of the amplifier. It will be noted that they are on opposite sides of a bridge. When Z_1/Z_2 is equal to R_1/R_2 the bridge is in balance and none of the voltage across T_2 can appear across T_1, and therefore the amplifier will not "sing". But, if a signal voltage is impressed across Z_1, the voltage will divide across R_1 and T_1, with that part across T_1 being amplified through the amplifier and applied across T_2. As T_2 is in balance with T_1 through the bridge, it will not feed back, but the signal voltage appearing across T_2 will be impressed across Z_1 and Z_2 in series.

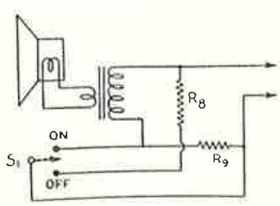
A practical circuit is shown in Fig. B. Comparing this with Fig. A, Z_1 and Z_2 are permanent magnet speakers which serve as microphones as well. R_1



A



B



C

and R_2 are the same arms of the bridge as those correspondingly numbered in Fig. A and are supplemented by the potentiometer R_7 for balancing the bridge. R_3 is a gain control for adjusting the output of the amplifier. T_1 should have a step-up ratio. T_2 should have characteristics suitable for matching the load consisting of Z_1 and Z_2 shunted by the series of R_1, R_2 and R_7 to the optimum load specified for the output tube used. With speakers of about 5000 ohms and resistances of 10,000, 5000 and 10,000 ohms respectively for R_1, R_7 and R_2, T_2 should have a ratio of about 1 to 1.2 (primary-to-secondary) to provide a proper load for the 6AQ5. The two speakers used should be identical if possible.

If, for any reason, either speaker needs to be cut out, a double-pole double-throw switch is necessary to remove the speaker and replace it with a resistance equal to the speaker impedance. If this is not done properly, the bridge will become unbalanced and the outfit will "sing". A single-pole double-throw switch in series with resistance can be used, as shown in Fig. A, to cause the circuit to feed back and "sing" which may be useful in calling. R_8 and R_9 are placed in each terminal set along with S_1. When S_1 is closed, both speakers are muted somewhat due to the shunt of R_8 and the voltage dividing action of R_9. But, when the switch is changed to the "on" position, the bridge will unbalance and "sing" until the other switch is thrown to the "on" position. R_8, at the operator's position, should be made variable to allow an additional bridge when both switches are in the "off" position. A similar change in both lines will not affect the balance, and, therefore, one of the shunting resistors may be variable to compensate for the irregularities of the other.

If it is desired to be able to turn the amplifier on from either end of the line, it will be necessary to run another pair of lines between the two stations with both switches connected in parallel across the line. ***NOTE: In the diagram, the wire between R_2 and Z_2 should not connect to grid of 6C4.***

PARTS LIST

R_1	10,000 Ω
R_2	10,000 Ω
R_3	0.5 MΩ volume control
R_4	400 Ω
R_5	50,000 Ω
R_6	2500 Ω
R_7	5000 Ω
R_8	5000 Ω (see text)
R_9	10,000 Ω
C_1	0.01 μF 400V
C_2	25 μF electrolytic
C_3	25 μF electrolytic
T_1, T_2	See text.

Reprinted from QST by courtesy of ARRL

Ionization Tubes *Gauge* Vacuum Pressure

Fig. 1—Portable, easily operated, commercial leak detection equipment (RCA model 722-SS) using hydrogen-sensitive ionization tube.

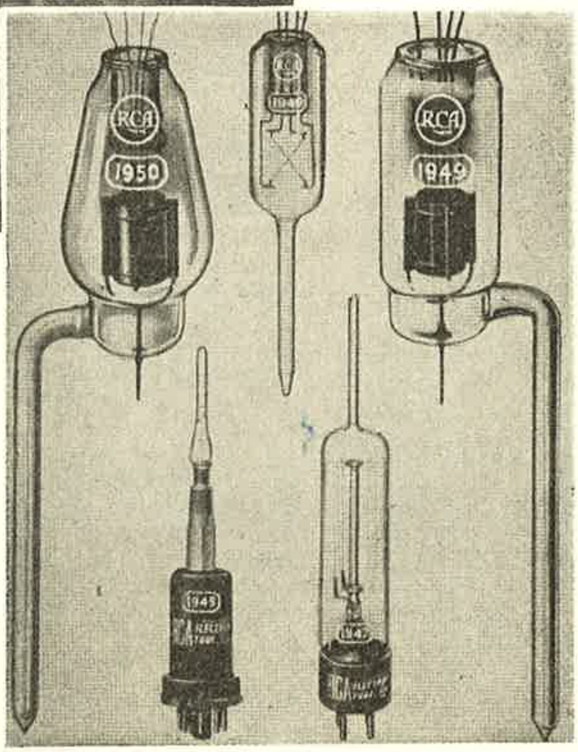


Fig. 2—Diversified line of vacuum-gauge tubes: a hydrogen-sensitive, ionization type (1945); four types for measuring gas pressures; two conventional ionization types (1949 and 1950); a thermocouple type (1946); and a Pirani gauge type (1947).

These new Radiotron Ionization Tubes from the Radio Corporation of America simplify the procedure for detection and localization of extremely slow leaks in all types of vacuum systems.

For the measurement of low vacuum pressures new electronic technics make use of a number of effects that undergo changes in a vacuum. Several common production systems utilize either the change in thermal conductivity of the atmosphere at various pressures, or the changes in ionization in a special form of electron tube under similar circumstances. In the latter the electron emission from a cathode under established voltage conditions ionizes the gas in the space between the cathode and the anode (or ion-collector), producing a change in the current which indicates the gas pressure.

The Radio Corporation of America has recently offered a diversified line of vacuum-gauge tubes for application particularly at high-vacuum levels, a field which is now finding numerous industrial uses. In the line is a hydrogen-sensitive, ionization type—1945—for detecting and locating minute leaks, and four types for measuring gas pressure in vacuum systems. These four include two conventional ionization types—1949 and 1950; a thermocouple type—1946; and a Pirani type—1947. The latter type contains only a filament that is heated and connected in one arm of a bridge circuit. Its tem-

Reprinted from Electronic Industries and Electronic Instrumentation by courtesy of Caldwell-Clements Inc.

perature and hence its resistance depend on the thermal conductivity of the atmosphere around it.

Of particular interest is the ionization gauge tube which is sensitive to hydrogen but not to other gases or vapours, making it useful in detecting and locating leaks in vacuum enclosures. Unlike conventional ionization gauge tubes, this tube is constructed with a palladium plate which provides a vacuum-tight barrier to the vacuum system when cold, but when heated, serves as a permeable membrane, which permits hydrogen deliberately introduced in the vacuum system to flow into the 1945 and be detected.

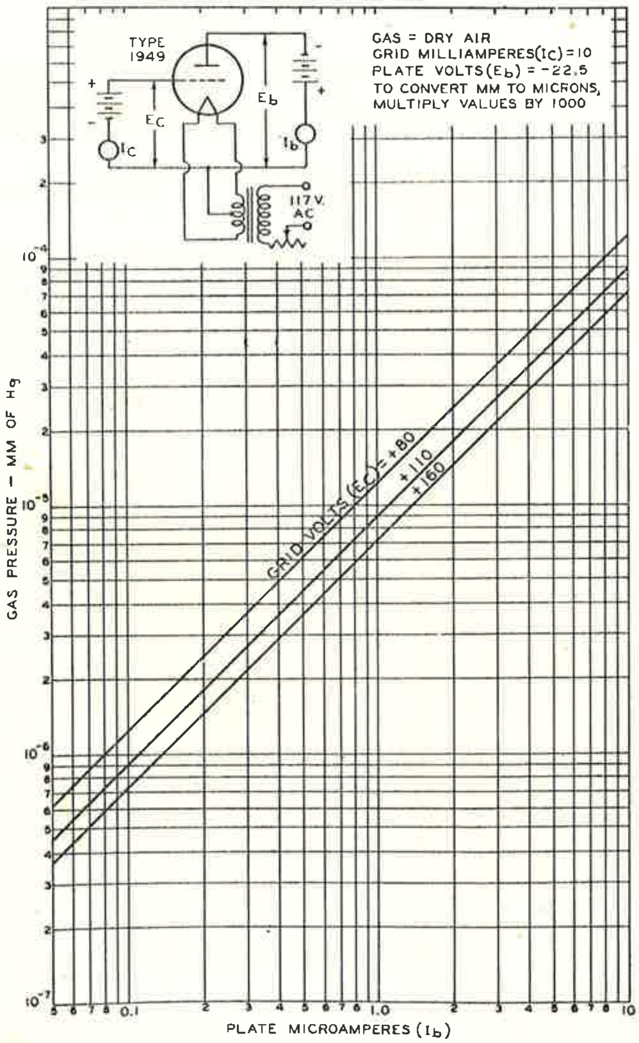


Fig. 3—Calibration curves of 1949 tube.

Practical applications

Practical application of this tube in locating a leak consists simply of connecting it to the vacuum system and of probing the external surface or joints of the system with a jet of gas containing a high percentage of hydrogen. If a leak is present, hydrogen enters the vacuum system at the point of leakage, passes through the hot palladium plate, and produces an increase in current to the ion collector.

Because of its high vacuum, it can detect far smaller leaks than feasible with conventional ionization gauges operating at the same pressure as the vacuum system. Actually, an increase in hydrogen pressure of less than 10^{-7} mm of mercury (10^{-4} micron) can be detected. This high sensitivity can be obtained on systems using rotary vacuum pumps or other apparatus often available in high-vacuum laboratories, and does not require the use of diffusion pumps.

Since gas may be frequently admitted, it is necessary to connect the tube to an exhaust system which can be applied when necessary. A typical setup is shown in Fig. 5. As here shown, the ionization tube is connected to a microammeter through an amplifier which can be even a single pentode such as the 6BA6 or equivalent. An amplifier capable of amplifying d.c. currents in the order of 0.005 microampere should be preferably of the bridge type in order to balance out the zero-signal amplifier current.

The palladium plate, heated by electrons from the cathode, is maintained at the proper temperature (about 800°) when the anode circuit dissipates a power of 6 watts. At this temperature the metal becomes "porous" to hydrogen gas. For example, 185 volts on the anode with a plate current of 32 milliamperes will provide a dissipation of 6 watts.

Leak detecting procedure

The test procedure for detecting and locating a leak in a vacuum tube is as follows: With the inlet tubing to 1945 immersed in the cold trap and with all stopcocks open, the system is pumped to a pressure of about 10^{-4} mm. A hydrogen hood connected to the source of test gas is lowered over the tube or vessel under test and the output meter is then observed for indications of a leak. If an increase in meter reading indicates the presence of a leak, the hydrogen hood is raised and suspected points on the tube are probed with a fine hydrogen jet until an increase in meter reading indicates the exact location of the leak.

New features

This tube is a somewhat new departure in commercial ionization gauge tubes. A conventional ionization gauge is usually similar to a simple triode, surrounded by the atmosphere being tested. In other words, here there is no difference of pressure between that in the tube and the system. As with the 1945 type of tube, the greater the amount of gas present the greater the ionization current. The tubes are generally most useful in the range of 0.0001 and below, and cannot be used at pressures above .001 mm.

The 1949 is a triode having two tungsten filaments (one of which is a spare). The grid is operated at a positive potential and the plate at a negative potential as in Fig. 3. Electrons from the filament are accelerated to the positive grid. They bombard and ionize some of the molecules of any gas present in the tube. The resultant positive ions are attracted to the negative plate and constitute the plate current. The ratio of this current to the grid current is proportional to the gas pressure for pressures below about 0.0001 mm. A set of calibration curves is shown in Fig. 4.

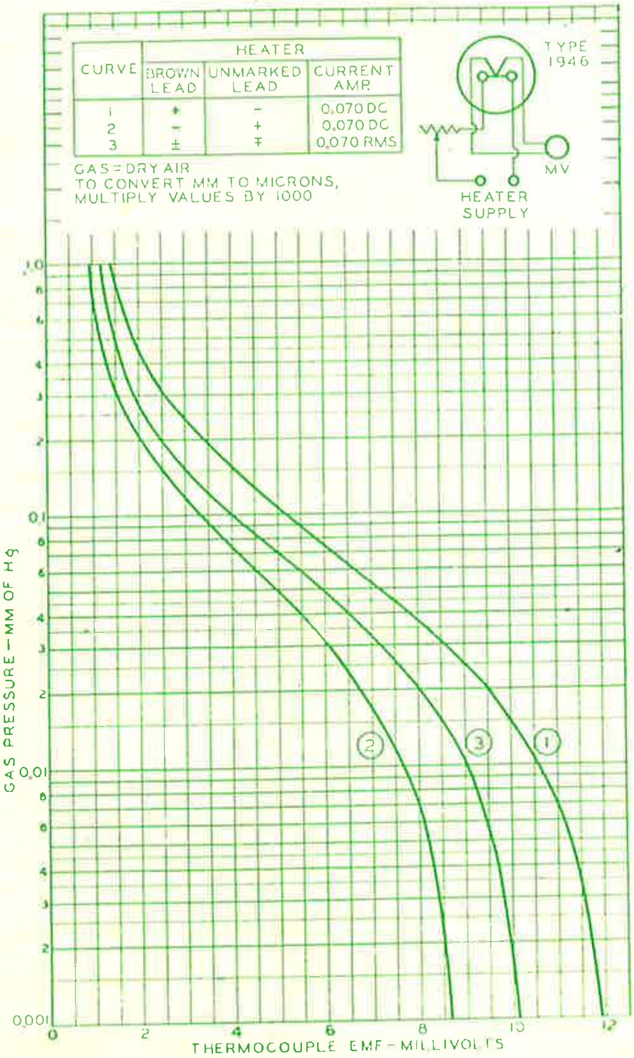


Fig. 4—Calibration curves of the 1946.

Filament life precautions

Precautions should be taken in the event of a leak in the vacuum system to remove the filament voltage immediately, preferably by means of an interlock device which will open the filament circuit automatically when the pressure in the system exceeds 0.001 mm to avoid its burning out. The type 1949 tube is for use on a hard glass vacuum setup, while the 1950 is used with soft glass assemblies. A thermocouple with a contacting heater filament reaches and records a temperature depending on the cooling effect on the heater by the surrounding atmosphere. When the heater is supplied with a known current a vacuum gauge results, such as RCA 1946 type vacuum gauge.

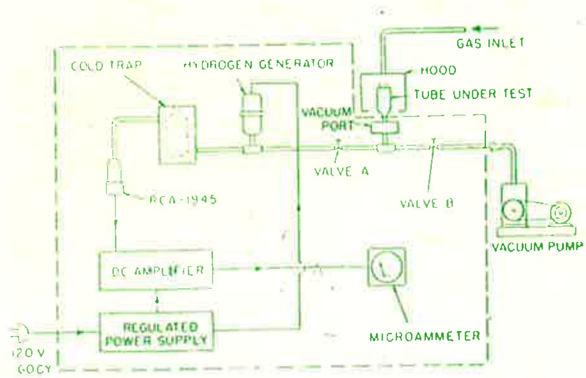


Fig. 5—Equipment set-up of type 1945 with indicating meter.

It can be used directly with a millivoltmeter, giving of the order of 1 to 10 millivolts output over the usual range of pressures (1 to .001 mm of Hg) for which this type best serves. The gauge can be connected to a direct coupled amplifier for deriving power for control applications. The internal resistance of the couple is around 5 ohms.

In comparison with the ionization type of vacuum gauge, this type has the feature of not being damaged under operating conditions involving loss of vacuum. Therefore the type 1946 can conveniently be used as a protective device in vacuum systems to prevent application of voltages to electronic components operating within a vacuum enclosure, until such time as the gas pressure has been reduced to the desired value.

For constancy of calibration, the 1946 should be protected from air currents. An absolute calibration will vary with the nature of the gas and the ambient temperature which should not exceed 50°C, the latter establishing the temperature of the cold junction. Fig. 4 shows typical calibration curves. Optimum sensitivity is obtained when the heater for the thermocouple is operated from a d.c. supply, and the "brown" heater lead is connected to the positive terminal of the heater voltage supply, curve (1) in Fig. 4. With reversed polarity curve (2) results. The use of a.c. on the heater averages both connections and curve (3) results.

The type 1946 tube has a hard glass envelope, and is designed particularly for vacuum measurements, while the type 1947 has a soft glass tube for gas pressures. Both have good sensitivity in the range 0.5 mm to .01 mm of Hg. The 1947 type tube is of the Pirani type, wherein the thermal dissipation from a heated filament changes its resistance. The filament therefore is made of a material that has a large and constant temperature co-efficient.

PRINTED BY CLOISTER PRESS (D. & W. SHORT), 45-49 GEORGE ST., REDFERN.