RADIO TEST EQUIPMENT

Lesson RRT-19

DE FOREST'S TRAINING, INC.
2533 N. Ashland Ave., Chicago 14, Illinois

RRT-19

Radio Reception
and Transmission

LESSON RRT-19

RADIO TEST EQUIPMENT

CHRONOLOGICAL HISTORY OF RADIO AND TELEVISION DEVELOPMENTS

1941—The Federal Communications Commission authorized commercial television broadcasting.

1941—Television progress demonstrated by RCA, including:

(1) A home television receiver with 13½" x 18" screen.

(2) Television pictures on a theater screen 15 by 20 feet.

(3) Pictures relayed by radio from Camp Upton to New York.

(4) Facsimile multiplexed with F-M sound broadcast.

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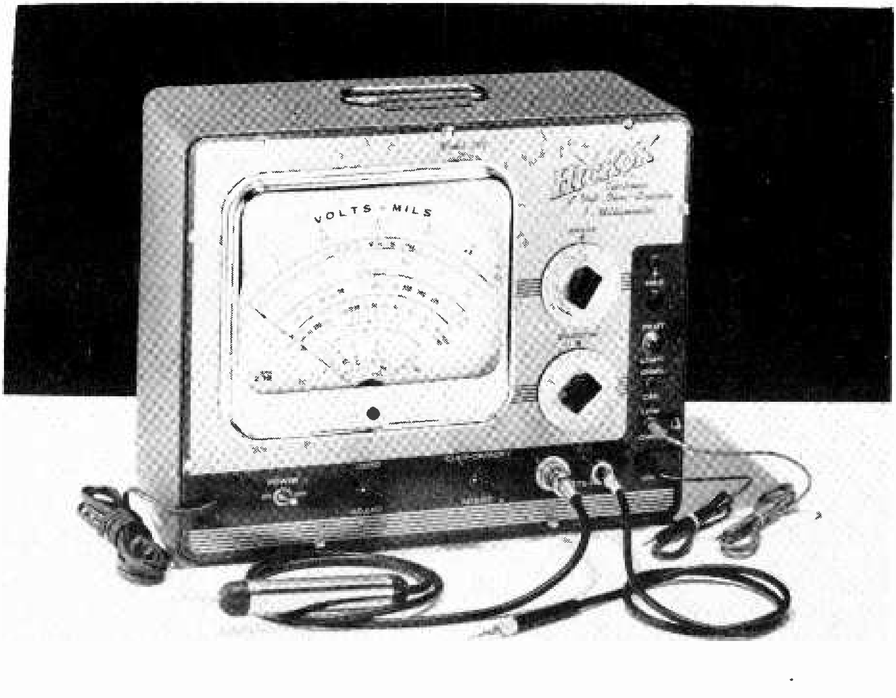
No one knows what he can do until he tries.
—Selected

TEST EQUIPMENT DEVELOPMENT

As with all other electrical and electronic apparatus, the profitable design, production, and maintenance of radio and television equipment depend largely upon accurate measurement of the various voltages, currents, and resistance values involved. In order that these many different measurements can be made, a large variety of test instruments has been developed. In fact, whenever a new branch of electronics is to be explored, the development of suitable measuring devices must accompany the research work in order that new quantities, or, as often is the case, new magnitudes of old quantities, can be investigated.



Electronic multimeter adapted for precise circuit analysis and general service work.

Courtesy Hickok Electrical Instrument Company

As the early development work in electricity and electronics dealt primarily with d-c and relatively low-frequency a-c, most of the equipment for measuring these quantities is of early origin, but the great majority of the devices for high-frequency a-c measurements are of relatively recent design. In the case of radio service equipment, with which this lesson is concerned, a few simple meters were adequate for testing the rather simple circuits of the early receivers. However, with the progress of the industry, the circuits became more complex and for efficient maintenance work, the number and complexity of test instruments increased also.

The construction and operation of conventional types of non-electronic voltmeters, ammeters, and ohmmeters were covered in earlier lessons. Other measuring equipment, also previously explained, includes multimeters, capacity meters, analyzers, and the Wheatstone Bridge. A review of these lessons may be of benefit at this time, as the present explanations assume that the action of these basic meter types is understood.

VOLTMETER ACCURACIES

It has been mentioned previously that the more sensitive a voltmeter, the more accurate its readings. The sensitivity of a voltmeter varies inversely with the amount of current required for full scale deflection of the pointer, therefore the most sensitive meter is the one which requires the least current. A second advantage of a highly sensitive meter is that the circuit under test can operate more nearly at the conditions which prevail when no meter is connected to it.

For example, if a meter requires one milliampere of current for full scale deflection of its pointer, a multiplier resistance of 100,000 ohms (100 divided by 0.001) is needed for its 100 volt range and its sensitivity is said to be 1000 ohms-per-volt (100,000 ÷ 100). If a more sensitive meter requires but 50 microamperes for full scale deflection, its 100 volt range employs a multiplier resistance of 100 ÷ .00005 = 2,000,000 ohms, and its sensitivity is 2,000,000 ÷ 100 or 20,000 ohms-per-volt.

To compare the relative accuracy of the measurements made with these two meters, suppose it is desired to measure voltages in the circuit of Figure 1, in which the resistor R has a value of 50,000 ohms. The plate of diode D is connected to the negative terminal of the d-c supply, so that normally there is no current in the circuit. Therefore, there should be no voltage drop across R and the voltage between points X and Y should be equal to that across the power supply terminals.

If the internal resistance of the supply is low, both the 1000 ohms-per-volt and 20,000 ohms-per-volt meters will read almost exactly the value, E_s of the supply, when connected across its terminals. However, to measure the voltage across the diode, the meter test prods are placed at points X and Y as shown, and the meter current must be carried by series resistor R.

Assume the supply output E_s is 100 volts, and for the first case, the 1000 ohms-per-volt meter is used to measure the voltage E_V. On its 100 volt range, the resistance of this meter is 100,000 ohms and, with resistor R of 50,000 ohms, the total circuit resistance is 150,000 ohms. According to Ohm's Law, the circuit current will be,

$$I = \frac{E}{R} = \frac{100}{150{,}000} = .000667 \text{ amp.}$$

Carrying this current, the voltage drop across resistor R will be,

$$E = I \times R = .000667 \times 50{,}000$$
$$= 33.3 \text{ volts}$$

and for the meter,

$$E = I \times R = .000667 \times 100{,}000$$
$$= 66.7 \text{ volts}$$

As the meter indicates the voltage across its terminals, it will read 66.7 volts which is but ⅔ of the voltage across X-Y when the meter is removed.

For the second case, assume voltmeter "V" of Figure 1 has a sensitivity of 20,000 ohms-per-volt, therefore, its 100 volt range has a resistance of 2,000,000 ohms. With resistor R of 50,000 ohms, the total circuit resistance is 2,050,000 ohms and with a 100 volt supply, the current will be,

$$I = \frac{E}{R} = \frac{100}{2{,}050{,}000} = .0000488 \text{ amp}$$

Carrying this current, the voltage drop across resistor R will be,

$$E = I \times R = .0000488 \times 50{,}000$$
$$= 2.4 \text{ volts}$$

and for the meter,

$$E = I \times R = .0000488 \times 2{,}000{,}000$$
$$= 97.6 \text{ volts}$$

In the circuit of Figure 1, the reduced reading of the meter is caused by the drop across the series resistor R. The higher the sensitivity of the meter, the lower its current, the lower the drop across the external series connected resistor and the more accurate the reading.

Similar inaccuracies occur when the meter is connected in parallel with a resistor to measure the voltage drop across it.

For example, assume diode D of Figure 1 is replaced by a 50,000 ohm resistor like R. Then, without the meter, for a 100 volt supply, the circuit current will be,

$$I = \frac{E}{R} = \frac{100}{100{,}000} = .001 \text{ amp}$$

and across each resistor, the drop will be,

$$E = IR = .001 \times 50{,}000 = 50 \text{ volts}$$

If meter V has a sensitivity of 1000 ohms-per-volt and is on the 100 volt range, its total resistance of 100,000 ohms is in parallel with the 50,000 ohm resistor replacing diode D. The effective resistance of this parallel combination will be,

$$R = \frac{50{,}000 \times 100{,}000}{50{,}000 + 100{,}000} = 33{,}333 \text{ ohms}$$

The total circuit resistance will be 50,000 + 33,333 = 83,333 ohms for a circuit current of.

$$I = \frac{E}{R} = \frac{100}{83{,}333} = .012 \text{ amp}$$

With this current, the drop across resistor R will be,

$$E = I \times R = .0012 \times 50{,}000$$
$$= 60 \text{ volts}$$

and for the parallel meter resistor combination,

$$E = I \times R = .0012 \times 33{,}333$$
$$= 40 \text{ volts}$$

With a 40 volt reading on the 100 volt range. the meter circuit

High grade vacuum-tube voltmeter designed and calibrated to read directly in rms values.

Courtesy Hewlett-Packard Company

may be switched to the 50 volt range with the mistaken idea of obtaining greater accuracy. Instead, the error will be increased because, on the 50 volt range, the meter resistance is but 50,000 ohms. Under these conditions, the effective resistance of the meter and the 50,000 ohm resistor it is connected across will be,

$$R = \frac{50{,}000 \times 50{,}000}{50{,}000 + 50{,}000} = 25{,}000 \text{ ohms}$$

The total circuit resistance will be,

$$50{,}000 + 25{,}000 = 75{,}000 \text{ ohms}$$

and, for the circuit current,

$$I = \frac{E}{R} = \frac{100}{75{,}000} = .0133 \text{ amp.}$$

With this current, the drop across resistor R will be,

$$E = I \times R = .0133 \times 50{,}000$$
$$= 66.6 \text{ volts}$$

and for the meter resistor combination,

$$E = I \times R = .0133 \times 25{,}000$$
$$= 33.3 \text{ volts}$$

For this type of test, the highest range of the meter will provide the most accurate readings.

Substituting a meter with a sensitivity of 20,000 ohms-per-volt, on the 100 volt range its resistance will be 2 megohms. Using the other values of the previous examples, the effective resistance of the meter and parallel resistor will be,

$$R = \frac{50{,}000 \times 2 \text{ meg}}{50{,}000 + 2 \text{ meg}} = 48{,}780 \text{ ohms}$$

The total resistance of the circuit will be 50,000 + 48,780 = 98,780 ohms and for the circuit current,

$$I = \frac{E}{R} = \frac{100}{98{,}780} = .001012 \text{ amp.}$$

With this current, the drop across resistor R will be,

$$E = I \times R = .001012 \times 50{,}000$$
$$= 50.6 \text{ volts}$$

and across the meter resistor combination,

$$E = I \times R = .001012 \times 48{,}000$$
$$= 49.4 \text{ volts.}$$

VACUUM TUBE VOLTMETERS

For routine testing of plate, screen grid and cathode circuits, the conventional types of non-electronic voltmeters are satisfactory for most practical work. With circuits arranged to provide voltage, current and resistance ranges, they are perhaps the most common and useful of all maintenance test equipment. However, for satisfactory measurements of small voltages which appear in high resistance circuits, much higher voltmeter sensitivity is needed on the lower ranges. This requirement is met by the electronic or vacuum tube voltmeter, abbreviated vtvm.

As its name implies, the vacuum tube voltmeter employs one or more tubes which are arranged so that the unknown voltage, applied to the input grid circuit, causes changes of plate current that are indicated by a d-c meter, with a scale calibrated directly in volts. With negligible grid current, the energy required to operate the meter is of such a low value that when making tests, the circuit conditions are not affected appreciably, and quite accurate readings can be obtained.

To compare the low voltage accuracy of the vacuum tube voltmeter with that of the non-electronic type, assume that the supply voltage, E_S, in Figure 1, is equal to one volt. As before, with no current in the circuit, the voltage E_V across the diode should be equal to E_S, that is, $E_V = 1$ volt. On a 1 volt range, the resistance of the 20,000 ohms-per-volt non-electronic meter is 20,000 ohms, and when its test prods are placed at X and Y in Figure 1, with R equal to 50,000 ohms, the total circuit resistance 20,000 + 50,000 = 70,000 ohms. With a 1 volt supply the circuit current will be,

$$I = \frac{E}{R} = \frac{1}{70{,}000} = .0000143 \text{ amp.}$$

the drop across R will be,

$$E = I \times R = .0000143 \times 50{,}000$$
$$= 0.715 \text{ volt (approx.)}$$

and the drop across the meter will be 0.285 volt which is an extremely inaccurate reading.

Using a vacuum tube voltmeter, which generally has an input resistance of at least 10 megohms, the total resistance of the circuit will be 10,050,000 ohms. With a 1 volt supply, the circuit current will be.

$$I = \frac{E}{R} = \frac{1}{10{,}050{,}000}$$
$$= .000{,}000{,}0995 \text{ amp.}$$

the drop across R will be,

$$E = I \times R$$
$$= .000{,}000{,}0995 \text{ x } 50{,}000$$
$$= .00497 = .005 \text{ volt (approx.)}$$

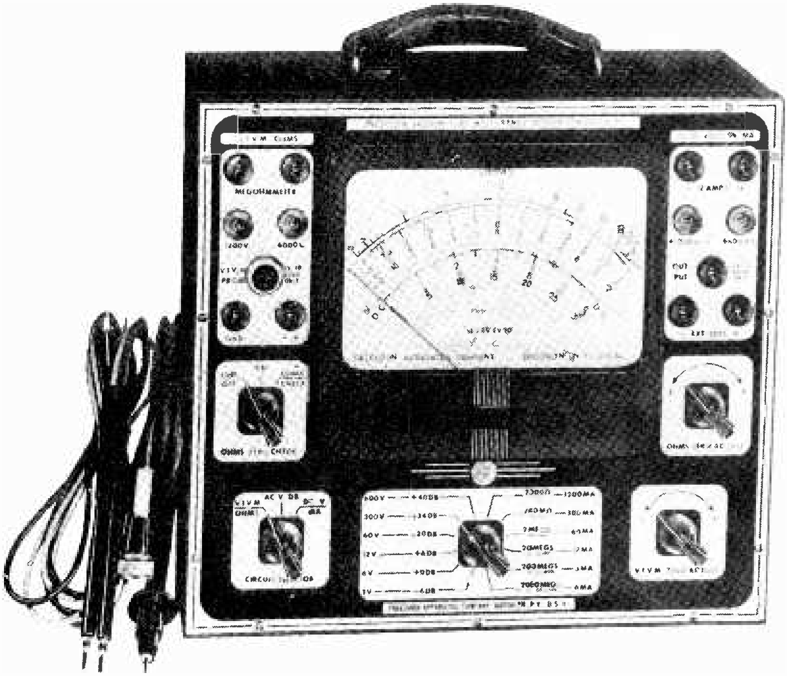
and the drop across the meter will be,

$$E = I \times R$$
$$= .000{,}000{,}0995 \text{ x } 10{,}000{,}000$$
$$= .995 \text{ volt.}$$

In this case, the error is but one half of one percent and provides sufficient accuracy for practically all maintenance and laboratory work.

Usually the non-electronic meter mechanism of high sensitivity is extremely delicate, and therefore subject to damage from mechanical jarring or electrical overload. The meter mechanism of the vtvm need not be of the delicate high sensitivity type, and isolated by the circuit from the voltage to be measured, it is protected from electric overload.

There are many forms of vtvm's, classified according to whether they measure d-c, a-c, or both; whether they measure rms voltages or peak values; and also as to their mode of operation. The a-c types can be subdivided into those best suited for low frequency voltages and those adapted for high frequency work.



Vacuum-tube multi-range circuit tester designed for general laboratory and service measurements.

Courtesy Precision Apparatus Company

SLIDE-BACK VTVM

A simplified basic circuit of a d-c type of slide-back vtvm, shown in Figure 2, includes two conventional type non-electronic meters. The voltmeter "V" is in the grid cathode circuit of the tube while the microammeter "M", with limiting resistor R, is in the plate circuit. One test prod, "H" connects directly to the grid while the other test prod "G" connects to one terminal of voltmeter V. The "C" or bias battery is connected between voltmeter V and the cathode while the "B" or plate battery is connected between the cathode and microammeter M.

Potentiometer P is connected across battery A and also across voltmeter V so that, by adjusting its movable contact, any desired portion of the A battery voltage can be impressed across the voltmeter and indicated on its dial. Before a measurement is made, the circuit must be calibrated, or "zero adjusted", by moving the potentiometer arm so that no A battery voltage is across voltmeter V and placing test prod H in contact with test prod G.

Under these conditions, the potentiometer, battery A and voltmeter V are shorted out of the circuit and the grid is connected directly to C battery negative. With this negative grid bias, the resulting plate current, indicated by meter M, can be used as a zero reference. In commercial models, additional adjustments are provided so that the plate current can be reduced exactly to some definite reference point.

To make a measurement, the test prods are placed separately on the circuit points, between which the unknown voltage appears, so that it is in series with the grid circuit. With the polarities indicated in Figure 2, the unknown voltage will increase the total negative grid voltage and thus cause a reduction of plate current. The polarity of battery A is opposite to that of the unknown voltage between the test prods therefore, as the arm of potentiometer P is moved to permit A battery voltage across meter V, the total negative voltage in the grid circuit will be reduced and the plate current will increase.

The arm of the potentiometer is adjusted until the plate current, indicated by meter M, is of exactly the same value as the original reference point. With this value of plate current, the effective voltage of battery A, indicated on meter V, must equal the unknown voltage across the test prods. The circuit derives its name because it is necessary to "slide back" the arm of the potentiometer to obtain the desired voltage reading.

With this arrangement, battery A supplies the operating current for voltmeter V which may have the conventional sensitivity of 1000 ohms-per-volt.. Due to the C battery, the grid is held negative with respect to the cathode therefore the resistance of the circuit is extremely high and there is negligible current in it. Connected in series with the grid, the normal operating conditions of the circuit under test are not changed by the presence of the meter but the balancing action of battery A and potentiometer P provide accurate readings on meter V.

VTVM FOR A-C MEASUREMENT

The common forms of vacuum tube voltmeters, for the measurement of a-c, employ a triode tube operating as a plate or bias type detector. As explained for the circuit of Figure 2, the unknown voltage is impressed across the grid circuit and the resulting increase of plate current is indicated by a meter in the plate circuit.

If the grid bias is of such value that the operating point of the tube is midway in the lower curved portion of its plate current-grid voltage characteristic curve, the change of plate current will be almost exactly proportional to the square of the effective value of a-c grid input voltage. This is called the "square law" action and for instruments of this type, usually the plate circuit meter is calibrated in rms volts.

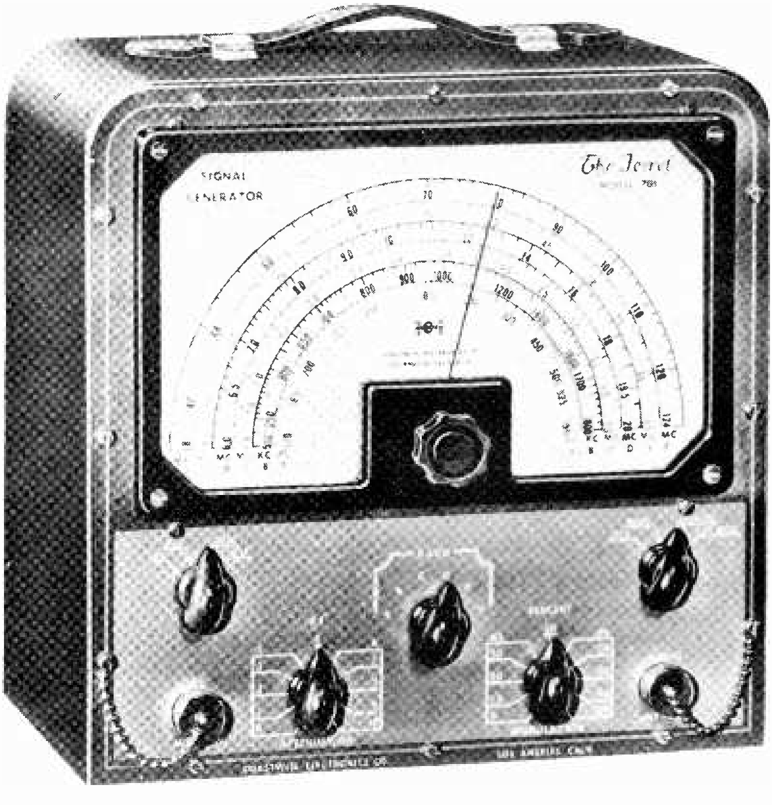
If the grid bias is increased to plate current cutoff, the change of plate current will be very nearly proportional to the effective value of the positive alternation of input grid voltage to cause what is known as half-wave square law action. However, if the negative grid bias is increased beyond plate current cutoff, the change of plate current is proportional to the peak or maximum value of the positive alternations of input grid voltage and the circuit operates as a "peak" voltmeter. If the grid of the tube is biased properly, the slide-back type of vtvm can be used for the measurement of a-c voltages. In this case, the reading on the grid voltmeter is considered as equal to the peak value of the positive alternations of the measured voltage.

Vacuum tube voltmeters may be calibrated at 60 cycles and, if properly designed, will provide readings for all audio and low radio frequencies. At higher radio frequencies, the distributed capacitance and inductance of the wiring, as well as resonance of the input circuit, cause inaccuracies. The input voltage waveform affects mainly the half-wave square law and peak types because their operation depends only on the positive alternations of input voltage. If the input voltage is non-sinusoidal, it is advisable to reverse the position of the test leads and check for a change of reading. When such a change of reading occurs, the average of both will approximate the correct value.

Depending upon the action of an electron tube for its operation, the calibration of a vtvm is affected by changes of supply voltages and cathode emission. Thus, for the simpler types, it is customary to make frequent calibrations, in some cases before each reading is taken.

WIDE FREQUENCY RANGE VTVM

On account of the necessity of making one or more adjustments each time a reading is taken, the slide-back vtvm has been replaced almost entirely by a type that employs a Wheatstone Bridge circuit in which a d-c meter is the indicating device. With this arrangement, once the bridge has been balanced to zero, any number of readings can be taken without making any other adjustments.



All-purpose signal generator for a-m, f-m, and television servicing. Operates from 170 kc to 110 mc.

Courtesy Coastwise Electronics Company

In a circuit of this type, shown in Figure 3, the bridge circuit is connected between $B+$ and $B-$. Starting at $B+$, one arm consists of variable resistor R_{11} connected to point X with R_{12} as a second arm connected to point **Y**. Between point X and ground, the third arm consists of the plate circuit of tube V_2 and its cathode resistor R_{10}, while resistor R_{13}, connected between point Y and ground, is the fourth arm. The plate circuit of the tube operates as a variable resistor, the value of which is controlled by the grid voltage.

The grid circuit can be traced from the grid, through bias battery B_C, up and over to the left, down through the switch and voltage divider and back up through R_{10} to the cathode. With the tube in operation, the bias battery will maintain the plate current at some constant value and thus, in effect, fix the resistance of the plate circuit. The resistance of R_{11} is then adjusted until the drop across it is equal to that across R_{12}. When this condition is obtained, points X and Y will be at equal potentials and as it is connected across these points, there will be zero current in the meter.

A change of grid voltage will cause a change of plate current, which is equivalent to a change of plate circuit resistance, thus, the bridge circuit will be unbalanced and there will be current in the meter. The meter current will be proportional to the amount of unbalance which, in turn, is proportional to the change of grid voltage therefore the meter dial is calibrated in volts. As it is applied to grid, the unknown voltage can be read directly on the meter dial.

Designed for a-c measurements, in the circuit of Figure 3 the unknown voltage is connected across the test probe terminals, shown at the upper left, and impressed across condenser C_1 in series with tube V_1 connected as a diode.

When an a-c voltage, e_i, is impressed on the test probe, rectification by the diode connected tube V_1 will allow condenser C_1 to become charged to the peak value of the positive half cycles. When this occurs, the diode plate will no longer be positive with respect to the cathode, and tube conduction ceases. The tube will not conduct again throughout the cycle except for a very short time on the next positive input voltage peak. By making R_1 of high resistance (10 to 20 megohms) and C_1 of sufficient capacitance (.02μfd), the time constant will be large and C_1 will discharge very little between positive peaks as long as the value of the input voltage is not reduced.

On the negative half cycles of input, the voltages combine to charge condenser C_2 through R_2 and this condenser-resistor combination acts as a filter with only a small a-c component in its d-c output. This voltage, passed on to the rest of the vtvm, is negative with respect to ground and its amplitude is directly proportional to the peak value of e_i.

If the input voltage should be reduced while a voltage reading is being taken, both E_{C1} and E_{C2} will exceed the new peak value of e_i. C_2 will, therefore, discharge through R_1 and R_2, and C_1 will discharge through R_1 until a new equilibrium is established.

E_{C2} is applied through the input voltage divider and range switch S to the grid circuit of V_2. The fraction of E_{C2}, taken from the voltage divider, charges C_3 to the polarity shown, and this voltage, E_{C3}, adds to the bias voltage, E_{BC}, causing the plate current of V_2 to be reduced. With reduced plate current, the drop across R_{11} will decrease, and point X on the bridge becomes more positive than point Y. This difference of potential causes current in meter M, and the deflection of the needle will be proportional to the change in the plate current. Since this in turn is proportional to the magnitude of the voltage being measured, the meter scale can be calibrated to read directly in volts.

VTVM's of the type illustrated in Figure 2 are useful for measurements up to a few hundred kilocycles. At higher frequencies, the effects of tube input capacitance, wiring capacitance, and the difference in tube characteristics, limit the usefulness of the instrument.

These effects are minimized in the direct diode rectification type of Figure 3. Here the input voltage is converted to d-c, after passing through very short leads, therefore, the effect of wiring capacitance is of very little consequence. As a result, this type of vtvm is useful over a range of 20 cycles to 100 megacycles or more.

MULTIPURPOSE VTVM

The circuits of Figures 2 and 3 are arranged for the measurement of voltage only but, like the conventional types of multimeters, the vacuum tube voltmeter circuit can be arranged for the measurement of other electrical quantities. A circuit of this general type, shown in Figure 4, will measure a-c volts, d-c volts and ohms, each on several ranges.

The indicating meter, "M", is connected in a bridge circuit, similar to that of Figure 3 but here, to reduce errors in readings due to changes in the tube circuits, both variable resistance bridge arms consist of tube plate circuits. For example, in Figure 4, an increase of plate supply voltage, due to change of line voltage or load, will cause equal increases of plate current in both tubes and therefore will not unbalance the bridge.

From the cathode of power supply rectifier tube V_7, there is a circuit through filter resistor

R_{30}, part of zero adjust potentiometer P and resistor R_{28} to the plate of tube V_1. From the plate, the circuit continues through the tube to the cathode, through resistors R_{26} and R_{25} to the supply negative. Also from potentiometer P, there is a circuit through resistor R_{29} to the plate of V_2 and from its cathode through resistors R_{27} and R_{25} to the supply negative. Notice here, resistor R_{25} is common to both cathodes and the plate supply is grounded at the junction between resistors R_{31} and R_{32}, which form a voltage divider across it.

Both tubes operate as triodes and the control grid of V_1 connects to the common terminal of selector switch S_1-B while the control grid of tube V_2 connects to the common terminal of switch S_1-C. Switch S_1-D, at the bottom center, operates to turn the power on and off while switch S_1-A, at the lower left, completes the "Ohms" input circuit. The entire switch accommodates four circuits in six positions and, as shown by the broken lines, all sections are ganged mechanically. The six positions provide 1: zero center, 2: ohms, 3: a-c volts, 4: + volts (d-c), 5: — volts (d-c), and 6: off.

Audio-frequency signal generator.
Courtesy Radio Corp. of America

The range switch, shown as S_2 in the center of the diagram, also accommodates four circuits in six positions and, as indicated by the broken lines, all sections are ganged mechanically to provide control by a single knob. Switches S_2-A and S_2-B provide four ranges of a-c volts, switch S_2-C provides six ranges of d-c volts and switch S_2-D provides six resistance ranges.

With the selector switch in the "zero center" position, gang S_1-B connects the grid of V_1 to ground through switch S_2-C and part of the d-c volts divider which consists of resistors R_{13} through R_{18}. Gang S_1-C connects the grid of V_2 to ground directly. Gang S_1-D closes the 117 volt a-c supply while gang S_1-A is open. Thus, with no "d-c volts" input, both grids are at ground potential but negative with respect to the cathodes because of the voltage drops across resistors R_{26}, R_{27}, R_{25} and R_{31}. Under these conditions, potentiometer P is adjusted until the plate currents cause equal drops across resistors R_{28} and R_{29} and the meter reads zero.

With the selector switch in the "OHMS" position, the grid of V_1 connects to ground through selector switch S_1-B, range switch S_2-D, part of the "ohms" voltage divider, which consists of resistors R_{19} through R_{24}, and battery B. Switch S_1-D still completes the power supply circuit while switch S_1-A connects the ohms input terminal to resistor R_{19}.

Under these conditions, when test leads are connected to the ohms and ground terminals, and the test prods placed across an external circuit, the value of the resulting battery current in the voltage divider will be controlled by the resistance of the external circuit. Selected by range switch S_2-D, the desired portion of the voltage drop across the divider will be impressed on the grid of V_1 to make it more positive with respect to ground.

This change of V_1 grid voltage will cause an increase of plate current and a higher voltage drop across cathode resistors R_{26} and R_{25}. As R_{25} is in the cathode circuit of V_2, the increased drop across it will cause the grid of V_2 to become more negative with respect to the cathode and its plate current will decrease. Thus, with increased plate current in R_{28} and reduced plate current in R_{29}, there will be a voltage across the meter and it will indicate the amount of unbalance in the bridge circuit. As the external or unknown resistance controls the voltage applied to the grid of V_1, and therefore the amount of unbalance, the meter scale can be calibrated directly in ohms. By making connection to different points on the divider, switch S_2-D provides six resistance ranges. For example, in the "$R \times 10^4$" position shown, the actual meter reading must be multiplied by 10^4 or 10,000 to obtain the correct value of the external or unknown resistance.

With the selector switch in the "ACV" position, the grid of V_1 connects through switches S_1-B and S_2-A to the voltage divider consisting of resistors R_2 through R_6, while the grid of V_2 connects through switches S_1-C and S_2-B to the voltage divider consisting of resistors R_7 through R_{11}. Switch S_1-D holds the 117 volt a-c supply circuit closed and switch S_1-A is open.

The "A-C volts" input at the upper left connects to a high frequency test probe the output of which appears across condenser C_2 and voltage divider R_2 through R_6. This probe includes two diodes, V_3 and V_4 with condenser C_1 to block any d-c input component and resistor R_1 to isolate the shunt capacitance from the circuit under test. During the input alternations that the test probe is positive with respect to ground, condenser C_2 charges through C_1, R_1 and V_3. During the input alternations that the test probe is negative with respect to ground, condenser C_2 can discharge only through the voltage divider while C_1 can discharge through R_1 and V_4. Thus, condenser C_2 charges quickly to approximately the peak value of the input but no sustained charge can build up in C_1. The time constant of the C_2 discharge circuit is long enough to prevent an appreciable drop of voltage during the negative input alternations and the resulting d-c voltage, across C_2 and the voltage divider, is impressed on the grid of V_1 through range switch S_2-A and selector switch S_1-B.

As explained for the ohms ranges, this voltage will cause an increase of V_1 plate current with a corresponding decrease of V_2 plate current and the resulting unbalance of the bridge circuit will be indicated on the meter. The grid circuit of V_2 connects to ground through selector switch S_1-C, range switch S_2-B and a circuit which duplicates that for the grid of V_1. When diodes V_3 and V_4 are in operation, with no input voltage there will be sufficient current in their circuits to unbalance the bridge. With the duplicate circuits of V_5 and V_6, the grid circuit voltages of tube V_2 will be the same as those of tube V_1 therefore the meter will indicate unbalance due only to the external voltage connected to the test probe. Switches S_2-A and S_2-B provide four voltage ranges by impressing different portions of the input voltage on the grid at V_1.

With the selector switch in the "+V" position, the grid of V_1 is grounded through switch S_1-B, switch S_2-C and the "D-C Volts" divider while the grid of V_2 is grounded directly through switch S_1-C. Switch S_1-D maintains the supply circuit and switch S_1-A is open. When the d-c volts and ground terminals are connected to a d-c source, with the ground negative, the desired portion of the drop across resistors R_{13} through R_{18} is applied across the grid circuit of V_1 and the action is the same as for the ohms ranges. Switch S_2-C provides six ranges from 3 volts to 1000 volts.

In some cases, the available terminal of the external source may be negative with respect to ground and to cause the proper deflection of the meter hand, the selector switch is turned to the "—V" position. When this is done, the grid of V_1 is grounded directly through switch S_1-B while the grid of V_2 connects through switch S_1-C to switch S_2-C. Thus, with reversed input polarity, the action of tubes V_1 and V_2 is reversed also and the meter reads correctly.

Crystal frequency standard for general calibrating purposes.
Courtesy The James Knights Company

With the selector switch in the "OFF" position, section S_1-D opens the 117 volt supply circuit and all the other gangs are open.

SIGNAL GENERATORS

In the explanations of the earlier lessons, it was shown that, in addition to operating as an amplifier and detector, electron or vacuum tubes can act also as a-c generators and produce voltages of high frequencies. Operating in this manner, a tube is known as an oscillator and, as such, is used in radio transmitters as well as superheterodyne receivers. For testing and maintenance work, an a-c source of known or controlled frequency is often necessary therefore, radio and television test equipment includes several general types of oscillators.

These can be classified generally according to frequency as a-f or r-f and the r-f types may be amplitude or frequency modulated. In use, they provide outputs which duplicate the common signal inputs for audio amplifiers, radio, f-m and television receivers.

R-F SIGNAL GENERATOR

A vacuum tube oscillator, with its associated circuits, designed to operate at radio frequencies, is known as an r-f signal generator and, in the design, testing and maintenance of electronic equipment is used for, 1: sensitivity measurements, 2: selectivity measurements, 3: stage gain measurements, 4: r-f and i-f alignment, 5: local-oscillator tracking, 6: determination of signal-to-noise ratio, 7: determination of image ratio, 8: audio response and distortion checks, 9: checks on avc operation, and so on.

In addition to a variable-frequency oscillator, most commercial signal generators include one or more of the following: 1: an r-f amplifier, 2: an audio oscillator, 3: a modulator stage, 4: a fixed frequency r-f oscillator, 5: a mixer stage, 6: an output attenuator network, and 7: an output voltmeter. Sometimes an r-f oscillator is designed for a specific application, in which case it usually will have a special characteristic such as pure waveform, high power output, wide frequency range, or excellent frequency stability. Normally only one, or at most two, of these characteristics can be included economically in a single instrument, and most of these special generators are designed for laboratory work rather than general service applications.

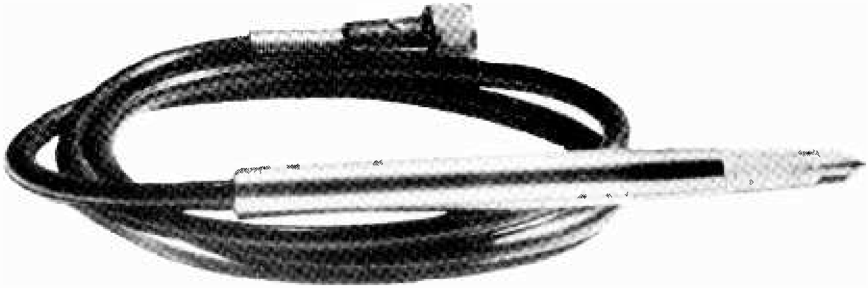
Many of the radio service type r-f signal generators provide frequency modulation as well as amplitude modulation of the r-f output. This makes them applicable to both a-m and f-m receivers; and in some cases to television receiver sound channel alignment as well. As an example, a simplified schematic diagram of a typical commercial r-f signal generator is shown in Figure 5.

This instrument includes the following circuits: 1: an r-f oscillator, V_1, that can be operated over several frequency ranges, and the frequency over any one range adjusted by means of variable condensers C_1 and C_2, 2: a heterodyne detector, V_2, and a triode circuit, V_3 and T_2, which can be used as an audio-frequency oscillator or amplifier, 3: a reactance tube modulator, V_4, and a fixed frequency oscillator V_5, 4:

a pentode circuit V_6, which combines the functions of mixer, r-f amplifier, and modulator stages, 5: a crystal oscillator, V_7, 6: an output meter circuit, V_8 and M, 7: an output attenuator and a load coupling network, and 8: the power supply, T_1, V_9, L_{20}, C_5 and C_6.

The variable frequency r-f oscillator circuit of tube V_1, is of the tuned grid type with plate feedback, and by switching to various grid and plate coils, it can be tuned by C_1 and C_2 over a number of frequency ranges. In the commercial models, which operate usually from 100 kc to 120 mc or higher, various numbers of ranges are installed, whereas only six are shown in the simplified drawing in Figure 5. Note that for bands, A, B, C and D, tuning condensers C_1 and C_2 are in parallel across coils L_7, L_8, L_9 and L_{10} respectively, while for bands E and F, the tank capacitance is reduced by disconnecting C_1. For band F, which operates at the highest frequencies, inductances L_6 and L_{12} may consist only of short lengths of wire connected between switch contacts.

The output of V_1 is coupled through C_7 to grid number 1 of the pentode V_6, in the plate circuit of which the inductors L_{13}, L_{14}, L_{15} and L_{16}, used for bands C, D, E and F respectively, are resonant near the low frequency end of each band. Operating as an r-f amplifier, the output of V_6 is coupled through C_8 to the output attenuator, and thence through the coaxial cable and coupling network to the r-f output test leads.



Test prod and cord for use with signal tracer shown on following page.
Courtesy Coastwise Electronics Company

As indicated by the broken lines, all the movable contacts of the band or range switch are ganged mechanically and controlled by a single knob or dial. When the desired range has been selected, the exact frequency is obtained by adjusting the capacitance of the ganged variable condensers C_1 and C_2.

To check the calibration of the r-f oscillator, various known harmonics of the V_7 crystal oscillator frequency are compared with the output of V_1, at corresponding dial settings of C_1 and C_2, by beating the two r-f waves in the heterodyne detector V_2. For this purpose, the amplified output of V_1 is coupled from the plate of V_6 through C_9 to the grid of V_2. The plate tank, C_3-L_{17}, of the crystal oscillator V_7 is resonant at the fundamental of the crystal, CR, and its output is coupled through C_{10} to the grid of V_2.

Tube V_2 operates as a grid-leak detector, and the difference or beat frequency of the two r-f inputs appears in its plate circuit. With switch S_1 in position 1, the beat note output of V_2 is applied to the grid of V_3 which acts as an a-f amplifier. Then the amplified beat signal is coupled through T_2, C_{11}, and S_9 (in position 2) to the output jack, J_2, into which a headset can be connected to make the beat note audible. The r-f oscillator output frequency is equal to the corresponding crystal oscillator harmonic when C_1 and C_2 are adjusted so that the beat frequency is zero. By the same method, the frequency of an unknown r-f wave can be determined by applying it to jack J_1 and setting switch S_2 at position 2. The unknown frequency can then be compared with the r-f oscillator output.

For amplitude modulation, switch S_1 is set to position 2 as shown, and tube V_3 operates as an a-f oscillator at a frequency of 400 cps. With switches S_9 and S_6 in position 1, the 400 cps output of V_3 is coupled through C_{11} and C_{12} to grid number 3 of tube V_6, which now operates as a modulator and causes the audio frequency voltage to vary the amplitude of the r-f output. For a-m at frequencies other than 400 cps, switch S_6 is set to position 2 so that any desired external audio voltage, connected to jack J_3, can be used for modulating purposes.

For frequency modulating the r-f output, switch S_9 is set to position 2 and the 400 cycle output of V_3 is coupled through C_{11} and C_{13}, switches S_{3-2} and S_4 to the grid circuit of reactance modulator tube V_4. If 60 cycle modulation is desired, S_3 is set to position 2 which through points "X" connects the grid circuit of V_4 to a low voltage secondary of power transformer T_1. The fixed frequency (r-f) oscillator, V_5, operates at either of two frequencies, determined by the setting of switch S_5, and the frequency of its output is caused to vary over a small range by the action of reactance modulator, V_4. The amount of deviation depends upon the setting of the a-f volume control potentiometer P_1 in the grid circuit of V_4.

The frequency modulated output of V_5 is coupled through C_{14} and applied across the cathode resistor R_1 of tube V_6, which now operates as a mixer. Here the f-m wave is mixed with the output of V_1, and the resulting sum and difference frequencies, which are also frequency modulated, appear in the output circuit of V_6, and thus are available as the f-m output of the generator. Switch S_7 is closed to short R_1 when a-m is desired.

Modern signal tracer equipped with electronic volt-ohmmeter for visual observation, and permanent-magnet speaker for aural tests.

Courtesy Coastwise Electronics Company

The output meter circuit, consisting of diode connected rectifier V_8 and d-c microammeter M, the variable output control P_2 and the ladder type output attenuator are coupled to the output of V_6 through C_8. When adjusted to a given level, by plate potentiometer P_3 as indicated by a red line on the scale of meter M, the output of V_6 can be subdivided into units (approximately microvolts) in terms of which the output control dials are calibrated.

A network and switch S_8, to provide different degrees of coupling between the signal generator and a receiver, are enclosed in a shield at the end of the coaxial cable. With switch S_8 in position 1, the output voltage across resistors R_2 and R_3 is available directly between test prods D_1 and G. With the switch in position 2, condenser C_{15} is in series with D_1 and permits it to be connected directly to tube grids and similar circuits without affecting the d-c voltages across them. Also, C_{15} protects the output attenuator when the test lead is connected to points of high d-c potential in a receiver.

For receivers having a balanced antenna circuit, for use with a dipole antenna, S_8 is set to position 3, so that test leads D_1 and D_2 are connected to the proper matching network, and the r-f voltage is taken from opposite ends of R_3. The ground lead, G, is connected to the receiver chassis for all positions of S_8.

The primary circuit of the power supply transformer, T_1, contains a filter network to isolate the r-f energy from the a-c power lines.

CRYSTAL CONTROLLED R-F GENERATORS

A popular type of r-f signal generator, for broadcast receiver maintenance, employs a crystal oscillator that has switching arrangements for selecting any one of several crystals of different frequencies. The various crystals are resonant at the most commonly used alignment frequencies, such as 175, 262, 455, and 1000 kc, so that the desired i-f or r-f frequency can be obtained quickly and accurately simply by turning the selector switch to the value shown on the dial. The big advantage of this arrangement is that the frequency of the r-f output is very accurate, since a crystal oscillator can operate only at its resonant frequency. Usually an a-f oscillator is included for modulating purposes, and means are provided for selecting an r-f output that is unmodulated, modulated by the internal audio oscillator, or modulated by an external audio signal.

A-F SIGNAL GENERATORS

The audio frequency signal generator is useful for frequency response and distortion checks of a-f amplifier circuits in a radio receiver audio section, a public address amplifier, a recording or phonograph amplifier, an intercommunication unit, a hearing aid amplifier, or any one of a large number of other a-f amplifier applications. As explained above, it is also useful to modulate r-f signal generators. In the commercial field, an a-f generator is employed for testing the characteristics of all types of audio equipment, including microphones, amplifiers, loudspeakers, a-f transmission lines and associated networks, telephone equipment, sound motion picture equipment, and as a signal source for Wheatstone Bridge measurements.

General-purpose electronic signal tracer or Stethoscope. Has built-in speaker, and is equipped with plug-in jacks for phones and vacuum-tube voltmeter.
Courtesy Feiler Engineering Company

With the increased use of high fidelity f-m radio receivers, the use of an a-f generator for determining the frequency response of the audio amplifier circuits has become more common. For such measurements, the required frequency range is usually from about 15 to 20,000 cycles per second, depending upon the nature of test and the unit to be tested. The two common types of a-f signal generators for producing sine wave voltages over this range, are 1: the beat-frequency oscillator, and 2: the resistance-capacitance tuned oscillator.

BEAT-FREQUENCY OSCILLATOR

The block diagram of a beat-frequency oscillator (bfo), shown in Figure 6, contains two r-f oscillators, one operating at a frequency that can be varied, and the other operating at a fixed frequency. These r-f oscillators are of the LC tuned-circuit type, and the outputs of both are applied to the input of a mixer tube where they heterodyne to produce a beat note equal to the difference frequency.

For example, with the fixed frequency r-f oscillator operating at 200 kc, the variable oscillator can be tuned over a range from 200 kc to 220 kc to obtain beat frequencies from 0 to 20,000 cycles per second at the output of the mixer.

An advantage of the bfo type of generator is that the entire audio band of frequencies can be obtained on one range with the dial of the tuning condenser of the variable oscillator calibrated directly in audio frequencies. A second advantage is that because of the relatively small frequency variation of the variable oscillator, the bfo output voltage remains very nearly constant over the entire audio range.

Besides the desired beat or difference frequency, the mixer output contains the two r-f ocsillator frequencies, the sum of these, and other related higher frequencies. Therefore, a low pass filter is used to attenuate all frequencies above the highest desired audio frequency, and permit only the a-f beat notes to be passed on to the audio amplifier which employs degenerative or negative feedback, and is designed to have a very uniform frequency response characteristic. The a-f output level is controlled by a constant impedance attenuator, such as a T pad.

RESISTANCE-CAPACITANCE TUNED OSCILLATOR

The simplified schematic diagram of the resistance-capacitance tuned oscillator, shown in Figure 7, consists essentially of a two-stage resistance-coupled amplifier, in which positive feedback is coupled from the second stage to the first by means of the R_1-C_1-R_2-C_2 network, and negative feedback by means of the R_3-R_4 network. For example, any increase in the plate current of V_1 causes its plate voltage to decrease, due to the greater IR drop across the load resistor. This reduction or negative voltage pulse is coupled through C_3 to the grid of V_2, causing its plate current to decrease. The resulting positive swing of the plate voltage of V_2 is fed back through C_4 to the grid circuit network of V_1, and appears also across the voltage divider R_3 and R_4, the center junction of which is connected to the cathode of V_1.

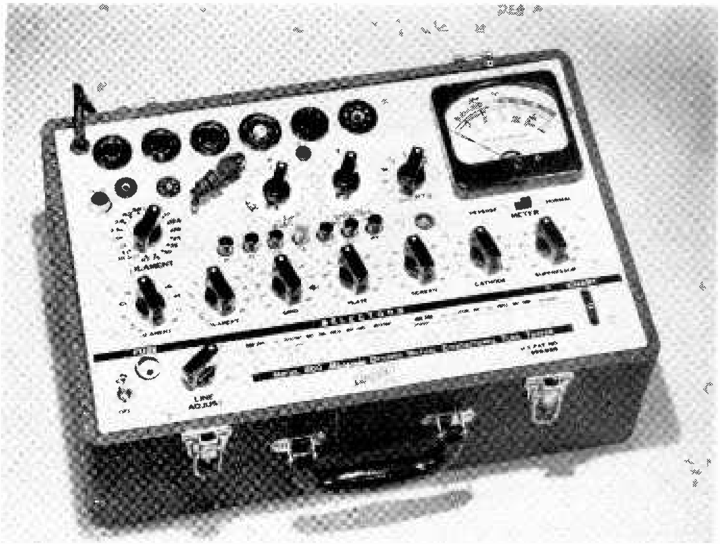
The portion of the feedback voltage across R_2 and C_2 makes the grid of V_1 more positive, thus further increasing its plate current and causing the action to continue. The feedback voltage across R_4 makes the cathode of V_1 swing positive with respect to ground, therefore the grid becomes more negative with respect to the cathode and tends to decrease the plate current. However, the circuit resistance values are chosen so that for medium and low plate current values, the positive feedback voltage at the grid of V_1 will be greater than the negative feedback at the cathode and the result will be a net increase in plate current.

In this way, the plate current of V_1 would increase to the saturation point if it were not for the fact that the resistance of R_4 varies automatically. As indicated by the diagram symbol, R_4 is an ordinary incandescent lamp and, connected between cathode and ground, its filament carries the plate and screen currents of tube V_1. Rated usually at 3 watts, low values of plate and screen currents heat the filament but slightly and its resistance remains low. As the current increases, the filament temperature rises and its resistance increases rapidly until the drop across it biases the grid sufficiently to prevent a further rise of plate current.

When this occurs, a negative pulse is no longer applied to the grid of V_2, which then becomes less negative, permits the plate current to increase and thereby causes plate voltage to decrease. This negative voltage pulse, fed back through C_4 to the grid of V_1, causes its plate current to decrease. By similar action, the increasing positive plate voltage of V_1 is coupled through C_3 to the grid of V_2 so that its plate current continues to increase while that of V_1 continues to decrease. Finally, the negative bias on the grid of V_1 is overcome by the feedback across R_4, and the plate current of V_1 again begins to increase, thereby reversing the action and the entire cycle repeats.

As the action is continuous, the circuit is an oscillator, with the lamp R_4 restricting the operation to the linear portion of the Ip-Eg characteristic of V_1. Due to this effect, the plate current and voltage variations have sine waveforms, and after being amplified by V_2, are available as the oscillator output. In commercial equipment of this type, the circuit of Figure 7 usually is followed by one or two stages of audio amplification.

In Figure 7, the frequency of oscillation is determined by the values of R_1, C_1, R_2 and C_2 and as the maximum tuning ratio usually obtained is only about 10:1, several ranges must be employed to cover the entire audio band. This is done by switching in different sets of tuning resistors, R_1 and R_2 and the tuning over each range is accomplished by the ganged variable condensers, C_1 and C_2, with a dial calibrated in audio frequencies.



Dynamic mutual conductance Tufe Tester.
Courtesy Hickok Electrical Instrument Company

Advantages of the RC type oscillators are a very high degree of frequency stability with only a short warm-up period to attain stable operation, and a sine wave output that contains a low percentage of distortion. The use of several ranges further offers the advantage of a larger dial scale for a given frequency range.

SIGNAL TRACERS

A system of radio receiver repair, that has become fairly popular, is known as "Signal Tracing". It operates on the basic principle that all parts of a radio receiver concern the signal in some way, either in the r-f, i-f or a-f stage; and if the signal suffers a deformation or interruption at some point, it is evident that one of the circuit components associated with that point is defective. Signal tracing, then, can be defined as a testing procedure whereby the point at which the fault occurs is located by checking for the existence or condition of the desired signal.

Many types of signal tracing instruments have been developed, ranging all the way from the simple headset for a-f voltage checking to the complete "Chanalysts" with several tuned circuits, indicating devices, and test probes. If a rectifier, such as a crystal, is connected in series with the headset, the circuit can be used for the detection of a modulated r-f or i-f voltage. However, without amplification, this arrangement does not possess sufficient sensitivity to indicate the presence of the weaker signals in the receiver input circuit. Thus, the basic components of a practical signal tracer include: 1: a detector, 2: one or more stages of amplification, and 3: an indicating device.

The detector can be the crystal type of some material such as galena, iron pyrites, or germanium; or may be one of the various types of vacuum tube detectors used in a-m radio receivers. In the earlier signal tracer models, the amplifiers were often of the LC tuned-circuit variety; however, to eliminate the necessity of tuning the tracer, the later designs usually employ untuned, resistance-coupled amplifier circuits. The indicating device usually takes the form of a voltmeter, electron-ray "eye" tube, or loudspeaker. Some makes incorporate a phone jack so that a headset can be connected to obtain greater sensitivity for the weaker signals.

The visual indicator (voltmeter or eye tube) is useful for checking stage gain and the r-f output of the local oscillator in a receiver. The aural indicator (speaker or headphone) permits rapid signal tracing without requiring the operator to take his eyes from the circuit under test, and also provides a direct means of checking for the point at which any distortion of the signal originates. Most commercially manufactured signal tracers include both aural and visual type indicators.

The diagram of a typical commercial type signal tracer, shown in Figure 8, consists of the grid-leak detector tube V_1, amplifier tubes V_2 and V_3, meter M for visual indication, the speaker and phone jack J_2 for aural indication, and the internal power supply made up of T_2, V_4 and filter R_6-C_6, R_7-C_7, and R_8-C_8.

The triode detector V_1 is mounted in the test-lead probe, together with the grid leak R_1 and condenser C_1, about the same as the arrangements employed for the vtvm circuits in Figures 3 and 4. In fact, a signal tracer can be considered as a special type of vtvm, the output of which operates a speaker or headset, as well as a visual indicating meter.

The test probe of this signal tracer can be applied at any point in a receiver circuit, from the antenna coil to the loudspeaker voice coil, and when present, the signal, will be heard in the instrument speaker, and/or cause deflection of the meter pointer. When the r-f and i-f portions of a radio receiver are being examined, the modulated carrier will be detected by V_1, and its a-f output will be coupled through condenser C_2 to the two-stage resistance coupled amplifier, V_2, and V_3 with the amplified a-f signal coupled through transformer T_1 to the loudspeaker.

Tube Tester designed for the busy service shop.
Courtesy Philco Corporation

For greater sensitivity, when checking a point of weak signal strength, a headset can be substituted for the speaker by inserting its cord plug into phone jack J_2. This connection opens the speaker voice coil secondary circuit of T_1, and the a-f voltage, at the plate of V_3, is coupled through C_5 to the headset. When necessary, the output amplitude can be reduced by means of volume control potentiometer P in the grid circuit of tube V_2.

For gain measurements, switch S_2 is set at position 2, as shown, to connect the direct-current meter M across its rectifier circuit R, to which the a-f output of V_3 is coupled through condenser C_4.

When the test probe is connected to an audio circuit, triode V_1 acts as an audio amplifier, and the signal is applied to the loudspeaker and output meter of the tracer as explained above.

To check the operation of the local oscillator of a receiver, the signal tracer is used as a vtvm to measure the oscillator output voltage. As this output consists of unmodulated r-f, it can not be heard in the speaker, and it will not operate the meter when the latter is connected to the output of V_3 as shown. Therefore, for this test, switch S is set to position 3, which connects the meter so that it becomes the indicator for the vtvm bridge circuit. The arms of this bridge consist, respectively, of tube V_1, resistors R_2, R_3 and R_4 connected on the same plan as the bridge circuit of Figure 3.

The signal tracer can be employed as a high-gain a-f amplifier for checking the operation of a microphone or phono pickup, by connecting the output of the unit to be tested into the input jack J_1 in Figure 8. This eliminates the need of a special audio amplifier for making tests of this type.

TUBE TESTERS

Due to the large percentage of radio receiver troubles that are the result of defective tubes, generally, one of the first steps in radio receiver trouble shooting routines is testing the tubes. Compared to other circuit components, tubes are relatively delicate, can be injured by jarring, extreme temperature changes, etc.; and as a certain amount of deterioration normally occurs during use, their quality gradually decreases.

Because of the comparative complexity of electron tube action, there is no single test that will determine their complete operating condition. For this reason, most commercial tube testers include a number of "test circuits", any one of which can be connected to the tube under test by means of a suitable switching arrangement. Due to the large number of tube types and the variety of base-pin connections, as well as the different values of filament, plate and screen voltages employed, tube testers require rather complex switching circuits to permit the application of the required potentials to the different terminals of the various types of tube sockets.

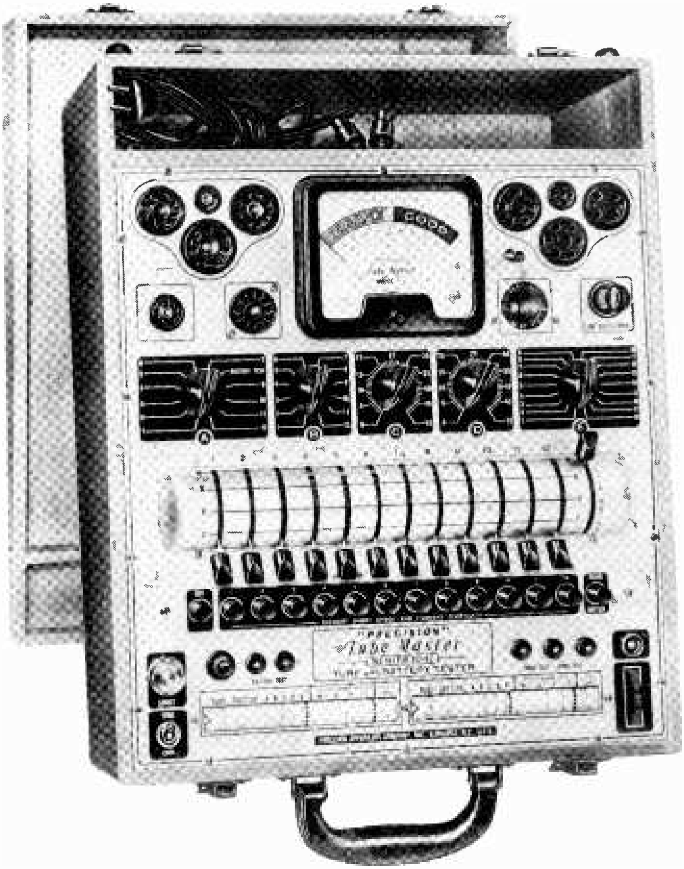
The main characteristics upon which the performance of a vacuum tube depends include: 1: the amount of cathode emission, 2: the plate resistance, 3: amplification factor, 4: transconductance, and 5: power output. However, the correct values of these characteristics vary for different operating conditions of a given tube, and depend upon the specific circuit application. For this reason, no one value of transconductance, power output, etc. can be stated as being correct for all applications of any tube.

Because of these variables, sometimes a tester will indicate a tube is "GOOD" although it will not work in the radio circuit in which it is to be used; or less frequently, will give a reading of "BAD" yet the tube will operate to some extent in the equipment for which it is intended. Observing these inconsistencies, some radiomen reach the erroneous conclusion that tube testing instruments, in general, are of little practical value, and prefer to employ the method of substituting tubes, known to be good, until an improvement in receiver performance is noted. Although this substitution method is often considered as the "final" test, it has the disadvantage of requiring at all times a large stock of tube types.

In addition to making a number of minor tests, commercial tube testers are designed to indicate the worth of a tube in terms of only one of its important characteristics. Thus, in accordance with the major characteristic which they test, these instruments are classified as: 1: emission, 2: transconductance, or 3: power output testers. Due to the variations in characteristic values of a tube under different operating conditions, a tester is calibrated to indicate tube quality in accordance with certain average standards. Consequently, the highest percentage of correct tube indications can be obtained only by checking, over a period of time, the correlation of the readings on a particular tester with the actual operating performance of the tubes tested.

SHORT, LEAKAGE, AND FILAMENT CONTINUITY TEST

A tube tester can be damaged by excessive current if a quality test is attempted on a tube in which a short exists between certain electrodes. For this reason,



Modern tube tester equipped with short, gas, noise, and filament continuity test.
Courtesy Precision Apparatus Company

means of checking for internal tube shorts are provided, and this test should always be made first.

A simplified "short" testing arrangement is shown in the circuit of Figure 9-A which includes the single pole, double throw switches numbered S_1 through S_7. Power is obtained from the secondary of a transformer, marked E, the upper end of which connects to the left terminal of each numbered switch. The lower end of E connects through resistor R and neon lamp L to the right terminal of each numbered switch, the common terminals of which each connect to a separate tube electrode.

In the switch positions shown, S_5 connects the screen grid to the lower end of secondary E, through L and R while all the other electrodes connect through their respective switches to the upper end of E. Thus, if there is an internal short between the screen grid and any other electrode, there will be a closed circuit across secondary E and lamp L will glow to provide a visual indication. Similar tests can be made on any electrode by throwing its switch to the right, in Figure 9-A, while all other switches are thrown to the left.

Many internal shorts exist only when the tube is heated and the electrodes are expanded. Therefore it is customary to provide a source of heater voltage, as indicated by the battery in Figure 9-A. In this way, short tests can be made while the heater is in operation but, when the cathode is tested, the tube will act as a rectifier and complete the test circuit. However, this d-c current will cause only one plate of the neon tube to glow, and hence it does not indicate a short circuit.

The resistor R is chosen so as to permit sufficient current to make lamp L glow if the leakage resistance between the tested element and the others is less than a predetermined value, such as 1 or 2 megohms. Thus, the same circuit is used to test for leakage resistance as well as for shorts. Any tube having a short or leakage should be discarded immediately without further test. The continuity of the heater or filament can be checked by setting switch S_3 to the position indicated by the dotted arrow. For this test, lamp L should glow, if it does not, an open heater is indicated.

EMISSION TEST

The simplest method of checking the quality of a tube is by means of an electron emission test. The emission from the cathode falls off as the tube becomes exhausted, and therefore, a low emission reading on the tube tester is an indication that the tube is at, or is nearing the end of its useful life. In the basic circuit used for emission testing, as shown in Figure 9-B, all the elements of the tube, except the heater and cathode, are connected to the plate. The heater is operated at its rated voltage, the value of which is selected by means of switch S_1. After the proper heater temperature is reached, switch S_2 is closed to apply a low potential to the plate. The tube operates as a diode, and the rectified tube current, indicated by the meter M, correspond directly to the total cathode emission.

In the circuit shown, the variable meter shunt R_1 is adjusted for each type of tube while series resistor R_2 protects the meter from excessive current. Generally, when the meter reading is below the predetermined average for a particular type, the tube can be considered as no longer able to function properly.

An exception, however, is found in the coated-filament type tubes, for they are capable of such large emission that they can operate satisfactorily even after their emission has fallen far below the original value. Thus, at times it is difficult to draw a sharp line between satisfactory and unsatisfactory emission readings. To meet this condition, commercial tube testers employ a meter scale which is divided into two large sections, labeled GOOD and BAD, separated by a broad line or space marked "?" (questionable).

TRANSCONDUCTANCE TEST

The fundamental action of a tube is that a change in plate current occurs as a result of a change in grid voltage, and the ratio of these respective changes is called its mutual conductance or transconductance. As the magnitude of this factor indicates the operating fitness of a tube, a transconductance test provides better correlation between test results and actual performance than a plain emission test. Both the amplification factor and plate resistance are checked indirectly by means of this type of test, since the value of transconductance is numerically equal to the amplification factor divided by the plate resistance.

Furthermore, cathodes often develop active spots of relatively small area, from which the electron emission is very great, therefore an emission test may indicate the tube is good even though the cathode as a whole may be worn out. However, the small grid area adjacent to these active spots cannot control the electron stream properly, and by a transconductance test, the change in plate current caused by a change in grid voltage will show the operating condition of the tube to be unsatisfactory.

Transconductance tests are of two general types, "static" and "dynamic". A simplified circuit for static transconductance tests is shown in Figure 9-C which is arranged to provide normal operating voltages to all of the tube electrodes. Although not shown, the complete heater circuit is like that of Figure 9-B. With switch S of Figure 9-C in position 2 as shown, potentiometers P_1 and P_2 are adjusted until meter M indicates a reference value of plate current. Then, switch S is turned to position 3, to cause a definite reduction of negative grid bias and cause an increase of plate current indicated by meter M.

As a known value of grid voltage change is employed, the meter scale can be calibrated directly in terms of transconductance (micromhos) instead of milliamperes. Commercial transconductance type tube testers employ meter scales reading either in terms of micromhos, good-?-bad, or both. This system is called the "static" method, because only d-c operating potentials are applied to the tube elements. Because of the sequence of operation it is known also as the "grid shift" method.

The "dynamic" type of transconductance test is accomplished by means of a test circuit like that of Figure 9-D. Here again, normal d-c operating voltages are applied to the various tube electrodes, in addition to an a-c signal voltage injected into the grid circuit by means of transformer T. In this case, the meter M measures only the a-c component of the plate current and as the value of the a-c grid voltage input is known, the scale of the meter can be calibrated directly in terms of transconductance.

The dynamic type of transconductance test is generally considered to be superior to the static type, because with an a-c voltage applied to the grid, the tube is tested under conditions which more closely approximate those of actual operation.

POWER OUTPUT TEST

The one single test which probably gives the best correlation between test and actual operating conditions is known as the "power output test". In the case of power output tubes, the primary function, that of producing a-c power, is checked closely while for voltage amplifier tubes, the measured power output is indicative of the amplification and output voltages which can be obtained.

The basic circuit for a power output test is given in Figure 9-E, where the a-c output voltage, developed across the plate load impedance, L, is coupled through condenser C to the output metering circuit consisting of resistor R and meter M. The d-c plate current is blocked from the meter circuit by condenser C therefore, the power developed in R will be proportional only to the a-c output of the tube. As the value of R is known and M indicates the a-c current I, the power output, W, can be calculated by means of the formula:

$$W = I^2R$$

But the value of R is constant, therefore the meter scale can be calibrated directly in terms of power and the operating fitness of the tube can be determined quite accurately.

For example, if a normal signal is applied to the grid of a tube, a low measured output can be caused by a reduced amplification factor, low mutual conductance, an open, misplaced, or shorted tube element. As another example, if a high order of peak a-c voltage, within the maximum value allowable under the given operating conditions, is applied to the grid, a certain high value of power output should be obtained. If the indicated power output is low, the cause is usually a worn out cathode (low emission), high plate resistance, or both.

In maintenance work, exactly which of these various faults exists is of little concern, the important point is that the tube is unable to produce the output needed for proper operation, and therefore, should be replaced.

As shown by the examples given above, to check a tube for all possible defects, the power output method provides for testing the tube at high as well as medium and low operating conditions. A check of this type is provided by the circuit of Figure 9-F which is designed to swing the tube continually over a wide range of operating conditions, so that the resultant meter reading is a composite indication of the performance at all of the points within the range covered.

To provide these conditions, the plate and screen supply, as well as the control grid bias, are a-c voltages obtained from the secondary windings L_3 and L_2, respectively, of the power transformer T. Connections are made so that the control grid bias becomes more negative as the plate and screen swing positive, and vice versa.

Of course, the only part of the cycle which is useful for test purposes is that during which plate current exists, that is, during the alternations of the 60 cps supply voltage that the plate of tube V is positive with respect to the cathode. The signal input is supplied by an oscillator which has a much higher frequency than that of the power supply, so that during very short intervals of time, the operating potentials can be considered constant, while the plate current and voltage variations are due to the grid signal only.

The oscillator tube plate is supplied with 60 cps a-c so that it is positive only during the same portion of the supply voltage cycle as the plate of the tube V under test. With an a-c plate supply, the oscillator output varies in amplitude, being greatest when the plate of tube V is most positive and the control grid is most negative. Thus, during each positive half cycle of the 60 cps supply, the operating potentials and signal input are varied from low to high conditions and back to low again, with no operation taking place during the negative half cycles of the supply voltage. The meter indicates an average output value, as its pointer cannot follow the high frequency variations of plate current.

GAS TEST

In addition to checking tube quality, most commercial tube testers include several supplementary circuits a number of which were described in connection with Figure 9-A. Another important test is detecting the presence of excessive gas in high-vacuum type tubes. When gas is present, the electrons, traveling at high velocity from the cathode to the plate, collide with and knock electrons out of some of the gas atoms, which are then left with a net positive charge and are called "ions". These positive ions are attracted to the negative control grid and neutralize themselves by taking on electrons from the surface of this element. To replace these electrons, an electron flow, called "gas current", takes place in the external grid circuit.

If the grid circuit contains a high resistance element, the voltage drop across it, produced by the gas current, will tend to make the grid positive with respect to the cathode. This is equivalent to a positive d-c grid bias voltage and the average d-c plate current of the tube will increase accordingly.

To test for gas, by means of the circuit of Figure 9-C, the d-c plate current reading is noted with switch S in position 2 which applies normal bias to the grid. Then S is switched to position 1 which connects the high value resistor R_1 in series with the regular bias supply. Any gas current in the grid circuit will be carried by resistor R_1 and the resulting drop across it, with a polarity opposite to that of the battery, will reduce the effective negative bias. Thus an increase in plate current, when S is switched from point 2 to point 1, indicates the presence of gas in the tube.

IMPORTANT WORDS USED IN THIS LESSON

BEAT-FREQUENCY OSCILLATOR—A form of oscillator in which an audio signal is developed by beating together two r-f generators, one of which is operated at a fixed frequency and the other at a variable frequency. The audio signal is the difference frequency.

EMISSION TEST—Checking a tube for the amount of electronic emission from the cathode.

GAS CURRENT—Current in the grid circuit of an electron tube, resulting from the ionization of small quantities of gas within the tube.

LEAKAGE TEST—Checking a tube for high-resistance leaks between adjacent electrodes, particularly between the cathode and heater.

PEAK VOLTMETER—A vacuum-tube voltmeter designed to measure only the peak values of an a-c voltage.

RC OSCILLATOR—A form of audio oscillator in which the tuning elements consist of fixed resistors each of which is shunted by a variable condenser.

SIGNAL TRACER—A form of service instrument by means of which the presence and condition of the received signal can be observed in the successive stages of a radio receiver.

SLIDE-BACK VOLTMETER—A form of vacuum-tube voltmeter in which the value of the unknown voltage is obtained indirectly by measuring the grid bias that must be applied to restore the plate current to the value that it had before the unknown voltage was impressed across the grid circuit.

VACUUM-TUBE VOLTMETER—An instrument in which the voltage to be measured is impressed on the grid circuit of a vacuum tube, and the resulting plate current variations are indicated by a meter calibrated directly in input volts.

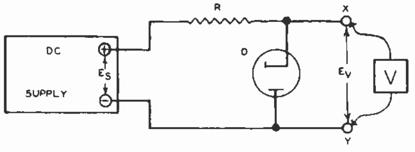


FIGURE 1

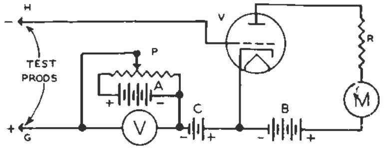


FIGURE 2

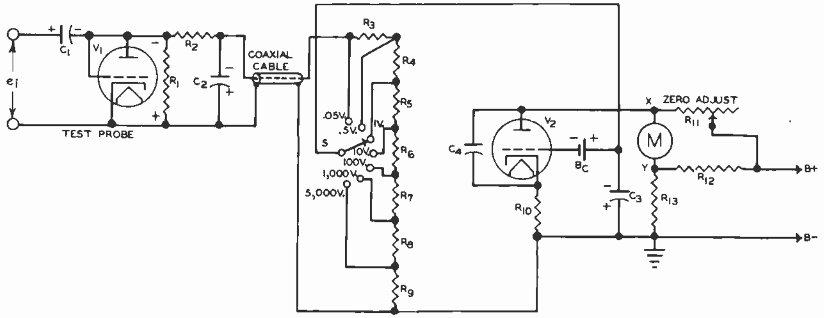


FIGURE 3

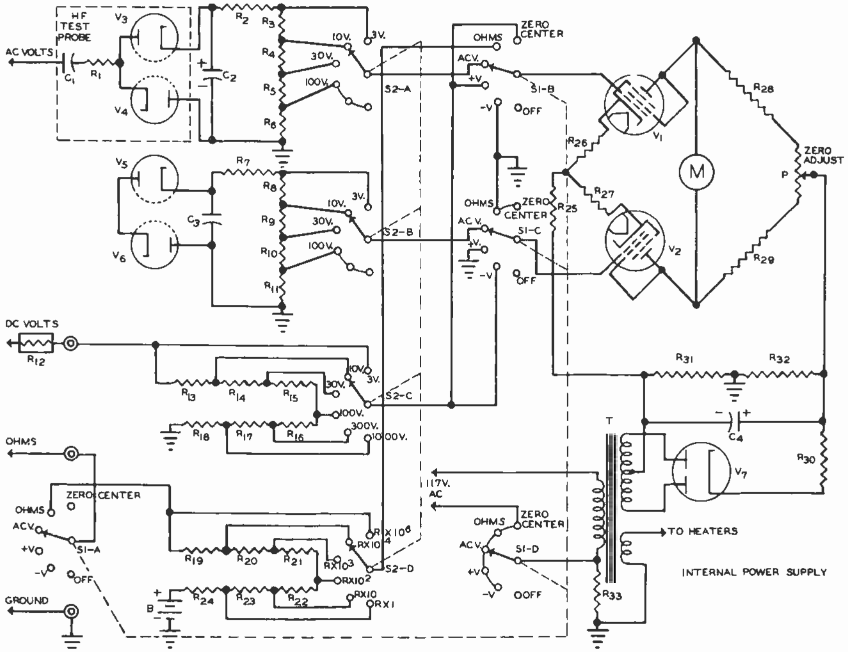


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FIGURE 4

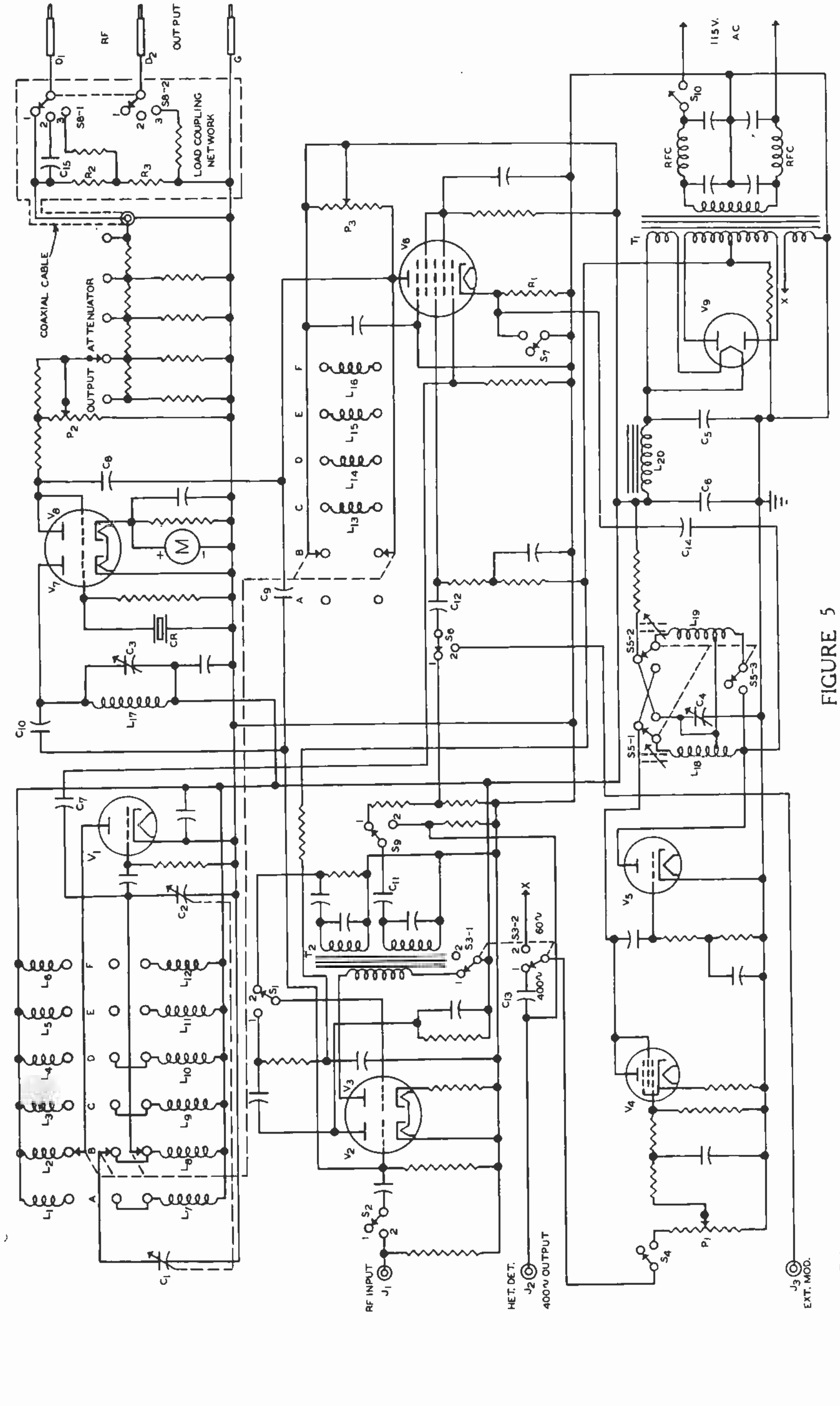

FIGURE 5

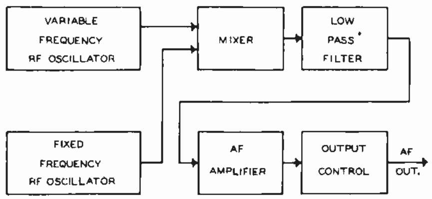

FIGURE 6

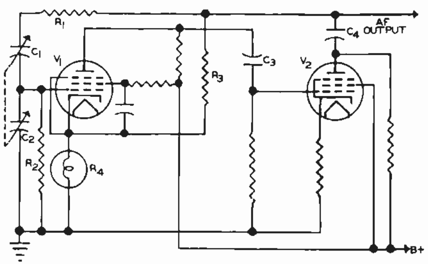

FIGURE 7

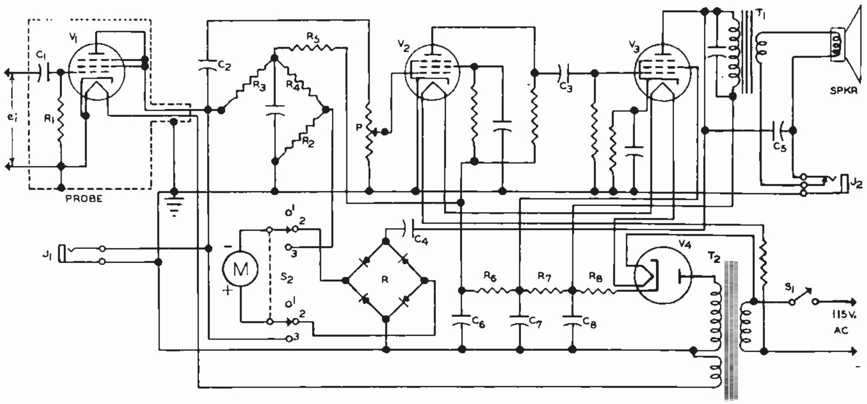

FIGURE 8

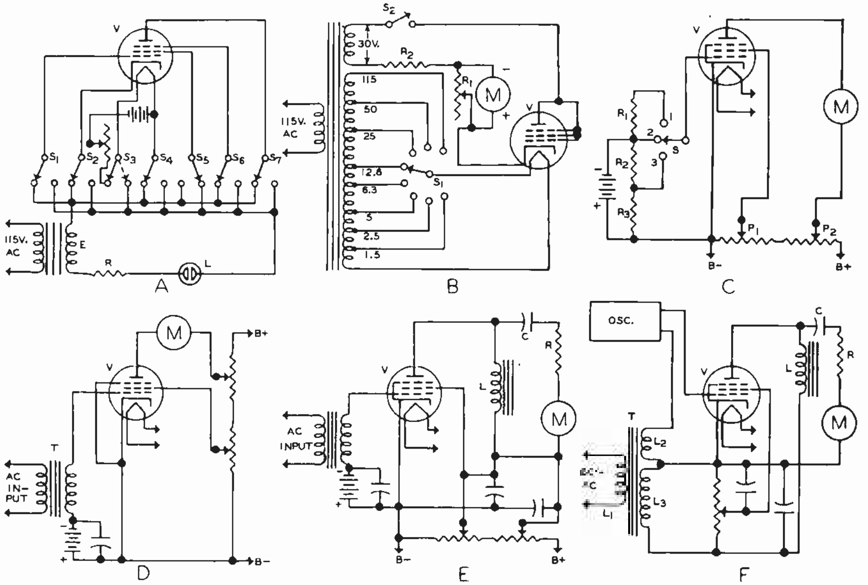

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FIGURE 9

FROM OUR *President's* NOTEBOOK

THE TEST OF A MAN

There's little satisfaction to be gained from doing things
That hold no difficulties; it's the tough old task that brings
Keen sense of worth and power to the man who wins the fight;
His failures test his courage and his problems prove his might:
Until a man has conquered loss and overcome defeat,
He cannot fully understand just why success is sweet.
I'm thankful for my disappointments, for the battles lost,
And for mistakes that seemed to charge an overwhelming cost;
I'm thankful for the days of doubt when it was hard to see
That all things work together for the good that is to be;
I'm glad for all that life has brought, because today I know
That men must brave adversities if they would greater grow.

—O. Lawrence Hawthorne.

Yours for success,

E. B. DeVry

PRESIDENT

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