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CONTROL-GRID CURRENTS IN RADIO RECEIVING VALVES

*By E. Watkinson**

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Summary.

The effects of "contact potential" on the operating conditions of a valve and its circuit are described, with particular reference to the operation of battery valves under zero-bias or "grid-leak bias" conditions.

Reverse grid currents, their causes and effects, are also discussed and precautions that may be taken to minimize variations of valve operating conditions by these currents are given.

1. Contact Potential.

As the expression is generally used, the "contact potential" of a multi-electrode valve is a voltage effective between control grid and cathode. It is primarily the combined effect of the difference between the work functions of the surfaces of the control grid and cathode and of the initial velocity of emission of electrons from the cathode.

The work function of a surface can be expressed as the energy required to remove an electron from that surface, so that the lower the work function of an electrode the easier it is for the electrode to emit electrons. Thus a cathode, designed to emit, normally has a small work function, while the work function of a grid, with which precautions have been taken to prevent emission, should be higher. Work functions are expressed as voltages, the values lying between one and five volts for most materials and combinations of materials used in valve manufacture.

In most valves operating under conventional conditions, far more electrons are emitted from the cathode than are required to make up the various electrode currents. The surplus electrons travel only a short distance from the cathode and then return to it. Since each electron has a negative charge, the composite effect of the electrons outside the cathode can be represented as a "potential minimum", a region in which the potential is more negative than that of either the cathode or the control grid. This region lies between cathode and control grid and is called the "virtual cathode".

Since electrons are emitted from the cathode with varying velocities, some of them are able to overcome the repelling effect of the potential minimum and of a negative electrode and to pass from the cathode to a negatively-biased grid. Increasing the negative bias will prevent more and more electrons from reaching the grid but since the distribution of the electron velocities is approximately Maxwellian there is no definite voltage at which all electrons are cut-off. This emission velocity effect can be represented as a voltage — the voltage required to reduce electron grid current to some specified level — and this voltage is another component of the "contact potential".

Because of its complex make-up, contact potential varies from valve type to valve type, from valve to valve of the same type and in any particular valve with time, with cathode temperature or with variations in use.

Moreover, although contact potential is expressed as a voltage, the figure generally quoted is not intended to be an accurate measure of the contact potential but is rather the value of bias that must be applied to reduce the control-grid current to some specified small value, e.g., 0.2 microamperes.

2. Effects of contact potential on valve operation.

The apparent effects vary considerably depending on the viewpoint of the engineer concerned. The circuit-design engineer usually thinks of contact potential as producing a negative bias on the control grid of a valve under grid-leak bias conditions, whereas to the valve-design engineer it is a positive bias which increases electrode currents.

However, experience shows that all of the effects of contact potential can be predicted by considering the grid-cathode circuit of a valve to consist of the components shown in Figure 1.

In this figure the points "C" and "G" represent the actual cathode and control-grid pins of the valve, the battery has the polarity shown, the resistor represents the impedance of the grid-cathode circuit to the valve and the grid and cathode symbols represent perfect electrodes without potential effects.

When the grid and cathode pins of the equivalent circuit of Figure 1 are connected together, the contact potential causes a current to flow in the external circuit. The direction of this current is such that

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* Senior Engineer, Applications Laboratory, Amalgamated Wireless Valve Co. Pty. Ltd., Ashfield, N.S.W.

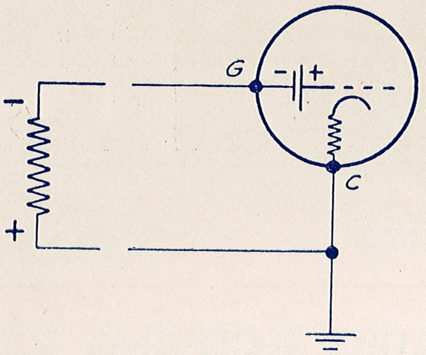

Figure 1.—Equivalent circuit representation of contact potential

if a resistor is included in the circuit, a negative voltage will appear at the grid end of the resistor, in accordance with the view held by the circuit designer.

If now a voltage is connected externally between grid and cathode, the total bias effective at the grid of the valve is the algebraic sum of the applied bias and the contact potential; furthermore, the contact potential has the same effect as a positive bias and the larger the contact potential the greater will be the electrode currents. This is in accordance with the valve engineer's viewpoint.

Since contact potential is an unstable voltage and since it is a part of the bias applied to the grid of a valve in most normal circuits, some instability in electrode currents and valve characteristics due to contact potential variations is to be expected unless the bias applied to a valve is much larger than its contact potential.

Nevertheless, one way in which this effect can be minimized is by means of grid-leak bias, which is obtained by connecting a resistor of large value, e.g., five or ten megohms, directly between control grid and cathode. Referring to the circuit of Figure 1, the voltage across the large resistor will be approximately equal to the internal contact potential but of opposite polarity, so that the total effective bias will be zero and thus will not vary as contact potential varies.

However, such a circuit is usually restricted in its use to fairly low-level AF or IF amplifiers and is dependent for its satisfactory operation on the absence of any reverse grid currents such as will be discussed later. When bias is obtained for each individual stage from a cathode resistor, the effect of changes in contact potential is largely compensated by feedback in the cathode resistor and much smaller values of control-grid circuit resistance may be used.

3. Effects of valve contact potential on associated circuits.

The most important of these effects is the possibility of circuit damping by valves with insufficient bias, due to conduction effects. The mechanism of this damping can be illustrated by means of Figure 2, in which the control-grid current of a directly-heated valve is plotted against positive and negative values of control-grid voltage.

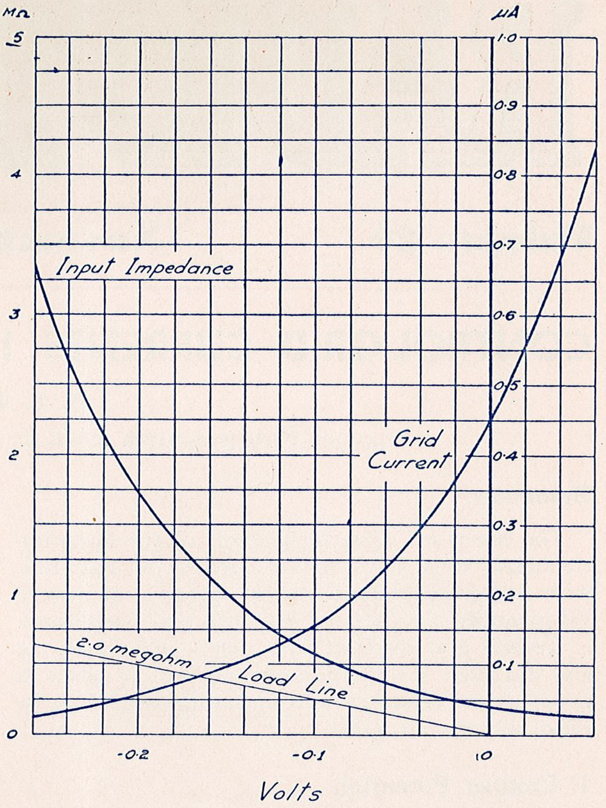

Figure 2.—Control-grid characteristic of directly-heated valve.

When a valve with the control-grid characteristic of Figure 2 is operated as an IF amplifier with its control grid returned through a low impedance to the cathode, the IF signal applied to the grid can be represented as an instantaneous change in bias. By projecting this change onto the grid-current curve the corresponding variation in control-grid current can be obtained. Since the change in voltage produces an in-phase change in current the valve appears as a resistance to the external circuit. Moreover, the steeper the curve of the control-grid characteristic the greater will be the current change for a given voltage change, i.e., the steeper the slope, the lower is the input impedance of the valve. This fact is demonstrated by the "input impedance" curve in which input impedance is plotted against control-grid voltage for small input voltages.

Since the input characteristic shown is that of a filament-type valve the amount of grid current flowing with negative voltages applied to the control grid is small. However, with indirectly-heated valves it may be found that control-grid current is not reduced to the cut-off value even with as much as —1.0 volt applied to the grid.

For this reason it is always necessary, if input impedance is to be kept high, for the negative bias on an indirectly-heated valve to be at least 1.25 volts, plus the peak value of the signal input voltage, plus any allowance necessary for bias reduction due to reverse grid currents (see sections 6 and 7) flowing in a grid resistor.

Consideration of Figure 2 shows that this filament-type valve, operated as a zero-biased IF amplifier, introduces a damping impedance of about 0.2 megohm across the input tuned-circuit, owing to the slope of its control-grid characteristic at the operating point. However, if a two-megohm grid leak, suitably bypassed, is connected in series with the IF secondary winding between control grid and ground, the valve will take up a new operating point at the junction of its grid characteristic and the load-line of the two-megohm resistor, drawn from zero voltage since no bias is applied to the valve. Owing to the decreased slope of the characteristic at this junction the damping is materially reduced, the input impedance being somewhat greater than one megohm. However, this type of circuit may not always reduce the damping to such an extent and if maximum gain must be obtained from a stage then a small amount of bias, perhaps —0.3 volt for a battery valve, should be applied to the grid.

Since the load line of a grid resistor of higher value will cut the grid characteristic at a point representing less damping than that occurring with the two-megohm grid resistor, it can be seen from Figure 2 that grid damping will be progressively reduced as the value of grid-leak in a grid-lead biased amplifier is increased.

A second effect of contact potential is the negative voltage which appears on a.v.c. lines due to the diode contact potential when the diode load is returned to ground. This voltage is sometimes used as bias for an IF amplifier. However, if the contact potential of the IF amplifier is greater than that of the diode, the IF amplifier will still damp the IF transformer and thus reduce the gain of the previous stage.

Contact potential is a difficult characteristic to control closely under quantity production conditions, so that although satisfactory operation may be obtained from some receivers, trouble may be experienced at any stage in the production of receivers incorporating such a circuit.

4. Different polarity of grid-current cut-off potential in AC and battery valves.

It was mentioned above that a contact potential voltage, as usually quoted, is in fact the voltage required to reduce the control-grid current to some specified small value such as 0.2 microamperes. It is a matter of experience that with AC valves this potential is almost invariably negative, whereas with battery valves it is more often positive. This raises the question whether the polarity of the battery shown in the equivalent circuit of Figure 1 should be reversed for one of these types of valve.

An examination of the reason for the difference in polarity indicates that this would be incorrect and that the polarity of the battery shown, i.e., negative towards the control-grid pin, is correct for both types.

Suppose that in a battery valve a potential of 1.4 volts is applied across the filament and the grid is biased to +0.7 volt with respect to the negative end. Since this represents a bias of —0.7 volt with respect to the positive end, this end of the filament will be cut-off while the negative end will be conducting. As the positive bias is decreased, the cut-off section of filament will extend further towards the negative end until at last only the most negative activated part continued to conduct. Thus the contact potential figure quoted for a battery valve is in fact the grid-current cut-off voltage of the most negative emitting section of the filament.

Owing to cooling effects at the end of the filament and to the fact that not all of the filament proper is enclosed by the valve electrodes, the most negative part of the cathode that has useful emission is not at the potential of the negative pin but is a significant distance along the filament towards the positive pin. This is part of the reason for more positive values of contact potential being quoted for battery valves. (It is also the explanation for the fact that a different value of grid-current cut-off voltage will usually be obtained if the filament connections of a directly-heated valve are reversed.)

However, since even at the arbitrary grid current value (0.2 microampere) selected to indicate "grid-current cut-off" some current still flows and since this is reduced towards zero as the bias applied to the control grid is made more negative, it is found in practice that the voltage developed across a large resistor connected between grid and cathode of a virtually gas-free battery valve is negative in spite of the measured positive grid-current cut-off voltage.

This effect is demonstrated in Figure 3, which represents the grid characteristic of a battery valve. Its contact potential, i.e., the voltage that gives a grid current of 0.2 microamperes, is +0.025 volt. As the voltage is reduced below this figure grid current decreases but only approaches zero in an approximately logarithmic manner.

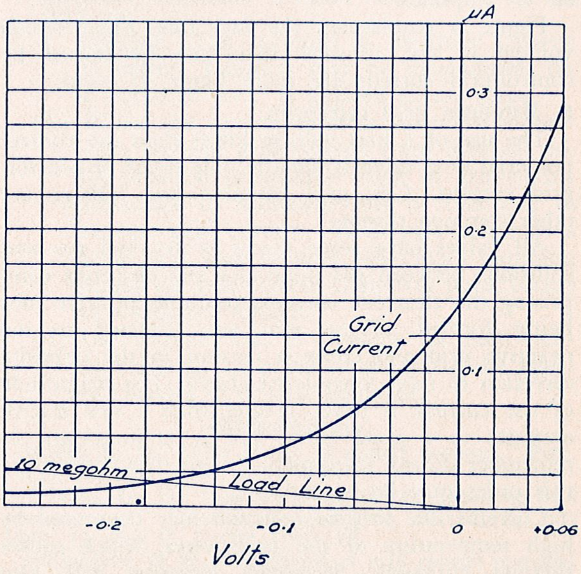

Figure 3.—Grid-leak bias of directly-heated valve with positive grid-current cut-off.

The load-line of a ten-megohm resistor connected between grid and the negative end of the filament of the valve is also shown and since voltage and current in the circuit are common to both valve and resistor, the operating point is at the junction of the two characteristics, i.e., at —0.18 volt, and this in spite of the positive contact potential of +0.025 volt.

The positive and negative values of grid-current cut-off in battery and AC valves thus have no fundamental significance. In either case, a variation in a valve which causes it to develop a more negative voltage across a high-resistance grid leak returned to cathode will also cause it to draw larger electrode currents under fixed-biased conditions.

5. Effect of screen voltage on control-grid current.

In a typical RF pentode, either battery or AC, the electrostatic field of the positive electrodes outside the control-grid region penetrates the part of the valve between control grid and cathode and modifies electron paths in such a way as to divert them from the control grid as the screen voltage is increased. Some reduction of control-grid current at a specified grid voltage can consequently be obtained in these valves by increasing the screen voltage.

Figure 4 shows the effect on the control-grid current and thus on the input impedance in a typical battery-type RF pentode of a variation of screen voltage under zero-bias conditions. With a screen voltage of 55, a control-grid current of 0.05 microamperes flows and the input impedance is almost 2 megohms. This would not cause serious damping in a conventional radio receiver. However, with the screen voltage reduced to 30 volts, the input current has risen to 0.26 microamperes, the input impedance is approximately 1/3 megohm and a loss of gain and selectivity due to grid-circuit damping may be expected if the valve is used as an IF amplifier.

Figure 4 emphasizes the fact that when screen voltage is low, troubles that may be caused by control-grid current are more likely to occur.

6. Reverse grid currents.

The use of a bias voltage lower than the contact potential of a valve is not the only cause of control-grid current. Gas, grid emission and leakage are other common causes.

All valves have some traces of residual gas and collisions between gas molecules and electrons comprising the electrode currents result in positive ions being formed. These ions are attracted to the negative grid and create a current in the opposite direction to those considered above. The magnitude of the current is never greater than a few microamperes in a good valve, but it is important to remember during equipment design that currents of this order may be encountered.

Currents due to grid emission may be caused by high temperature of the grid wires, which causes thermal emission. Secondary emission may also occur although it is unlikely to be a significant factor under conditions such as those under discussion.

Leakage from the positive electrodes in a valve can also cause currents in the same direction as gas current.

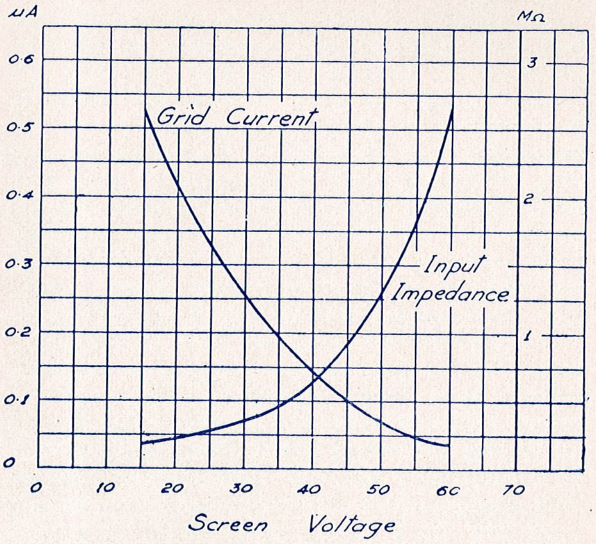

Figure 4.—Variation of control-grid current and input impedance vs. screen voltage.

Each of these types of current is in the opposite direction to the conduction current originally considered and is therefore called a reverse or negative grid current.

7. Effect of reverse grid currents on external circuits.

The most important effect of gas current, or any reverse grid current, is the variation, in the direction of decreased bias, brought about in static operating conditions in the presence of large values of control-grid resistance.

Figure 5 shows the control-grid characteristic of an indirectly heated valve with and without a permissible amount of gas current. Curve A is the characteristic of the valve in a gas-free condition and curve B shows the combination of this characteristic with the gas current, which tends towards zero as the plate current of the valve is cut-off.

Although the magnitude of the gas current in Figure 5 approaches the maximum that should be experienced, some gas current is present in every valve. Because of this, all control-grid characteristics have a cross-over point, usually at a negative voltage, at which the current changes from positive to negative, instead of making an asymptotic approach to zero from positive values.

Assume that the valve shown in Figure 5 is operating with a negative bias of 2.0 volts applied to its control grid and a resistance of 2.0 megohms between control grid and cathode. When there is no reverse grid current component in the grid characteristic (Curve A), the two-megohm load-line drawn through —2.0 volts does not cut the grid-current characteristic, so that no current flows in the grid resistor. There is thus no grid-current damping and the effective bias is equal to the applied value of —2.0 volts. However, if the valve has sufficient gas for the grid characteristic to be as shown in Curve B then the grid load-line cuts it at —1.0 volt resulting in a loss of one-half of the applied bias.

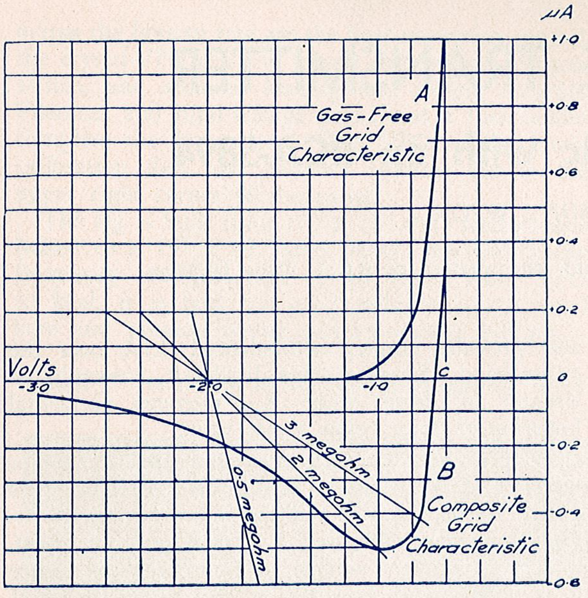

Figure 5.—Effect on bias of grid-circuit impedance and reverse grid current.

Consider now the effect of reducing the grid-circuit impedance to 0.5 megohm. The load-line and grid characteristic intersect at —1.9 volts and the bias is reduced by only 0.1 volt. Whereas in Figure 2 it was shown that for a grid-leak biased valve a large value of grid resistor is desirable to reduce input-circuit damping, Figure 5 demonstrates that a small value of grid resistor is required to minimize bias reduction in the presence of reverse grid currents.

The deciding factor in the choice of grid resistor in any particular case is the relationship between the applied bias voltage and the cross-over point (from positive to negative current) of the control-grid characteristic. If the applied bias is more negative than the cross-over point, a small value of grid resistor is desirable to avoid loss of bias, but if the cross-over point is negative with respect to the applied bias, then grid-circuit damping is inevitable, but will be reduced as the value of grid resistor is increased.

In Figure 5 it will be noticed that the voltage developed across the grid resistor increases more rapidly than the value of the resistor and it can be seen that this is mainly due to the rate of decrease of gas current with increasing bias. Thus because gas current is approximately proportional to cathode current other conditions being unchanged, this effect is more noticeable in a sharp cut-off than in a remote cut-off valve. The grid characteristic of Figure 5 is that of a sharp cut-off valve to emphasize this point.

The three-megohm load line in the same figure shows that the reduction in bias brought about by the use of this larger resistor has taken the operation point of the valve into a region in which the slope of the grid characteristic indicates that some grid damping will occur. Any further increase in the value of grid resistor will result in only a small additional reduction in the effective bias so long as the grid characteristic remains unchanged. Indeed the point C, which is the operating point with an infinite volue of grid resistor (i.e., the potential adopted by a floating grid), represents the loss of only a further 0.1 volt of bias.

However, this comparatively small change of bias results in a reduction of control-grid input impedance from about 0.5 megohm when a two-megohm grid resistor is used to less than 0.2 megohm with a three-megohm grid resistor.

Another danger if this valve is operated with a high value of grid leak is that due to the reduced bias the electrode currents and thus the electrode dissipations in the valve will increase. This may liberate further gas, and the resulting cumulative increase in reverse grid current may produce a grid characteristic giving a much greater decrease in grid bias, more severe damping and possibly such excessive heating of the valve that if may be destroyed. A detailed discussion of this effect has been given.[1]

8. Precautions.

Precautions that can be adopted to avoid trouble due to control-grid currents are:

(1) Apply adequate bias to avoid conduction current, e.g., —0.3 volt for battery valves and —1.5 volts for AC types (except short-wave triode-hexodes or triode-heptodes, which need —2 volts because some oscillator voltage will probably be present on the control grid).

(2) When bias is likely to be insufficient to prevent control-grid current in RF or IF pentodes, keep the screen voltage as high as possible. The increase in electrode current in battery receivers may be insignificant on a signal, if a.v.c. is applied to the stage.

(3) When the applied bias is intended to prevent positive grid current from flowing, use the smallest practicable value of grid-circuit resistance to minimize loss of bias due to reverse grid current. With grid-leak bias a large grid leak reduces grid-circuit damping unless the grid-current cross-over point occurs at a positive voltage.

(4) Use cathode bias if possible for each individual stage in order to minimize the effect of changes in contact potential.

Bibliography.

Bowie, R. M., "This matter of contact potential," Proc. I.R.E., 24, Nov. 1936, 1501.

O'Neill, G. D., "Contact potential and retarding field measurements," Sylvania Technologists, Part I, 2, July 1949, 13; Part II, 2, Oct. 1949, 12.

Michaelson, H. B., "Variations of grid contact potential and associated grid currents," Jour. Franklin Institute, 249, June 1950, 455. (Includes bibliography of ninety-two items).

Valley, G. E., and Wallman, H., "Vacuum tube amplifiers," Vol. 18, M.I.T. Radiation Lab. Series, McGraw-Hill, New York, 1948.

Henney, K., "Radio engineering handbook," McGraw-Hill, New York, 4th ed., 1950, 545.

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[1] Amalgamated Wireless Valve Co. Pty. Ltd., "Radiotron Designer's Handbook," Wireless Press, Sydney, 4th ed., 1952, 82.

144-MEGACYCLE TRANSMITTER

72-Watts Input on 144 Mc with an RCA-5894

*By R. M. MENDELSON,** W2OKO

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The appearance of a new tube often prompts the adventurous ham to re-appraise his equipment with a critical eye. W2OKO looked over the specifications for the new RCA-5894, a high-efficiency version of the 829, and found it was time he built an up-to-date 144-Mc rig. The result is a transmitter that takes advantage of the best features of this high-frequency twin beam power tube. Ready for 72 watts of modulated input, the circuit described below incorporates stable VFO tuning, broad-band multipliers for a minimum of tuning controls, a high-efficiency tank circuit, and coaxial output with antenna switching.

Since attention to wiring and construction detail often spells the difference between R3 and R5 at 144 Mc, more than usual "how-to" information will be supplied for this rig. The transmitter will be described in two parts. Part I contains a description of the set, the circuit diagram and parts list, and advice on wiring and construction for those who want to get off to an early start. Adjustment and operation will be described in Part II.

The RCA-5894, a twin beam power tube designed to operate at frequencies up to 400 or 500 Mc, offers many advantages in a modern 144-Mc rig. Since a survey of recent literature disclosed little information on how to capitalize on the tube's possibilities, the transmitter described in this article was developed.

The VFO and multiplier tubes are all well-known ham types. A 5894 is used for the final stage; this tube has balanced structure with low interelectrode capacitances and low cathode inductance. The 5894 is internally neutralized, eliminating all need for external neutralizing circuits. These features, plus the 5894's low rf losses and high power sensitivity, make it an excellent choice for operation with a full 'phone input of 72 watts at 144 Mc.

The complete schematic diagram is shown in Figure 3. The VFO operates in the 8-Mc range, using a 6AU6 in a conventional Clapp oscillator and feeding into a 5763 buffer stage. A 5763 multiplier stage triples to 24 Mc. By means of switch S_1, this stage may also be used as a crystal oscillator for scheduled contacts, net operations, etc. A second 5763 multiplier doubles to 48 Mc to feed a pair of 5763's in a push-pull tripler that drives the final.

The buffer and the two single-tube multipliers use slug-tuned coils in self resonant plate circuits. When the coils are peaked for 146-Mc operation, they give adequate drive from 144 to 148 Mc. The push-pull tripler, capacatively coupled to the final, also provides ample, well-balanced drive over the entire band. Screen-voltage divider R_{17} controls the amount of drive, while R_{18} prevents accidental lowering of drive below a safe value.

To prevent a parasitic oscillation in the final, it was necessary to use a series-tuned screen bypass circuit formed by C_{29} and the internal tube screen-lead inductance. R_{21} serves a dual purpose. First, it acts as a screen-voltage dropping resistor. Since it is wire-wound, however, it also serves as an rf choke at 144 Mc. Its location is important and is discussed under "Construction".

The efficiency of the final circuit stems from the 5894 and from its tank design. This type of design was described in *Electronics,* May, 1947 (p. 130), and sample calculations were given for 144 Mc. Referring to Figure 6, not that the basic circuit is a pair of parallel lines surrounded by a large copper shield. The parallel lines terminate in a copper disk. Separated from this disk by a mica insulator is another copper disk which forms the "bottom" of the shield. The shield prevents radiation from the tank lines and raises the circuit Q considerably.

Loading is varied, and output is taken by means of a movable hairpin loop coupled to the shorted end of the tank. As can be seen from Figure 3, the shield disk and mica insulation also acts as an rf bypass capacitor (C_{32}) for this end of the tank line. Dimensions of the components are fairly critical. The parts can be machined easily, however. They can also be made with hand tools if proper care is exercised. Details are included under "Construction".

Because of the push-pull operation, it is essential that the plate circuits of the 5894 be balanced if both plates are to run cool. Since a balanced antenna coupling is indicated, the hairpin loop should not be used to couple directly to a coaxial line. To make the coupling, a conventional antenna tuner cut for 144 Mc (*QST*, January, 1952, p. 50) is used in reverse. For feeding 50-ohm coaxial line, the input taps on the coil will be approximately one-half turn in from each end; however, they are best located experimentally — as described under "Operation".

Transmitter Layout

As shown in the panel layout, tuning controls are necessary only for the last multiplier plate and the final plate, and are located just below the grid-current and plate-current meters. From left to right

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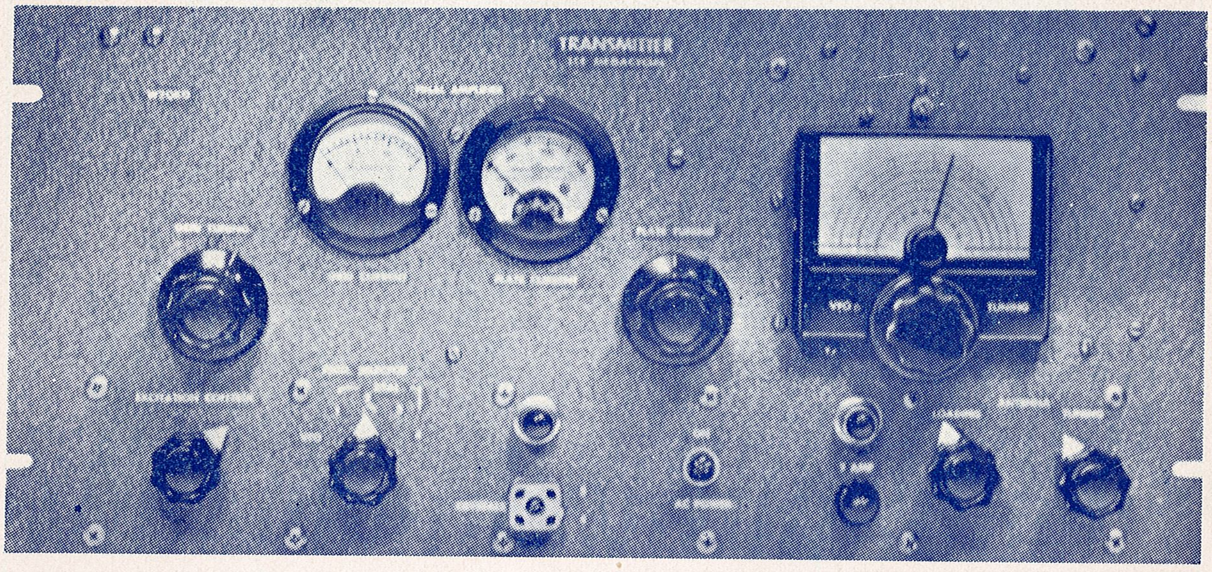
*RCA Tube Division, Harrison, N.J.

across the bottom row are the final excitation control, the crystal-VFO selector, crystal sockets, the filament switch, and antenna loading and tuning controls. Filament and high-voltage pilots and a fuse holder complete the lower level. The VFO tuning knob, calibration dial, and band-set adjuster are in the upper right corner of the panel.

The rig is built on a 17″ x 13″ x 3″ steel chassis bolted to a 19″ x 8¾″ steel panel. Because of the frequency multiplication of 18 times from VFO to final, it is best for good stability to use steel here and provide strong panel-to-chassis bolting.

Figure 1. Panel view of the 144-Mc transmitter. VFO bandset control is directly above the center of the VFO dial.



The VFO and buffer stages are mounted on the left side of a steel box behind the right end of the panel. The first two multiplier stages are on the left of the chassis toward the front. The tripler driver is located back of the doubler, on a sub-chassis and in line with the socket of the final tube. This arrangement allows short coupling leads to the final. Its symmetry also helps to keep the final grid circuit balanced. The 5894 is mounted horizontally, allowing easy connection to the plate tank circuit and adequate ventilation around the tube. This method also keeps heat from getting to the tuned lines where it might affect tuning stability. Tripler and final tuning controls are brought to panel mounts by simple pulley arrangements, as shown in Figure 5.

Antenna link coupling is made at the cold end of the tank lines and is carried by two feed-through bushings below the chassis to the antenna tuner.

The voltage-regulator tube for VFO plate and screen voltage is at the back of the chassis. On the chassis back wall are the antenna and receiver coax connectors and the power input plug.

Construction

If the usual precautions against feedback are observed, no difficulties should be encountered in the construction of this transmitter. Keep all rf leads as short as possible. Only dc and filament leads may be cabled; even on these, adequate rf bypassing should be used close to the tube sockets.

The VFO box is held to the panel with 12 screws. It has no rigid connection to the chassis. Added strength is provided by the use of 12 more screws to fasten the back plate to the box. Heat from the tubes is dissipated outside the box, because only the cold components and the rf tuned circuit are placed inside. Note that a bus-bar is used for all VFO and buffer ground connections. The bus-bar is grounded to the chassis only at the tuning capacitor rotor (C_2). Design of this sort has proved valuable in obtaining a steady VFO frequency. (See VFO described in HAM TIPS, December, 1953.)

The VFO coil is made of 2″ B & W coil stock, chosen for strength and high Q. The coil is best mounted by gluing to a piece of Lucite, using any good plastic cement between the Lucite and the coil's plastic frame. This larger Lucite piece may then be bolted to the front panel on 1″ porcelain standoffs. Keep the coil as far as possible from the cabinet walls. The tuning capacitor, which should be of the two-bearing type, is also bolted to the front panel. In this way the lead from coil to condenser is kept short; more important, the capacitor and coil are kept rigid with respect to each other.

To insure good shielding, paint should be scraped from the back of the panel where the VFO box makes contact. Similarly, scrape the paint from the area of contact between the box and its back cover.

Wiring of the multipliers up to the push-pull tripler requires no comment except to repeat the advisability of short rf leads.

Link coupling is used to the grids of the tripler because of its location. Feed-through bushings fix link coil L_6 and allow the tripler sub-chassis to be lowered into place after both the sub-chassis and socket wiring for the final have been completed.

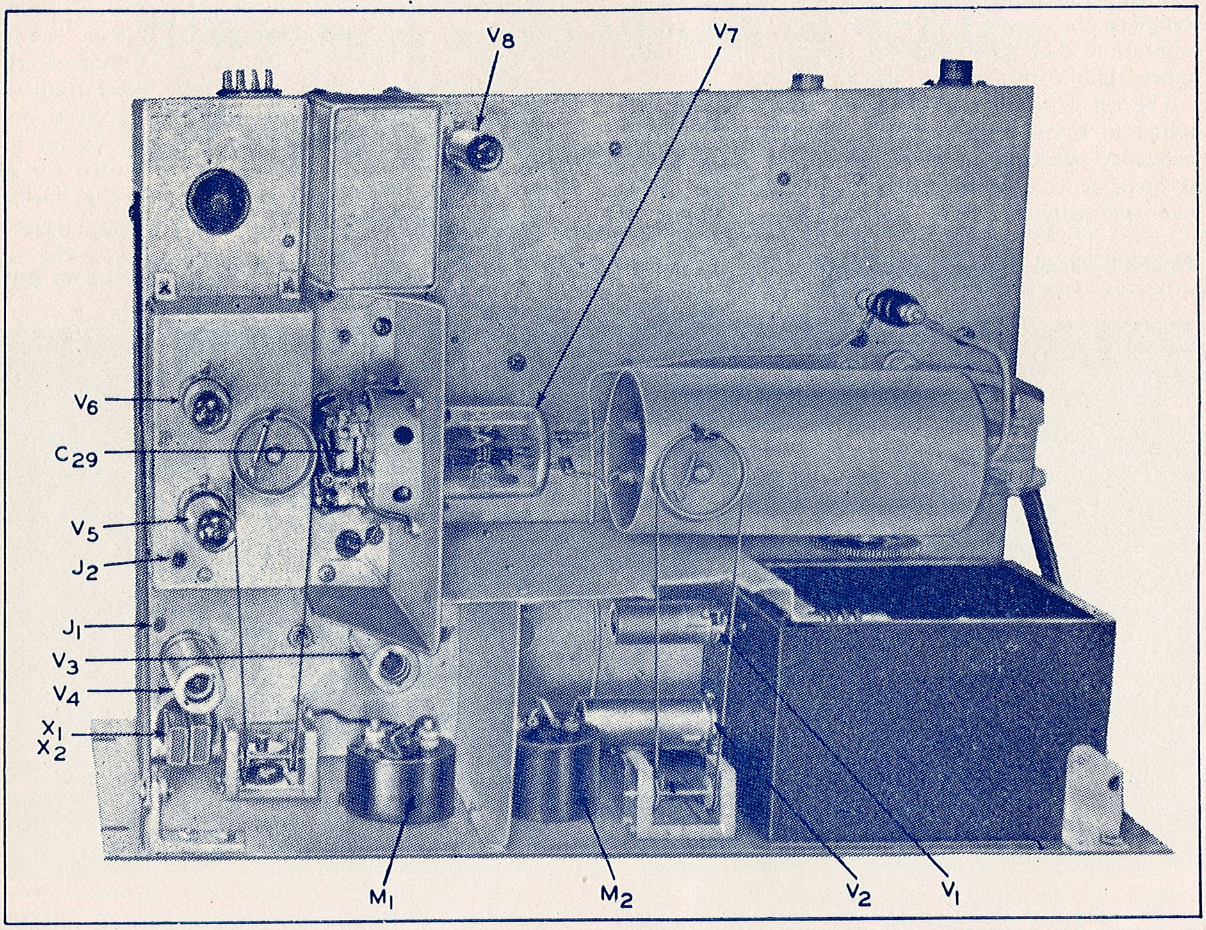


Figure 2. Top view. Note expansion loops in plate leads of the RCA-5894. The two pulley assemblies can also be seen.

Filament, plate, and screen leads from the sub-chassis are fed through a grommet and wired later to their proper points under the chassis. The grid coil is broad-tuned and is adjusted when the transmitter is put into operation. For reduced lead inductance, it is advisable to use $\frac{5}{16}$"-wide copper ribbon for the plate-to-tank leads. The use of tube shields on this stage is not recommended since the loss of rf power through the added plate-ground capacitance will be excessive.

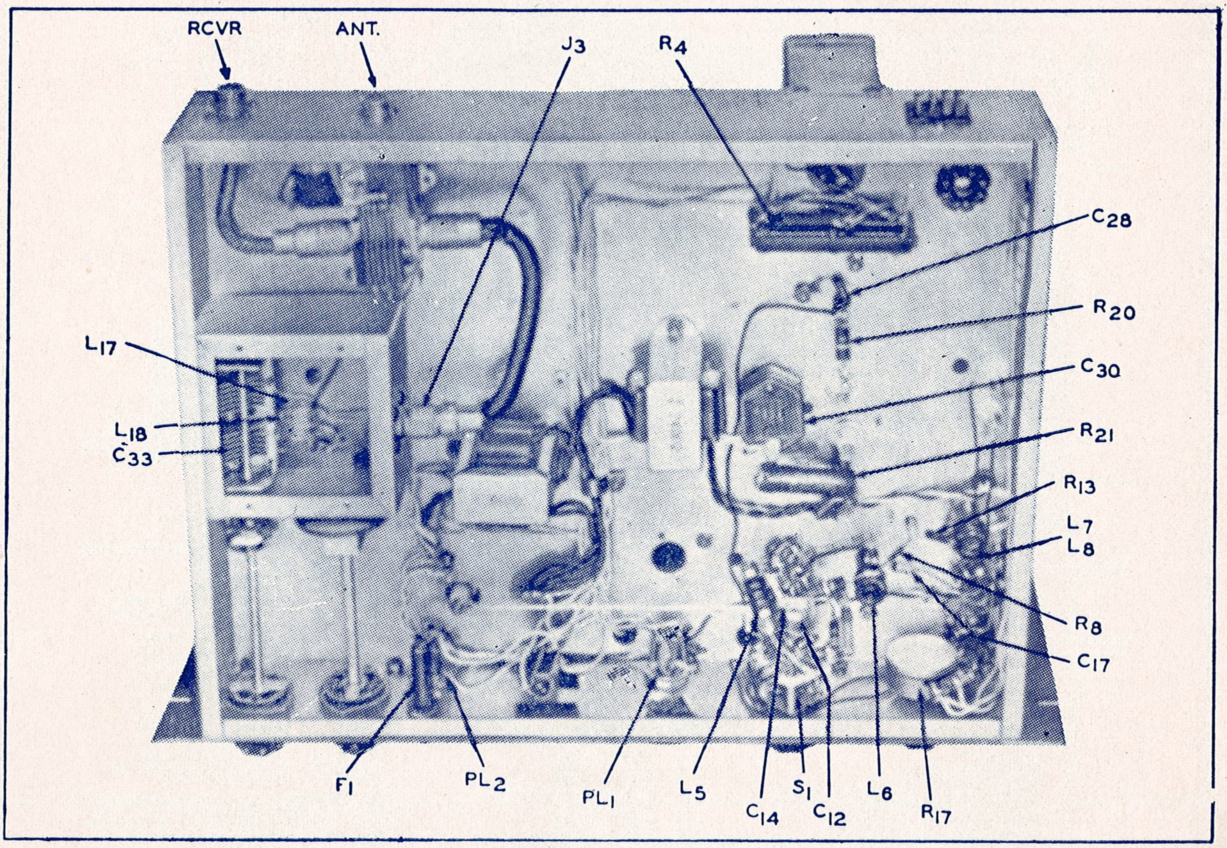
In wiring the final socket (which should contain ventilating holes and be shielded and sunken), note that the screen lead and grid return are fed through the chassis by bushings. Copper ribbon is used from the screen to its feed-through. The screen bypass trimmer should be mounted across the socket to the point at which the heater and cathode are grounded. Place it at a slight tilt so that it may be tuned from above. Under the chassis, the screen dropping resistor is mounted directly on the feed-through bushing and is bypassed by a high-voltage mica capacitor (C_{30}) at the B + end. The grid-bias resistor is mounted between its feed-through and a stand-off, from which a lead runs to the grid meter. Again, $\frac{5}{16}$" flexible copper ribbon, having a U-bend to take up thermal expansion, is used for plate-to-tank leads. This construction prevents the plate-terminal seals from being subjected to any strain.

The shields shown in the top views of the chassis keep any final rf away from earlier stages. They also separate the final grid and plate meters. These shields were installed during the design trouble-shooting of the rig but may not be necessary.

Depending on available facilities, some ingenuity may be required to build the final tank. The disks may be cut easily if a drill press and fly cutter are used; if not, a hacksaw and file will do an acceptable job. The copper shield tubing may be obtained from any large plumbing-supply house. If the dimensions shown are used, the tank will be right on frequency.

In this tank, a spacer of laminated mica and fiber glass was used. Regular mica may be substi-

Figure 4. Bottom view, showing arrangement of components for shortest rf leads.



tuted, however. The thickness should be at least $\frac{1}{16}$" to prevent arc-over but is not critical otherwise. Teflon sheet of at least the same thickness also may be used. Teflon was used here to hold the antenna coupling loop in alignment. Lucite may also prove satisfactory. In any event, these fittings should be kept snug to hold their setting.

In the transmitter shown, a mechanical linkage is used to vary the antenna loading. This linkage was put in before final design was reached and proved to be an unnecessary refinement. Once set, the link will not have to be moved very often — even with relatively large frequency changes.

Be sure the plate tuning capacitor (mounted just inside the shield tubing) is insulated from ground, but that shield itself is well grounded for rf by a 1" copper ribbon at the plate end. These precautions, together with the system of screen bypassing used, will prevent a 200-Mc parasitic oscillation that may otherwise appear.

The antenna tuner is straightforward except that its capacitor rotor is also insulated from ground. Use $\frac{1}{2}$" stand-offs and an insulated shaft coupling. Keep this circuit well shielded. Because the rf fields at the tuner are strong, complete enclosure is essential to prevent possible TVI and feedback to earlier stages.

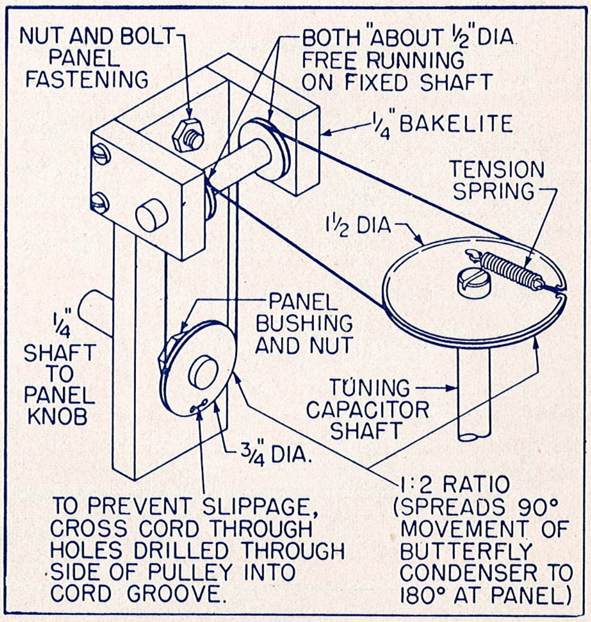


Figure 5. Suggested construction for the two pulley drives.

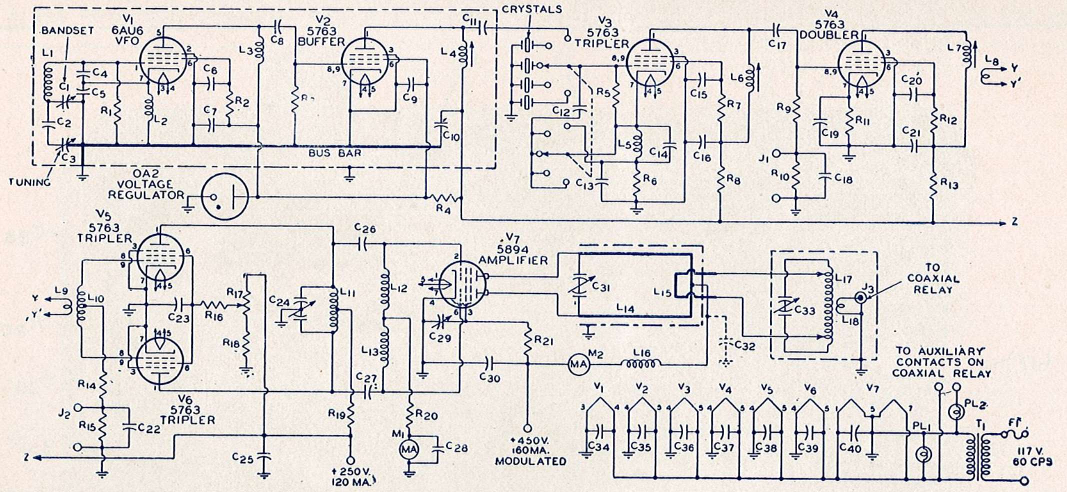


Figure 3. Schematic diagram and parts list.

C_1	50 μμf variable (Hammarlund APC-50)
C_2	5 μμf ceramic, zero temp. coeff. (Erie NPOK-050)
C_3	15 μμf variable, dual bearing (National SEU-15)
$C_{4,5}$	500 μμf silver mica (El-Menco CM15-E501J)
$C_{6,7,9,10,13,15,}$ $C_{16,34,35,36,40}$	0.01 μf ceramic (Centralab CRL D6-103)
$C_{8,17}$	50 μμf ceramic (Erie GP1K-500)
C_{11}	100 μμf ceramic (Erie GP1K-101)
C_{12}	10 μμf ceramic (Erie GP1K-100)
C_{14}	150 μμf ceramic (Centralab CRL D6-151)
$C_{18,19,20,21,22,23}$ $C_{28,37,38,39,41}$	0.001 μf ceramic (Centralab CRL D6-102)
$C_{24,31}$	10 μμf per section butterfly (Hammarlund BFC-12)
C_{25}	2 μf oil, 600 WVDC (Cornell Dubilier TJU 6020)
$C_{26,27}$	20 μμf ceramic (Erie GP1K-200)
C_{29}	7-45 μμf variable ceramic disk (Erie TS2A-7)
C_{30}	0.002 μf mica, 2500 WVDC (Cornell Dubilier Type 9L)
C_{32}	See text
C_{33}	15 μμf per section variable (Hammarlund HFD 15X)
F_1	Fuse, 3AG, 1 amp.
$J_{1,2}$	Insulated phone tip jacks
J_3	Output jack to coaxial relay
L_1	20 turns #16, 2″ diam., 2″ long (B&W 3907 coil stock)
$L_{2,3}$	RFC, 2.5 mh, 125 ma (National R-100U)
L_4	23 turns #26 enam., ½″ diam., close-wound (on slug tuned coil form National XR 50)
L_5	RFC, 2.5 mh, 125 ma (National R-100)
L_6	7 turns #26 enam., close-wound on same type form as L_4
L_7	4 turns #26 enam., close-wound on same type form as L_4
L_8	2 turns #16 enam., coupled to L_7
L_9	1 turn #16 enam., ¾″ diam
L_{10}	20 turns #16 enam., ½″ diam., spaced wire diam., plus ¼″ space at center for L_9
L_{11}	2 turns #16 bare, ½″ diam., spaced ⅛″
$L_{12,13}$	RFC, 1.8 μh (Ohmite Z144)
$L_{14,15}$	See text
L_{16}	RFC, 2.5 mh, 300 ma (National R-300ST)
L_{17}	5 turns #16 bare, ⅝″ diam., spaced ⅛″
L_{18}	1 turn #16 bare, ¾″ diam
M_1	Meter, 0-15 ma
M_2	Meter, 0-500 ma
$PL_{1,2}$	6-8 v, #40 or #47 pilot lights
R_1	47.000 ohms, 1 watt
$R_{2,8,13}$	1,000 ohms, 1 watt
R_3	50,000 ohms, ½ watt
R_4	3,000 ohms, 10 watts
R_5	68,000 ohms, ½ watt
$R_{6,11}$	330 ohms, ½ watt
$R_{7,12}$	12 000 ohms, 1 watt
R_9	82,000 ohms, ½ watt
$R_{10,15}$	1,000 ohms, ½ watt
R_{14}	33,000 ohms, ½ watt
R_{16}	8,000 ohms, 1 watt
R_{17}	20,000 ohms, wire-wound variable, 2 watts
R_{18}	20,000 ohms, 2 watts
R_{19}	100 ohms, 1 watt
R_{20}	10,000 ohms, 1 watt
R_{21}	15,000 ohms, wire-wound, 20 watts
S_1	DP 6-position ceramic rotary switch (Centralab 2505)
T_1	6.3 v, 10 amp (Stancor P6308)
	Miscellaneous
Chassis	17″ x 13″ x 3″ steel (ParMetal B-4536 or C-4536)
Panel	19″ x 8¾″ x ⅛″ steel (ParMetal 6604 or G6604)
Sub-chassis	5″ x 3″ x 2″ (Open-side half of Flexi-mount ICA-29341, or bend from aluminum stock)
VFO shield box	6″ x 5″ x 4″ steel (ICA-3812)
Ant. tuner box	4″ x 4″ x 2″ aluminum (ICA-29810)
Coaxial relay	(Advance CB/1C2C/115VA)

Note: Manufacturer's names and part numbers are given only to identify components used in this transmitter. Equivalent components by other manufacturers may be substituted wherever desired.

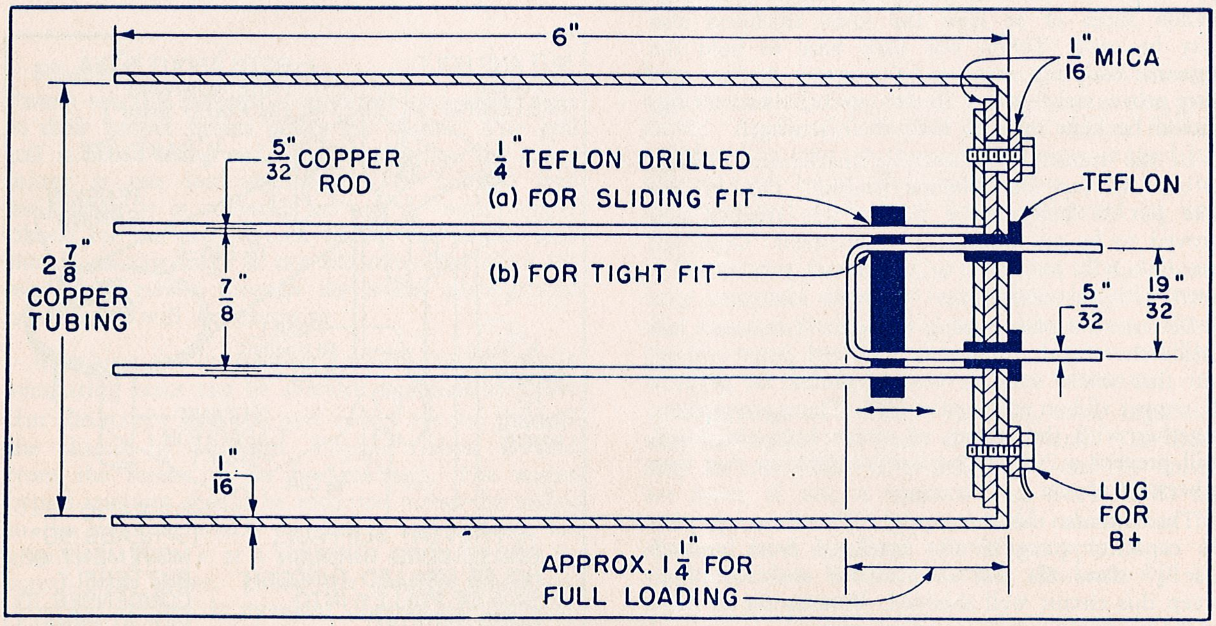
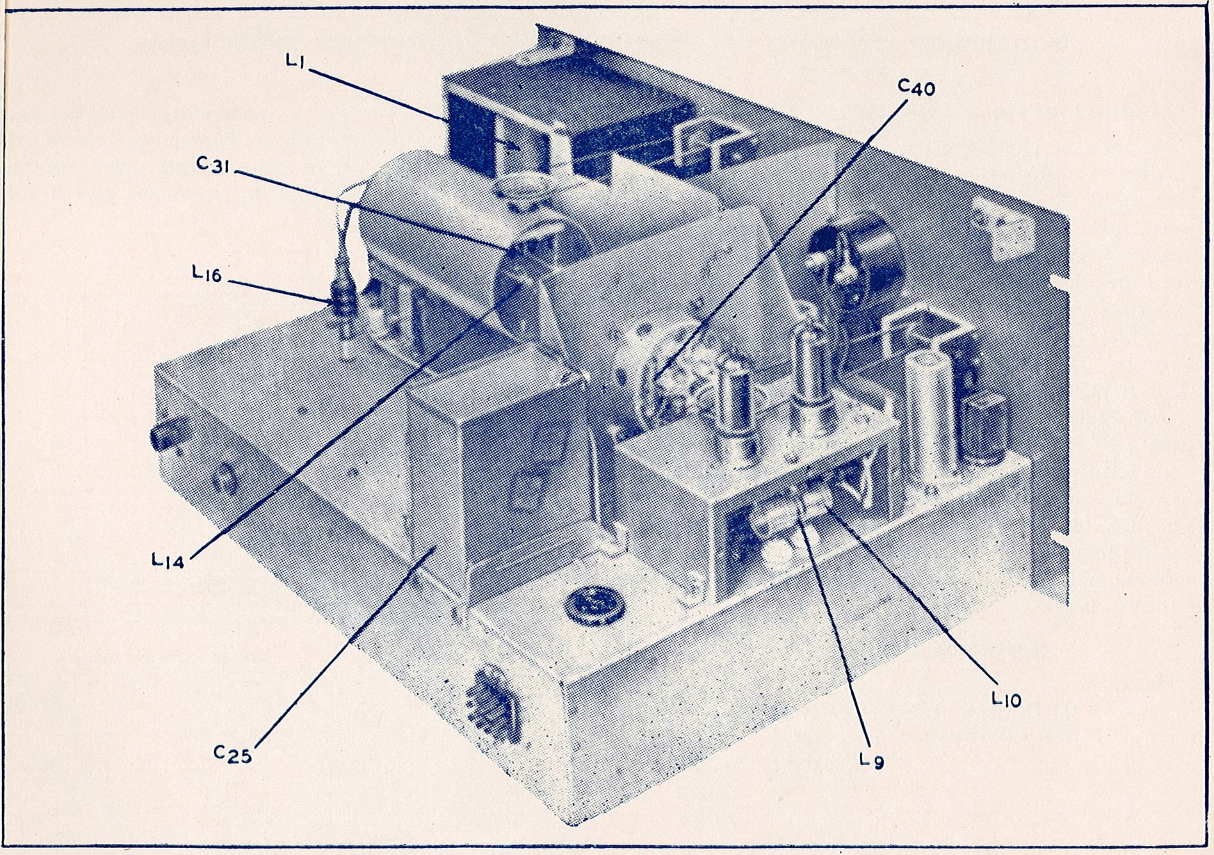


Figure 6. Construction details for the 144-Mc final tank assembly.

Figure 7. Detail view showing arrangement of components on the sub-chassis and the final socket.



NOTE ON PICKUP OUTPUT RATINGS AND RECORDING LEVELS

WITH COMMENTS ON THEIR EFFECTS ON PRE-AMPLIFIERS

by F. Langford-Smith

Pickups have, in the past, usually been rated for output as so many millivolts for a stated recording velocity, or in some cases for use on a specified frequency test record.

A much more convenient output rating is in terms of millivolts per centimetre per second velocity. Then all that is necessary is to multiply this rating by the maximum velocity recorded, to give the maximum voltage produced by the pickup on the particular record.

Unfortunately there is very little information on this question published by the manufacturers of records. However, through the courtesy of Mr. Buckland, of E.M.I. (Australia) Pty. Ltd., we have been given a range of maximum velocieties occurring in individual records from various manufacturers in several countries. This range is set out below:

Minimum 5 cm/sec.
Maximum 25 cm/sec.

This range covers both microgrove and standard records, and it appears that some of the highest known velocities are found in LP recordings — quite contrary to the earlier practice of recording LP at lower velocities than standard 78 r.p.m.

An article is now being prepared for publication in a future issue, including a table giving the output voltages of a very wide range of pickups all expressed in terms of millivolts per cm. per sec., and treating the subject in considerable detail.

NOTE ON PRE-AMPLIFIERS

This is a matter of prime importance in the design and testing of pre-amplifiers for use with pickups. It means that no significant overloading should occur between the pickup and the volume control even when the input voltage is five times the minimum value. With high level crystal pickups the only safe position for the volume control is before the grid of the first valve. The problem with low level pickups is not so simple.

Tests now planned for pre-amplifiers tested in the Radiotronics Laboratory include distortion with normal input voltage, and three and five times normal.

LEAK TL12 MAIN AMPLIFIER

Conclusion of tests described in the September 1955 issue.

14. Individual Harmonics using Wave Analyser

Measured at 1000 c/s, resistance load.

Power at which flat top first appears on oscilloscope 15.2 W.

In this test, the particular harmonic being measured is attenuated by a parallel-T network, tuned to the harmonic, between the oscillator and the input terminals to the amplifier. By this means, the effect of oscillator distortion is made so low as to be unmeasurable. In the oscillator used for these tests, the only measurable harmonics are the second and third, so that this precaution is not required for higher order harmonics.

In addition, an 1800 c/s high pass filter using air cored inductors and with an attenuation greater than 40 db at 1000 c/s, was connected between the amplifier and the wave analyser. Details of this method, and the equipment used, will be given in a future issue.

Harmonic Percentage

Harmon.	1	2	5	10	12	0.073
2	0.018	0.03	0.055	0.095	0.10	14 Watts
3	0.017	0.013	—	—	0.01	0.012
4	—	—	—	0.035	0.04	0.095
5	—	—	—	—	—	0.065
6	—	—	—	—	—	0.045
7	—	—	—	—	—	—
8	—	—	—	—	—	0.04
9	—	—	—	—	—	0.015
10	—	—	—	—	—	0.015
11	—	—	—	—	—	0.01
12	—	—	—	—	—	—
13	—	—	—	—	—	—

Readings below 0.01% were neglected.

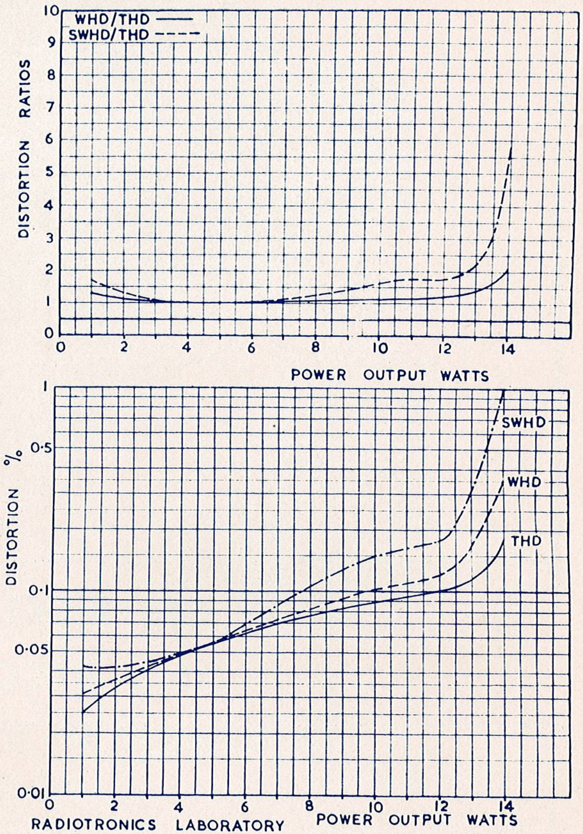
15. Total harmonic distortion using harmonics up to the thirteenth

The three formulae used for this calculation are given in Radiotronics, Vo. 20, No. 9 (September, 1955), page 106, equations 1, 2 and 3.

The three curves are shown in the lower portion of Fig. 6 where

THD = total harmonic distortion
WHD = weighted harmonic distortion
SWHD = special weighted harmonic distortion.

Since the TL12 is a particularly well-designed push-pull triode amplifier, harmonics above the fourth are insignificant even at full power output, so that both these weighting methods give results not far different from THD — see the upper portion of Fig. 6 for the ratios between these methods. This result does not hold for all types of amplifiers, and fairly high percentages of higher order harmonics occur with UL operation.



RADIOTRONICS LABORATORY FIG. 6 AMPLIFIER LEAK TL 12 FORM 5

Editor .... D. Cunliffe-Jones
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