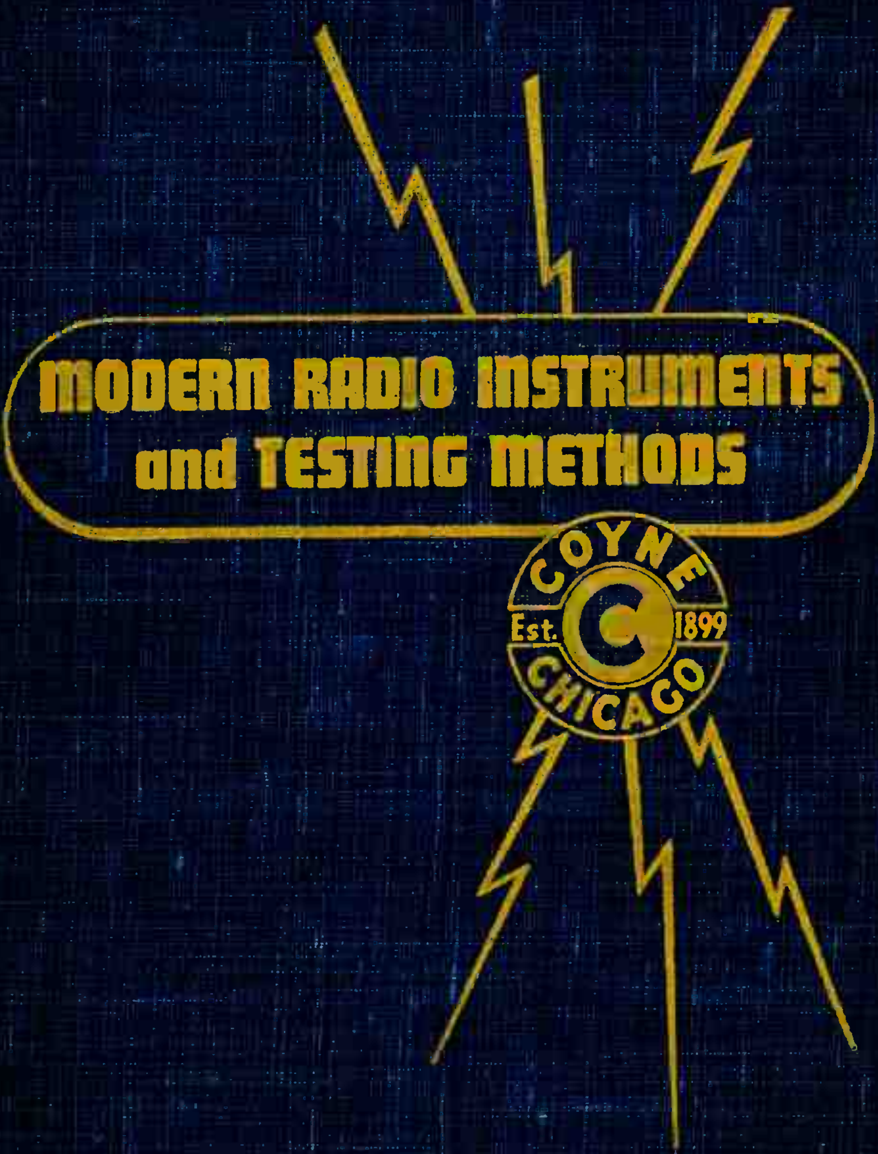
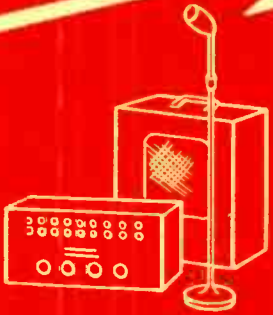
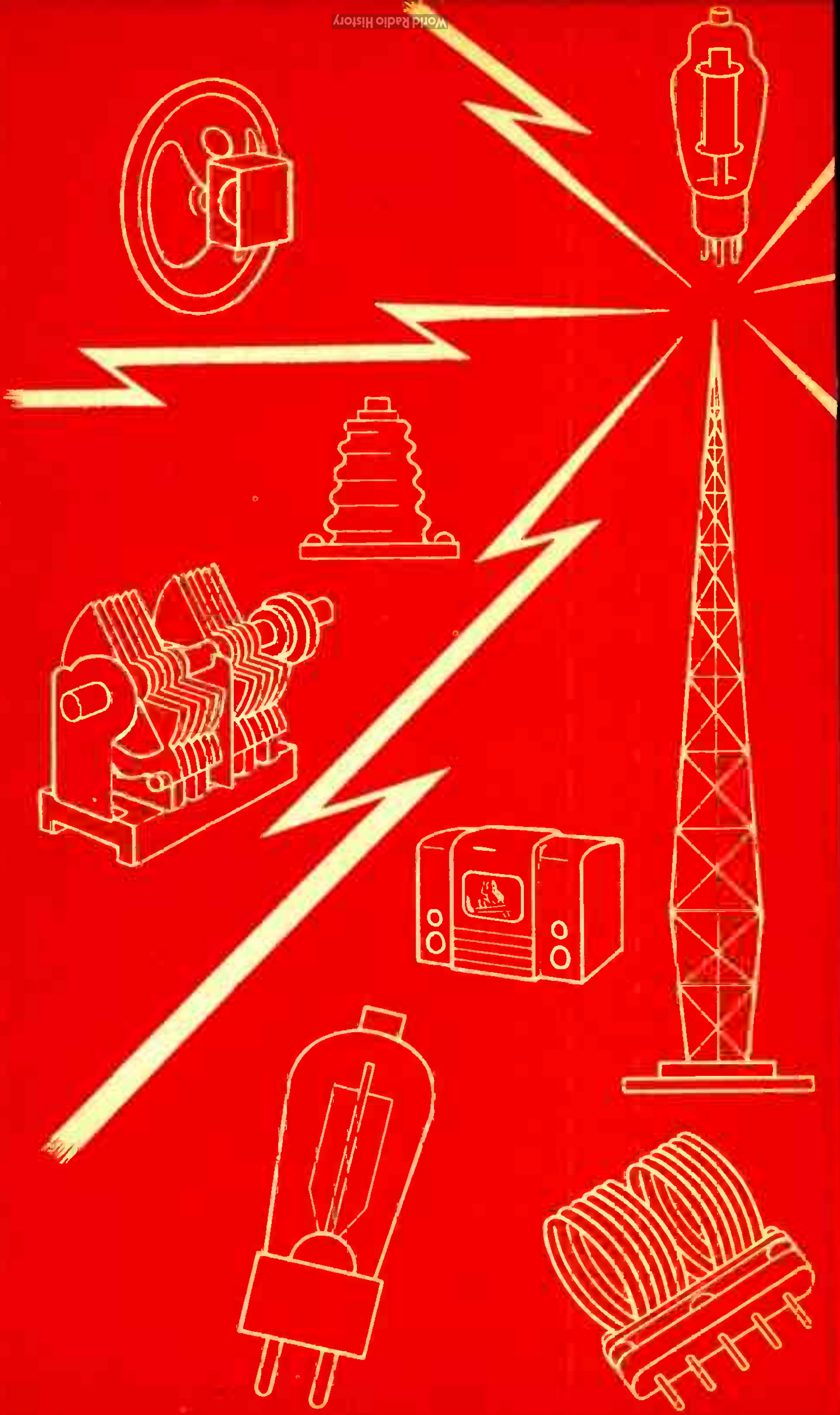
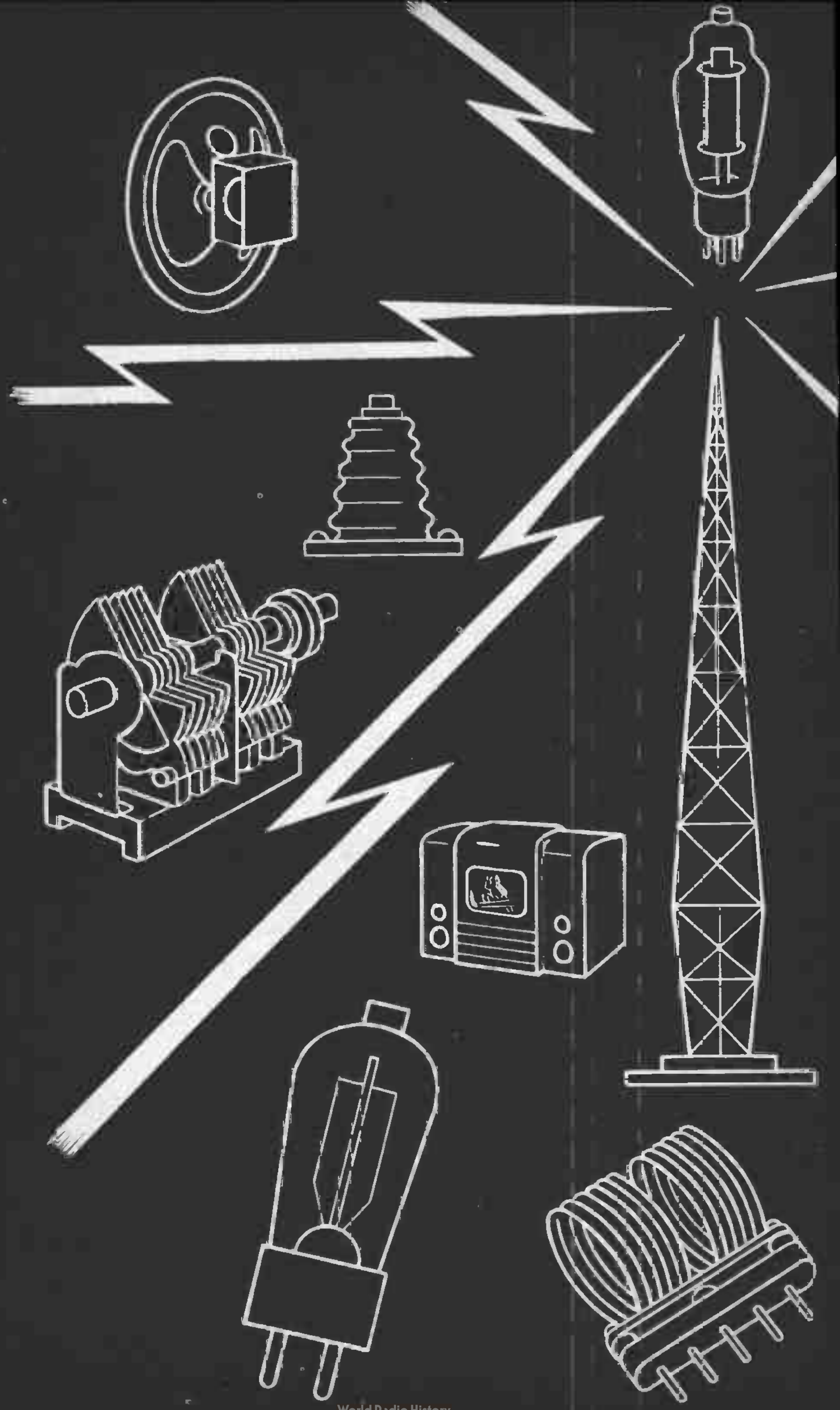
MODERN RADIO INSTRUMENTS and TESTING METHODS





COYNE
APPLIED PRACTICAL RADIO





MODERN RADIO INSTRUMENTS and TESTING METHODS

Printed in the United States of America

MODERN
RADIO INSTRUMENTS
and
TESTING METHODS

A Practical Book

on

Radio Covering . . .

INDICATING METERS
OPERATION & CARE OF METERS
MEASUREMENTS WITH DIRECT CURRENT
MEASUREMENTS AT HIGH FREQUENCIES
MEASUREMENTS WITH BRIDGES, ANALYZERS AND MULTIMETERS
ELECTRONIC VOLTMETERS
SIGNAL TRACING
SIGNAL GENERATORS & TEST OSCILLATORS
TUBE TESTING

by

THE TECHNICAL STAFF

of the

COYNE ELECTRICAL AND RADIO SCHOOL
CHICAGO 12, ILLINOIS

ACKNOWLEDGMENTS

We wish to acknowledge and express appreciation for the assistance and cooperation given to us in the preparation of this book from the following companies.

PRECISION APPARATUS COMPANY
WESTON ELECTRICAL INSTRUMENT CO.
HICKOK ELECTRICAL INSTRUMENT CO.
TRIPLETT INSTRUMENT COMPANY
RADIO CITY PRODUCTS COMPANY
SUPREME INSTRUMENTS COMPANY
REINER ELECTRONICS COMPANY
WESTINGHOUSE ELECTRIC & MFG. CO.
GENERAL ELECTRIC COMPANY
CHICAGO INDUSTRIAL INSTRUMENT CO.
SIMPSON ELECTRIC COMPANY

FOREWORD

This book covers the subjects of Modern Radio Instruments and Testing Methods. It is a PRACTICAL book. In explaining the use of modern radio instruments nothing was assumed or "taken for granted." To make everything crystal clear hundreds of dollars was spent in buying the very latest types of testing instruments. These instruments were then taken apart piece by piece and photographs of each stage of disassembly were made for use in this book.

This practice was followed so the reader could see exactly how these instruments were constructed. This PRACTICAL method also showed the part each circuit played in the overall operation of the instrument.

Our first chapter devoted to Indicating Meters illustrates clearly how much easier this new step by step photo instruction method can be followed (see pages 1-34). Every chapter in the book follows this same type of PRACTICAL instruction.

This book was not written to teach a man how to design testing instruments. The information of course will help anyone who plans to be a designing engineer but the book was written to GIVE AS MUCH INFORMATION AS POSSIBLE ON *HOW TO USE*, ADJUST AND REPAIR INSTRUMENTS.

We had the man "on the job"—the field radio serviceman in mind in writing this book. However, the PRACTICAL equipment "break down" photo instruction method makes the material easy enough for the beginner in radio to understand.

It is easy to understand that a good practical book on radio instruments would also include modern testing methods. These subjects "dove-tail" because when we explain how to use radio instruments we also outline modern time saving ways to do radio testing.

Radio instruments are costly. One of the ways this book is valuable is in its use as a reference book. To get the most

FOREWORD

out of any expenditure for testing equipment a serviceman should know every possible use that can be made of the equipment. You can refer to this book with complete confidence because all of the ideas and testing methods have been shop tested. They have been proven PRACTICAL.

Therefore, this book can serve either as a straight reference book to "double check" the uses and limitations of any type of testing instrument or it can be used as a self-study book for the man just entering the radio service field.

We sincerely feel this book covers the most up-to-date material on the subjects included and is the type of PRACTICAL book for which you should have constant and profitable use.

BWCooke

B. W. COOKE, *President*
Educational Book Publishing Division
COYNE ELECTRICAL & RADIO SCHOOL

TABLE OF CONTENTS

VOLUME IV

Chapter 1

INDICATING METERS

Nearly always it is true that the most valuable technician in any kind of electrical work is the "trouble shooter"; the one who determines what is wrong when performance is abnormal, and who points out the part or parts which are at fault. The first

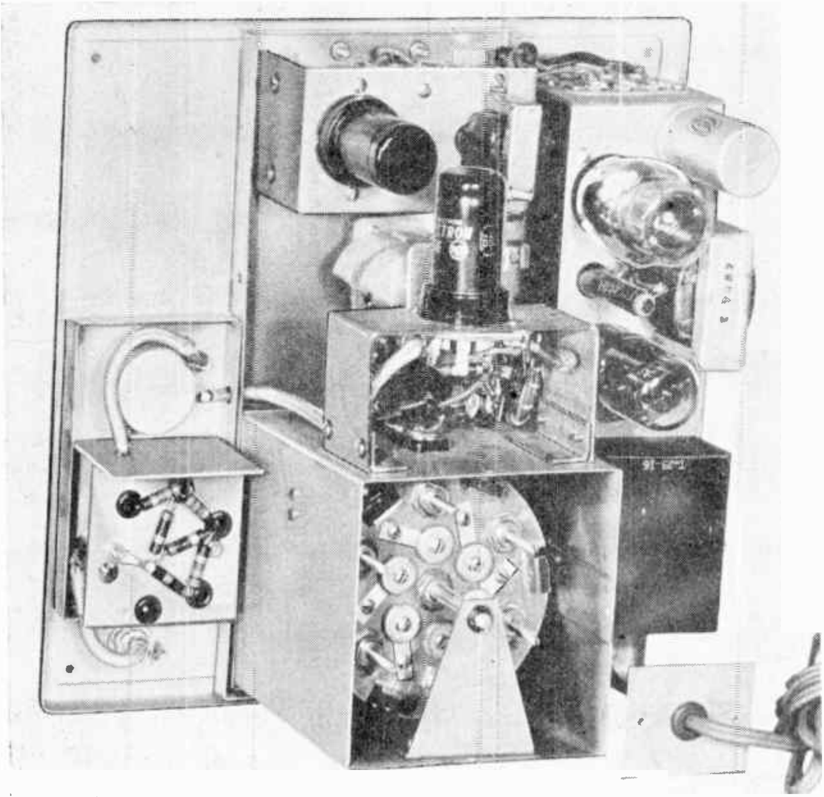


Fig. 1.—The interior of a Triplett signal generator as it appears with part of the shielding removed.

requirement for trouble shooting is knowledge of how the troublesome apparatus should operate, and why it should operate that way. One who thoroughly understands radio can locate the causes for many troubles with only three of the tools provided by nature; with the senses of sight, hearing, and touch. He may even use his sense of smell to locate burnt insulation, and some electricians identify low-voltage live circuits by the so-called galvanic taste.

But the technician who works with greatest speed and efficiency uses suitable testing and measuring instruments. Such instruments permit doing in a matter of minutes what might take hours without them, and permit the easy solution of many problems which otherwise never could be solved. Testing and measuring instruments may be simple, or highly complex. The complex instruments usually handle difficult jobs faster than the simpler types, but only provided that you know how to connect and operate the complex types, and know how to correctly interpret their indications. The results you get from any testing equipment are directly proportional to your understanding of the equipment.

It is as important to understand the operating principles of your testing equipment as to understand the principles of the radio apparatus on which you are working. Familiarity with and experience in operating any given piece of testing equipment allows doing work which would be quite beyond the ability of a novice working with the same identical equipment. For that matter, a thorough understanding of the simple fundamental methods of measurement in radio circuits will let you adapt and combine such methods in handling problems for which no special equipment is available. But no matter what piece of equipment you use, you must know how to use it correctly. Otherwise you may not only fail to get the desired results, but may destroy both the testing equipment and the radio apparatus on which you are working.

Radio Measurements. — Before talking about radio testing equipment it will be well to make a list of things to be measured and indicated, as in the accompanying table of *Radio Measurements.*

RADIO MEASUREMENTS

1. Current or electron flow; a-c, d-c, or combined.
2. Potentials.
   a. Potential difference; a-c, d-c, or combined.
   b. Electric charges, in coulombs.
   c. Electric polarity.
   d. Magnetic polarity.
3. Circuit conditions.
   a. Continuity, opens, high resistance.
   b. Short circuits and grounds.
4. Electrical properties.
   a. Resistance.
   b. Inductance, self- and mutual.
   c. Capacitance.
   d. Reactance, inductive and capacitive.
   e. Impedance.
   f. High-frequency losses.
   g. Q-factors.
5. Frequency.
6. Waveform.
   a. Modulation.
   b. Coupling transformers, during alignment.
   c. Input and output.
7. Power input and output.
8. Tube condition.
   a. Emission ability.
   b. Transconductance or mutual conductance.
   c. Shorts, opens, noise, gas, etc.
9. Receiver and amplifier performance.
   a. Sensitivity.
   b. Gain or amplification.
   c. Selectivity.
   d. Distortion, noise, and hum.
   e. Signal strength and quality.

The problems involved in making most of the radio measurements are quite different from those encountered in most other electrical fields. While some parts of radio amplifiers and receivers operate at power-line frequencies, we have in most of the parts frequencies in the audio and radio ranges which may go as high as hundreds of megacycles, and then we have peculiar effects due to inductance and capacitance.

Other problems arise because of the very small powers which exist in many radio circuits, which means that only negligible power may be taken to operate our measuring devices, or means that our instruments may add only negligible loads to such circuits. In some circuits there are oscillations which will be stopped by much additional loading. In some of the inductive devices even small direct currents might cause serious harm were such currents introduced from measuring equipment.

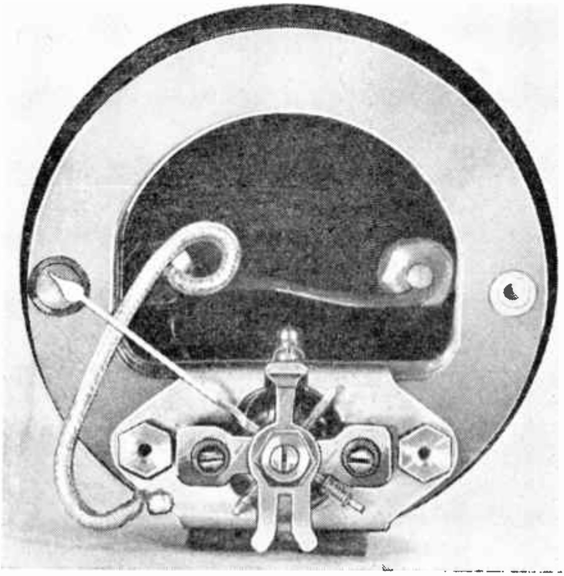


Fig. 2.—A moving coil permanent magnet meter with case and dial plate removed.

Having looked at a list of measurements to be made, we next may list the principal classes of instruments employed in making the measurements, as in the accompanying table *Radio Testing Instruments.*

RADIO TESTING INSTRUMENTS

1. Indicating pointer types, magnetic operation.
    a. Moving coil permanent magnet type. Measures only direct currents and potentials.
        1. Rectifier type. A rectifier combined with a moving coil permanent magnet instrument for measurement of alternating currents and potentials.
        2. Thermocouple type. A thermocouple combined with a moving coil permanent magnet instrument for measurement of alternating currents and potentials.
        3. Ohmmeter. A potential source and a resistance combined with a permanent magnet moving coil instrument for direct indication of resistance connected to the ohmmeter.
    b. Moving iron or iron vane type. For measurement of alternating currents and potentials.
    c. Dynamometer or electrodynamometer type. For measurement of alternating currents and potentials.
    d. Hot wire type. For measurements of alternating currents and potentials, by means of heating and expansion of a conductor carrying the actuating current. This type is obsolete.
2. Resonance types. A tuned or tunable circuit which may be made resonant at an applied frequency, and a resonance indicator. Used for radio-frequency measurements.
3. Bridge types. A circuit by means of which an unknown value, such as a resistance, reactance, or impedance, may be compared with a known standard value of similar kind.
4. Electronic types. Employing diodes, triodes, and other tubes as rectifiers, detectors, oscillators, or amplifiers, usually with an indicating device (meter, electron ray tube, etc.) actuated by plate current or plate circuit potential.
    a. Frequency meters, heterodyne type.
    b. Electronic voltmeters or vacuum tube voltmeters.
    c. Detector-amplifier combinations for signal tracing.
5. Cathode-ray types. Oscilloscopes or oscillographs whose indications are in the form of a luminous visible trace on the screen of a cathode-ray tube.
6. Tube testers. Instruments for measurement of tube characteristics such as amplification factor, plate resistance, and transconductance or mutual conductance; usually with one or more suitably graduated indicating meters. Also for checks of cathode emission ability, shorted or loose elements, and other defects with meters, neon lamps, or electron-ray tubes as indicators.

7. Signal sources. For furnishing modulated or unmodulated radio-frequency signals, also audio-frequency signals, used for testing amplifiers and receivers.
   a. Service oscillators. Electron tube oscillators, usually of a feedback type, with or without added amplification, and with fairly accurate calibration of signal frequency and output.
   b. Signal generators. Oscillators and amplifiers of precision construction, with accurate calibration of frequency and output.

The frequency handling characteristics of the various types of meters indicate where the instruments may be used. Iron vane meters, class *1-b* in our table, may be designed for frequencies as high as 500 cycles, but usually are used only at power-line frequencies. Dynamometer instruments, our class *1-c*, ordinarily are used only at power-line frequencies, but in special constructions may be used at frequencies as high as two or three kilocycles. Rectifier meters, our class *1-a-1*, usually are used at frequencies no higher than 20 to 30 kilocycles, but may be designed for operation up to about 15 megacycles. Thermocouple meters, our class *1-a-2* are radio-frequency types, usually good up to

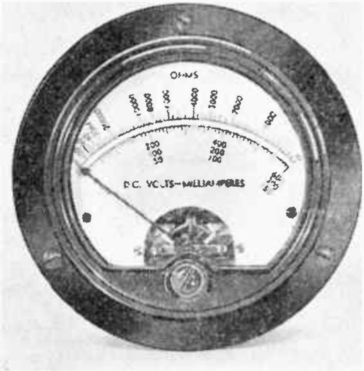


Fig. 3.—A single instrument with which may be measured voltage, current, and resistance.

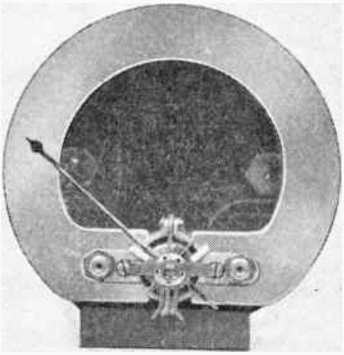


Fig. 4.—The magnet and movement of a moving coil permanent magnet meter. (Simpson)

about 10 megacycles, but with special constructions and appropriate corrections useful to several hundred megacycles. Bridges, our class *3*, ordinarily are used at frequencies no higher than those in the audio range. Resonance methods, our class *2*, and also the electronic types, class *4*, may be designed for operation at frequencies up to several hundred megacycles.

Moving Coil Permanent Magnet Instrument.—The indicating instrument most often found in all kinds of radio testing equipment is the moving coil permanent magnet type. Such an instrument may be called a *d'Arsonval* type, after the man who first employed the general principle. This type is used most often because, although it operates only on direct current, it is possible to use a contact rectifier, a thermocouple, or an electronic tube in connection with the meter and thus obtain an instrument actuated from alternating potential or current.

The principal operating parts of two d'Arsonval meters are shown by Figs. 2 and 4, where the cases and dial scales have been removed to expose the magnet and the "movement." The steel magnet, which is of the permanent type, is generally a circular or modified horseshoe shape with its north and south poles forming opposite sides of a cylindrical opening at the bottom. In this opening is supported the moving coil, sometimes called the armature, which consists of many turns of small-

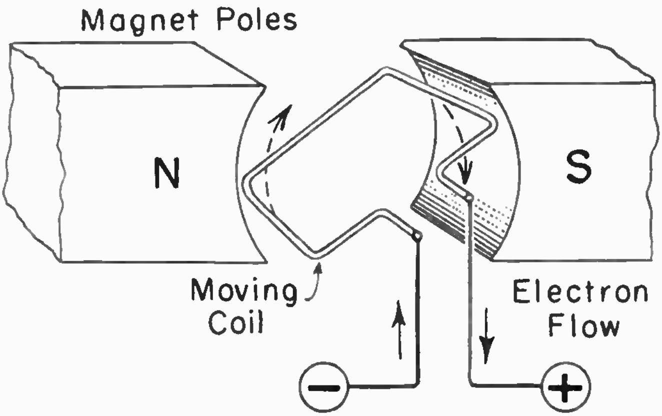


Fig. 5.—Why the coil rotates between the magnet poles.

diameter insulated wire wound on a rectangular frame called the bobbin. To the moving coil is attached the pointer which you can see extending upward and to the left in Figs. 2 and 4. When the moving coil rotates through part of a turn, the pointer is moved across a scale, such as the one shown on Fig. 3.

Why the moving coil rotates when electron flow passes through its turns is shown by Fig. 5. Here the coil is represented by a single turn, with a magnetic north pole at the left and a magnetic south pole at the right. Magnetic lines of force pass from north pole to south pole through the space occupied by the moving coil. When electron flow through the coil is in the direction indicated, from negative to positive terminal of the meter, the sides of the coil tend to move through the magnetic field in the directions shown by broken-line arrows. The force that moves the coil is exactly the same force that moves the armature or rotor of an electric motor in the magnetic field which exists between field or stator coils of the motor.

To make it easier for the magnetic lines to pass through the

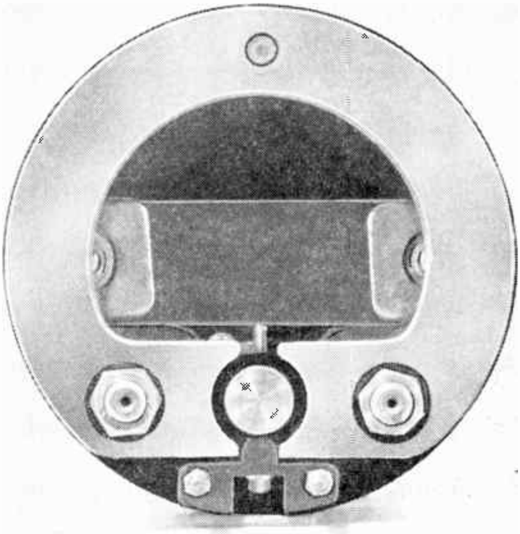


Fig. 6.—A cylindrical core of iron nearly fills the field space.

field space, and thus to increase the field strength, most of the space is filled with a cylindrical iron core which you can see between the magnet poles in Fig. 6.

The electromagnetic force which tends to rotate the moving coil when there is electron flow in the turns is opposed by two small spirally-formed "hair springs," one on either end of the coil. These two springs show plainly in Fig. 7, where the magnet has been removed, but where the central cylindrical core remains in position inside the moving coil. The inner ends of the hair springs are attached to the moving coil. The outer ends of the springs are attached to stationary parts of the movement. The springs are wound in opposite directions, so that rotation of the moving coil increases the tension on one spring while decreasing it on the other. The difference between the tensions is such that the moving coil and pointer may be deflected all the way to the

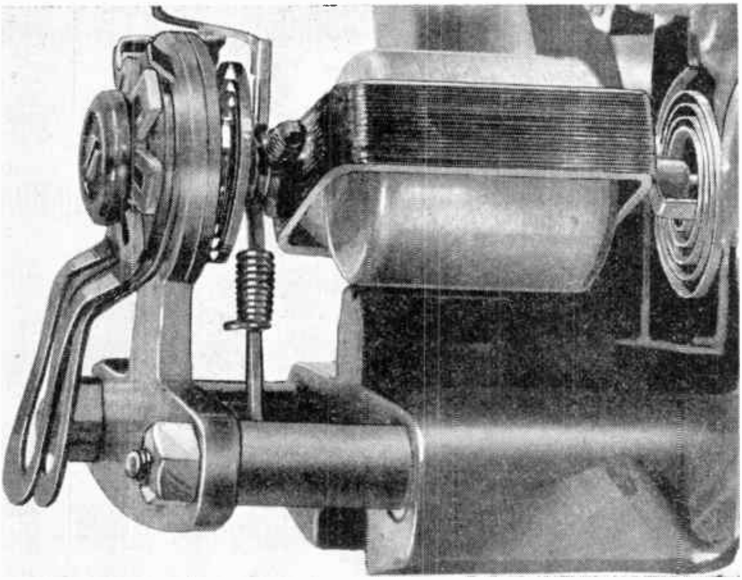


Fig. 7.—A moving coil with its supports and hair springs at front and rear.

full-scale position with but little force exerted by the electromagnetic effect.

Electron flow is carried into and out of the moving coil through the two hair springs. One end of the coil winding is connected to the front spring, and the other end is connected to the rear spring. The stationary parts to which the outer ends of the springs attach have conductive connections through to the positive and negative terminals which are on the outside of the meter case. The connection from one terminal to the front spring may be seen in Fig. 2. There is a similar connection from the other terminal to the rear spring.

In most meters there are cemented onto the front and back of the moving coil two cone-shaped pivots made of steel or of some suitable alloy. The pointed tips of these pivots rest in depressions formed in "jewels" carried in stationary parts of the movement. In some instruments the jewels are polished sapphires; in others they are made of boro-silicate glass. The construction is like that employed for the jeweled bearings of fine watches. The jewels may be carried in the inner ends of adjustable screws whose outer slotted ends may be seen outside of the ends of the moving coils in Figs. 2 and 7. The jewel screws are adjusted to leave end play of between one and two thousandths of an inch for the pivots.

With no electron flow or current in the moving coil, the tip of the pointer should rest at the zero mark on the scale, as in Fig. 3. The pointer may be brought to this position by means of a zero adjuster or zero corrector mechanism usually operated by turning a slotted head which appears on the outside of the front of the case or the glass covering the scale. On the inside of this slotted head is a projecting tip which engages in a slot or fork of the zero adjuster arm attached to the front of the movement. A forked adjuster arm may be seen in Fig. 2, and a slotted type in Fig. 7. The arm is part of a washer that fits around the jewel screw and is prevented from rotating too freely by some sort of friction device which usually includes a cupped or spider-armed washer held by a nut that locks the jewel screw in place after the jewel clearance has been adjusted. On the washer of which the adjuster arm is a part there is an extension to which is soldered the outer end of the hair spring. When the external slotted head is turned, its inner tip moves the adjuster arm one way or the other and changes the position or tension of the front hair spring to bring the pointer to zero on the scale.

The rear hair spring usually is soldered to an extension on a friction-held washer which may be rotated one way or the other to change the tension of the rear spring and bring the pointer to its correct zero position with the front zero adjuster arm in a vertical position. Such a rear adjustment may be seen in Fig. 8, where a movement and magnet have been separated from the meter base, but where the terminal connections still are in place. When the rear adjustment is once correctly set, any slight shifts in pointer position which occur during normal service may be corrected with the regular exposed slotted head.

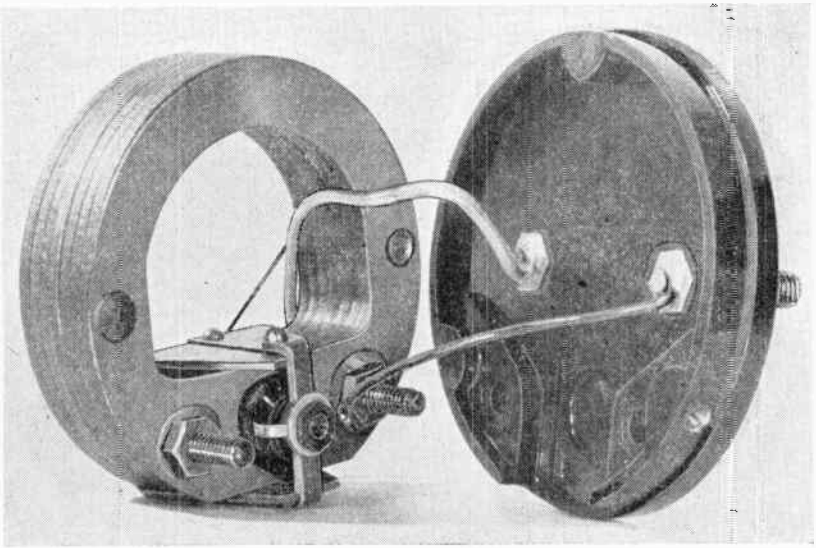


Fig. 8.—Connections between a movement and terminal screws in the meter case.

The permanent magnets for meters may be either the laminated type shown by Fig. 9 or the solid type shown by Fig. 10. A laminated magnet consists of a number of layers, each about $\frac{1}{16}$ inch thick, riveted together. Sometimes, but not always, there are pieces of soft iron between the poles of the magnet lamination and the cylindrical space in which the moving coil rotates. Such construction may be seen in Fig. 4. The soft iron pole pieces or pole shoes help to equalize any uneven flux distribution from the laminations themselves, and thus to provide a more uniform magnetic field for the moving coil. The laminations may be made from chrome, tungsten, or cobalt alloys of steel.

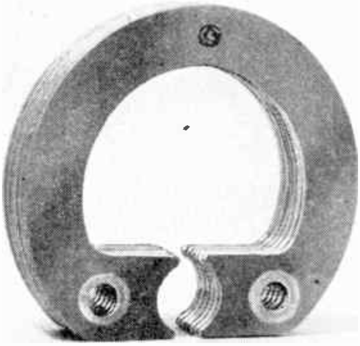


Fig. 9.—A laminated magnet.

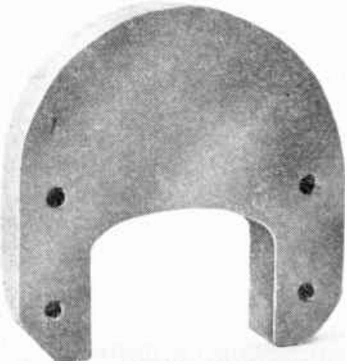


Fig. 10.—A solid magnet of Alnico.

Solid magnets, of which one shape is shown in Fig. 10, often are of Alnico magnet steel in service instruments. Alnico is an alloy containing aluminum, nickel, and iron. It has very great magnetic strength for a given size, and is so hard that after casting it can be machined only by grinding. Consequently, the Alnico magnets always are used in conjunction with soft iron pole pieces in which are formed the cylindrical openings for the moving coil, and to the outside of which are fitted the poles of the permanent magnet.

The moving coil permanent magnet meters are available for measurements in a wide range of current values. The most sensitive instruments in fairly common use have full scale deflection of their pointers with a current of only 10 microamperes. Full-scale sensitivities of 20 and 50 microamperes are in general use, but the types most commonly employed in general service work have full-scale deflection with a current of one milliampere, or 1,000 microamperes.

Shapes of pointer tips are shown by Fig. 11. The spade tip pointer is the most common, and is used whenever readings may be made from some distance. The knife edge pointer, with a long and very thin tip at the end of a cylindrical body, is used where the tip must extend across several concentric scales, also where closely accurate readings are to be made. The lance type is common for industrial meters, but seldom is found in radio service instruments.

The zero point on a scale is at the left when current will flow in only one direction through the meter. But when readings are required with current either in one direction or the other the zero point may be at the center of the scale or at any distance from either end. An instrument designed for "zero left" cannot be changed to "zero center" or other offset zero position by adjustments of the zero adjusters and hair springs. One reason is that the moving coil then would be moved from its normal position for no current.

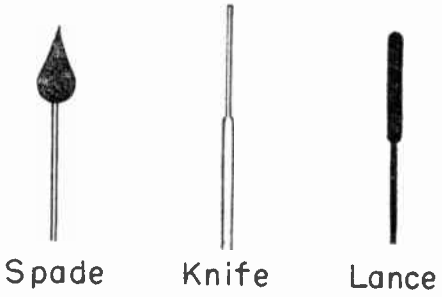


Fig. 11.—Shapes of pointers used in indicating meters.

When it is desired to make readings through only a limited range of values somewhat greater than zero the meter may be of the depressed zero or suppressed zero type. Hair spring positions and tensions are such that the pointer will not move away from its extreme left-hand position until the coil current is considerably greater than zero. As an example, a meter for indicating voltages only between 100 and 200 would be so constructed that the pointer would remain at the left until the applied potential difference was 100 or more volts, and would move all the way to the right with 200 volts.

One of the great advantages of the d'Arsonval instrument is a uniform scale, with which the pointer moves the same distance for a given change in coil current no matter whether the change is in the lower or higher indicated values. However, for some special applications it is desirable to "open up" some portion of the scale so that highly precise readings may be taken over a limited range. This is accomplished by using "shaded pole pieces," meaning that the tips of the magnet or pole pieces are cut back to weaken the field in which the moving coil travels for part of its rotation, while leaving a strong field for the remainder of the travel. A much greater change of coil current is needed to move the coil and pointer through the weak parts of the field than through the stronger parts.

Meter Shunts.—A meter or a meter movement which gives full-scale deflection of the pointer with some certain value of current may be adapted to measure any greater current values by connecting across the terminals of the meter or movement a shunt resistor as shown at the left in Fig. 12. Then current in the connected line divides between the movement and the shunt, which are in parallel with each other. The meter scale is calibrated and graduated to read the total current of the connected line, although only part of this total is passing through the movement.

To select a shunt of correct resistance it is necessary to know the resistance of the meter or the movement, also the current for full-scale deflection without the shunt, which is the original full-scale reading of the meter, and the value of full-scale reading with the shunt in place, this being the desired new reading.

These values are used in the following formula.

$$\text{Shunt resistance} = \frac{\text{meter or movement resistance}}{\dfrac{\text{desired full-scale current}}{\text{original full-scale current}} - 1}$$

The formula says to divide the desired full-scale current by the original full-scale current, and subtract 1 from the result of the division. Then this number is divided into the meter or movement resistance to find the required shunt resistance. The two current values, original and desired, must be in the same units; amperes, milliamperes, or microamperes. If the resistance of meter or movement is in ohms, the shunt resistance will be in ohms.

For example, assume that we have a meter whose original full-scale deflection is obtained with a current of 5 milliamperes, and wish to have a new full-scale deflection of 1 ampere, which is the same as 1,000 milliamperes. Assume that the resistance of the meter or movement, usually called the internal resistance, is 12 ohms. These known values are used thus,

$$\text{Shunt resistance} = \frac{12}{1000/5 - 1} = \frac{12}{200 - 1} = \frac{12}{199} = 0.0603 \text{ ohm.}$$

The computed resistance of the shunt must include the resistance of leads or connections between the line terminals of

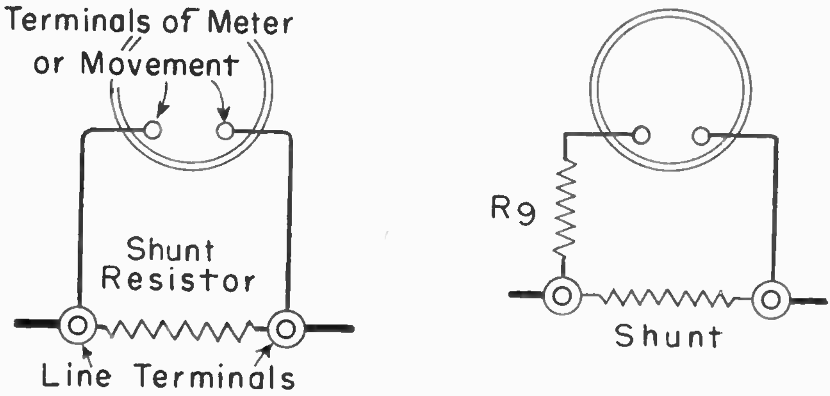


Fig. 12.—Connections of shunt resistors for current meters.

the shunt resistor and the meter or movement terminals, between which exists the meter or movement resistance used in the formula.

If the resistance of the meter or movement is known only approximately, error may be lessened by using two resistors as shown at the right in Fig. 12. An extra resistor *R9* is connected in series with either side of the meter or movement. The resistance of *R9* is to be nine times the approximate resistance of the meter or movement. Then, in our formula for shunt resistance, we use above the line a value equal to ten times the approximate resistance of meter or movement. Using the same assumed values as before, for the movement of 12 ohms (approximate) resistance, the formula would appear thus,

$$\text{Shunt resistance} = \frac{10 \times 12}{1000/5 - 1} = \frac{120}{200 - 1} = \frac{120}{199} = 0.603 \text{ ohm.}$$

The resistor used at *R9* would have resistance equal to nine times the approximate movement resistance of 12 ohms, so would be made 108 ohms.

Meter Multipliers.—The same moving coil permanent magnet movements that are used for measuring current values are used also for measuring voltages or potential differences by connecting in series with the movement a resistor which limits the current. The movement with resistor in series forms a voltmeter. The total resistance of resistor and movement must be such that maximum applied potential difference causes flow of just enough current to cause full-scale deflection of the pointer. The series resistor usually is called a multiplier. The multiplier is connected to a current meter as at the left in Fig. 13.

To select the correct multiplier resistance it is necessary to know the current for full-scale deflection, the desired full-scale volts, and, if the voltage range is to be a low one, also the internal resistance of the meter or movement. When the meter current is in milliamperes the formula for multiplier resistance is,

$$\text{Multiplier resistance} = \frac{1000 \times \text{desired full-scale volts}}{\text{full-scale milliamperes}}$$

The multiplier resistance determined with this formula really is the combined series resistance of multiplier and meter movement. Consequently, the value of movement resistance should be subtracted from the computed multiplier resistance when the movement resistance is one per cent or more of the computed resistance. Otherwise, the movement resistance will be such a small portion of the total as to have little effect on readings.

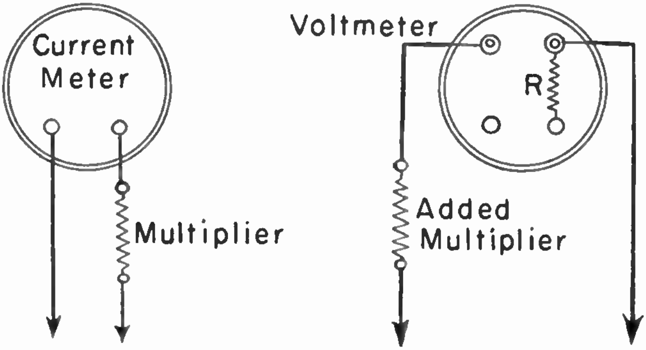


Fig. 13.—Connections of series multiplier resistors for voltmeters.

Supposing that we wish to use for a voltmeter with 200 volts at full-scale a movement having full-scale deflection with 200 microamperes (0.2 milliampere) and resistance of 400 ohms. These values would be used in the formula thus,

$$\begin{matrix}\text{Multiplier}\\ \text{resistance}\end{matrix} = \frac{1000 \times 200}{0.2} = \frac{200\ 000}{0.2} = 1{,}000{,}000 \text{ ohms}$$

The 400-ohm resistance of the movement is only $1/25$ of one per cent of the computed multiplier resistance, and so is negligible. If you compute the multiplier resistance for a 1-milliampere meter to be used as a voltmeter for full-scale reading of 1.5 volts the multiplier will come to 1500 ohms. If the movement resistance is 50 ohms it is 3.3 per cent of the computed multiplier resistance, and should be subtracted from the computed value of 1500 ohms; leaving 1450 ohms as the correct multiplier resistance to be used.

An instrument already designed and built as a voltmeter will have a series resistor inside of its case, as at *R* in the right-hand diagram of Fig. 13. The resistance of the voltmeter then is the sum of the resistances of the series resistor and movement. The range of the voltmeter, or its full-scale reading, may be increased by adding an external multiplier resistance in series with one terminal and the remainder in series with the other terminal.

The required resistance for an added multiplier is computed thus,

$$\begin{matrix}\text{Multiplier}\\ \text{resistance}\end{matrix} = \begin{matrix}\text{original}\\ \text{resistance}\end{matrix} \times \left(\frac{\text{desired full-scale volts}}{\text{original full-scale volts}} - 1\right)$$

For an example, supposing that we have a meter reading to 10 volts, whose resistance is 10,000 ohms, and wish to extend the range to 150 volts. These values would be used in the formula as follows.

$$\begin{matrix}\text{Multiplier}\\ \text{resistance}\end{matrix} = 1000 \times \left(\frac{150}{10} - 1\right) = 10000 \times (15 - 1)$$

$$= 10000 \times 14 = 140000 \text{ ohms}$$

Meter Resistor Requirements.—Both shunts and multipliers must be of such wattage ratings as to safely dissipate the heat resulting from the I^2R effect. Current through a shunt resistor, at full-scale, will be equal to the difference between full-scale reading with the shunt in use and the full-scale reading without the shunt. In an earlier example we computed a shunt resistance of 0.0603 ohm for a 5-milliampere meter converted to read 1,000 milliamperes. Then the current in the shunt will be 1,000 minus 5, or 995 milliamperes, which is 0.995 ampere. Then we use the formula showing watts equal to I^2R, or to amperes squared and multiplied by ohms. In the present case we would have,

$$\text{Watts} = 0.995^2 \times 0.0603 = 0.99 \times 0.0603 = 0.0600 \text{ watt.}$$

To operate at low temperature the watts rating should be double or more the computed dissipation, so here we might use a quarter-watt resistor.

A multiplier resistor for a voltmeter will carry the full-scale current of the meter movement in the resistance of the multiplier. The full-scale current of a current meter converted to a voltmeter will be known from the original scale. Knowing the full-scale volts and the resistance of a voltmeter, we need only divide the number of volts by the number of ohms to find the current in amperes. In an earlier example we assumed a 10-volt meter with 10,000 ohms resistance. Dividing 10 by 10,000 shows that the full-scale current is 1/1000 ampere or one milliampere. For this meter we computed a multiplier resistance of 140,000 ohms. Using the known current and multiplier resistance in the power formula gives,

$$\text{Watts} = 0.001^2 \times 140000 = 0.000001 \times 140000 = 0.14 \text{ watt.}$$

The percentage tolerance of meter resistors should be one-half or less of the percentage "accuracy" of the meter or movement. For instance, with a meter having a rated accuracy of two per cent the shunt or multiplier resistors should have a tolerance no greater than one per cent plus or minus.

Resistors should have minimum practicable variation of resistance with changes of temperatures (small temperature coefficient of resistivity), and, when used for alternating-current measurements with rectifier or thermocouple meters, should have minimum practicable inductance and distributed capacitance. Carbon resistors have almost negligible inductance and capaci-

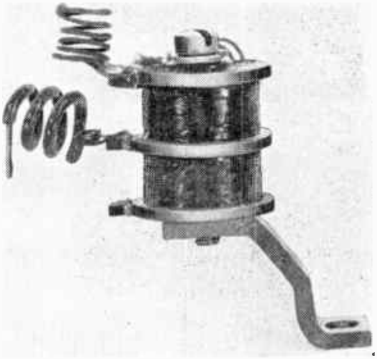


Fig. 14.—Coils such as used for shunts and multipliers.

tance at power and audio frequencies, also at standard broadcast and short-wave ranges of a few megacycles, but they have large temperature coefficients when of usual design and their wattage ratings should be three or four times the computed dissipation to maintain fair accuracy. Wire-wound precision resistors are available in types having small inductance and capacitance, and they have much lower temperature coefficients than ordinary carbon types. Fig. 14 is a picture of a shunt resistor and a multiplier resistor of wire-wound types such as mounted inside the cases of small meters.

Meter Resistance Measurement.—When the internal resistance of a meter or movement is not marked on the scale and is not otherwise known it may be measured according to the method described as follows and illustrated by Fig. 15.

"The meter is connected in series with a battery and a fixed resistor of such values that the reading is somewhat less than full scale. Then an adjustable resistor is connected across the meter as shown by broken lines. The adjustable resistor is set so that the meter reading is decreased to exactly half of its first value. Then the resistance of the adjustable resistor, as set, is equal to the internal resistance of the meter. This is true because, with half of the total current flowing through the meter, an equal half must be flowing in the adjustable resistor, and with equal currents in parallel resistances subjected to the same potential difference the resistances of the parts must be equal. The resistance of the adjusted resistor may be measured with

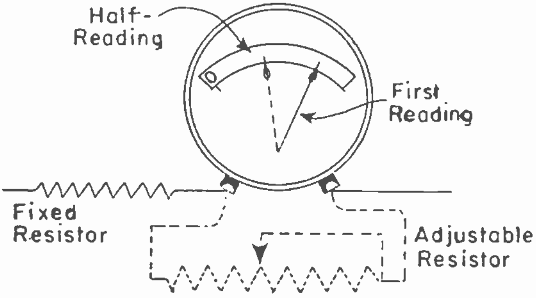


Fig. 15.—A method for measurement of meter resistance.

a resistance bridge, an accurate ohmmeter, or other resistance measuring apparatus."

Rectifier Meters.—The moving coil permanent magnet type of instrument is used for measurement of alternating potentials and currents by applying the a-c potential to a rectifier circuit whose d-c output is connected to the instrument movement. Fig. 16 is a picture of such a meter from which the permanent magnet has been removed so that the small rectifier unit may be seen mounted on the meter base which is the back of the movement.

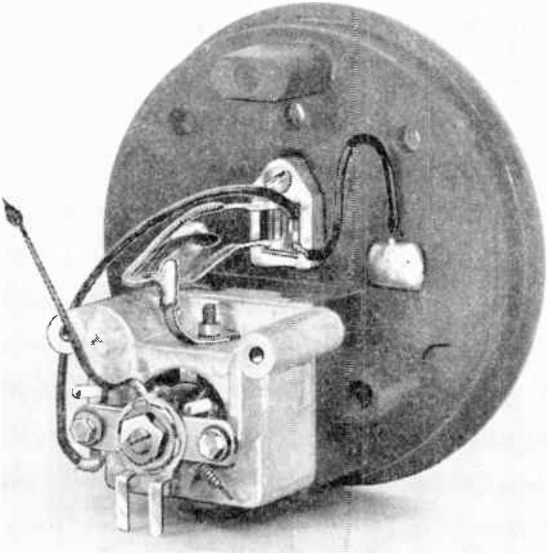


Fig. 16.—A rectifier mounted in the back of the instrument case, above the movement.

The rectifiers generally employed for instrument work are of the copper-oxide dry disc type, in which each rectifying element consists of a disc of copper, on one side of which is a coating of copper oxide. The resistance to electron flow from the copper to the oxide layer is very low, but resistance is high to flow in the opposite direction. When alternating potential is applied, there are large pulses of electron flow during half cycles in which the copper is negative and the oxide positive, and only very weak pulses in the opposite direction in the opposite half cycles.

With usual construction there are four rectifying discs connected in what is called a bridge circuit, as shown by Fig. 17. The discs are represented by arrowheads pointing in the direction of low-resistance electron flow. In the center of the bridge circuit is represented the d-c instrument movement with its negative and positive terminals marked. During half-cycles of one polarity the electron flow is as shown by arrows on the left-hand diagram, and during opposite half-cycles the electron flow is as shown on the right-hand diagram. Note that electron flow through the instrument movement is in the same direction during both half-cycles. Thus we have a full-wave rectifier circuit in which two out of the four rectifying units pass electron flow to the movement during each half-cycle.

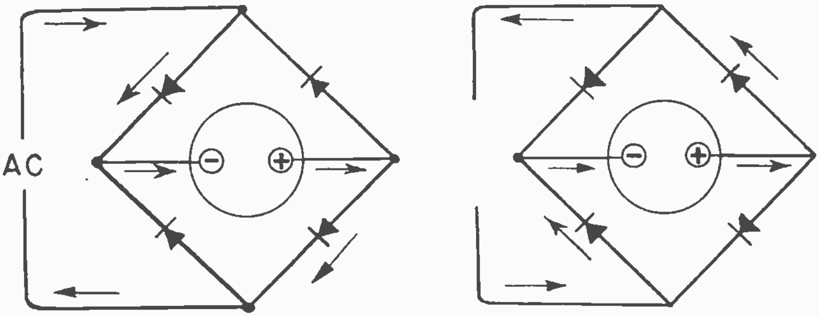


Fig. 17.—Directions of electron flow in a rectifier meter during one cycle.

The manner in which the four discs are assembled in one style of instrument rectifier is shown at the left in Fig. 18. The electrical arrangement is shown at the right. Between the rectifying discs are thin washers of metal for making contact with the surfaces of the discs. The leads for making connections are attached to the thin contact washers. Direction of free electron flow through each disc is indicated by a small arrow. With the arrangement represented here the contact washer for the positive lead presses against the frame that encloses and supports the assembly. Consequently, the frame is alive and must be insulated from other metallic parts. Some instrument rectifiers are mounted within cases made of insulating material so that no exposed parts except the leads are alive. The actual overall length of the frame of the unit pictured at the left in Fig. 18 is about one-half inch.

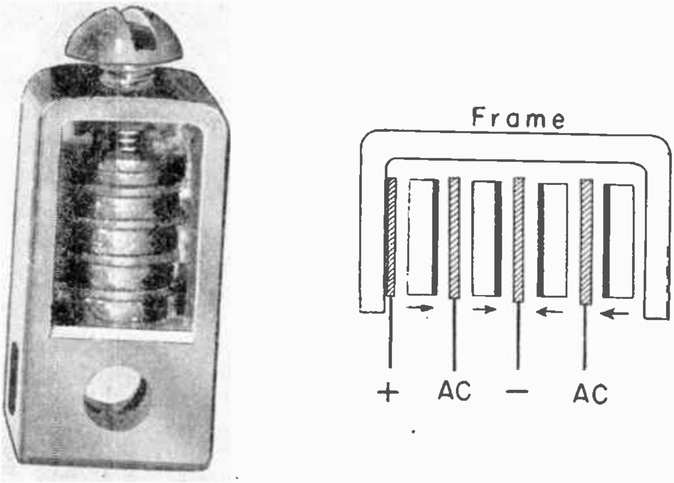


Fig. 18.—A full-wave instrument rectifier, and the arrangement of the discs.

Rectifier current-measuring instruments are available with full-scale readings as low as 100 microamperes, and in various greater ranges up to values in amperes. Voltmeter full-scale readings run from one volt up to 1,000 volts in instruments generally available. Shunt resistors used with current measuring meters ordinarily are connected across the a-c terminals rather than across the movement terminals, thus allowing the rectifier elements to carry only the relatively small currents which flow through the d-c movement. Multiplier resistors are connected between one of the a-c terminals and the rectifier element, not between the rectifier and the d-c movement. Otherwise the rectifier elements would be subjected to the full measured a-c voltages, and would be destroyed. Since rectifier meters are designed especially for use on alternating potentials and currents, it is important that resistors for shunts and multipliers have negligible inductance and distributed capacitance.

The resistance of instrument rectifiers undergoes considerable variation with only moderate changes of temperature, the resistance decreasing as the temperature rises. When a meter has been calibrated for accurate readings at a normal room temperature, such as 68° F., there will be a five per cent change in resistance with either rise or drop of 10 to 15 degrees in temperature, and with still greater variations of temperature the resistance changes at an increasing rate.

The frequency of measured alternating potentials and currents affects the readings of rectifier meters, chiefly because the capacitances of the conductive rectifying discs and their relatively high-resistance oxide coatings tend to bypass more and more of the current around the d-c movement with rise of frequency. Thus the scale readings become lower and lower in relation to actual applied potentials and currents as the frequency increases. The frequency error usually is negligible for ordinary work up to frequencies somewhere between 5,000 and 10,000 cycles, a range which takes in most of the audio frequencies. Then there will be a fairly steady drop in readings up to somewhere around 50 kilocycles, and at still higher frequencies the indications tend to become erratic and to have no definite relation to applied potentials and currents.

The current supplied by the rectifier to the d-c movement consists of a series of one-way pulses, each similar in form to a half-cycle of the applied alternating potential. The d-c movement indicates the average value of these current pulses, which is equal to 0.636 of the peak value. But it is usual practice to calibrate a rectifier meter so that its scale reads the effective or r-m-s value of the applied alternating potential or current, and this value is equal to 0.707 of the peak value. The ratio of scale markings to actual potentials or currents then is 0.707/0.636, or about 1.11. If a smooth direct potential or current is applied to the rectifier meter, the meter will indicate values about 1.11 times the actual circut values, or will read about 11 per cent high on direct current.

The scale calibration or graduation for rectifier meters ordinarily is made by using sine-wave potentials. If the measured potential or current has a waveform much different from a sine wave the readings will be inaccurate. If wave peaks are relatively flat, approaching a direct potential condition, the meter will read high. If the peaks are relatively sharp or narrow, the meter will read low.

Still another peculiarity of instrument rectifiers is that their resistance decreases as the current through them increases. With a typical rectifier meter designed to have one milliampere of alternating current for full-scale reading the rectifier resistance at full-scale may be about 580 ohms. At half-scale (0.5 a-c milliampere) the resistance may rise to 850 ohms, at quarter-scale to about 1,360 ohms, and still higher at lower readings. With meters designed for larger currents at full-scale the changes of resistance are not so noticeable. In a 5-milliampere meter the increase of resistance between full- and half-scale may be about 20 to 25 per cent, and between full- and quarter-scale about 60 per cent.

When such meters are used in circuits having low resistance, the resistance of the meter will form a considerable portion of the total resistance opposing flow of current. When the meter resistance undergoes large changes with variation of current, there are resulting large changes in the total resistance, and current in the circuit will be varied by changes of meter resistance. The meter still will read the actual current, but this actual current will be much different from its value without the meter in the circuit. The smaller the current which would exist without the meter, the more this small current is reduced by the increased resistance of the meter.

When the rectifier meter is a voltmeter for measuring fairly high voltages, there will be a series multiplier of high value in the meter itself. This series resistance is so much greater than the resistance of the rectifier that changes of rectifier resistance with variation of meter readings have little effect. As an example, consider the resistances of 580 ohms for full-scale current and of 1,360 ohms for quarter-scale current as mentioned in an earlier paragraph. If that 1-milliampere meter is to be used as a voltmeter with full-scale reading of 250 volts the multiplier resistance and meter resistance together must be 250,000 ohms. The change between 580 and 1,360 ohms is 780 ohms. This change amounts to only about $\frac{1}{3}$ of 1 per cent of the total resistance, and would not have any important effect on accuracy of readings.

Were the same rectifier and d-c movement used for a full-scale reading of 5 volts the total series resistance would be 5,000 ohms, including the multiplier, the rectifier, and the movement. Then the 780-ohm change of rectifier resistance between full- and quarter-scale would be more than 15 per cent of the total, and would have a decided effect on accuracy of readings were the change of resistance not allowed for in graduating the scale.

Because of the change of rectifier resistance with change of current, the scales of rectifier meters will be somewhat crowded at the low current end. The less the full-scale voltage or the full-scale current to be measured, the greater will be the crowding of the scale at the lower end. Fig. 19 shows relations between a scale for alternating currents or potentials and direct currents or potentials when a d-c movement is used without a rectifier

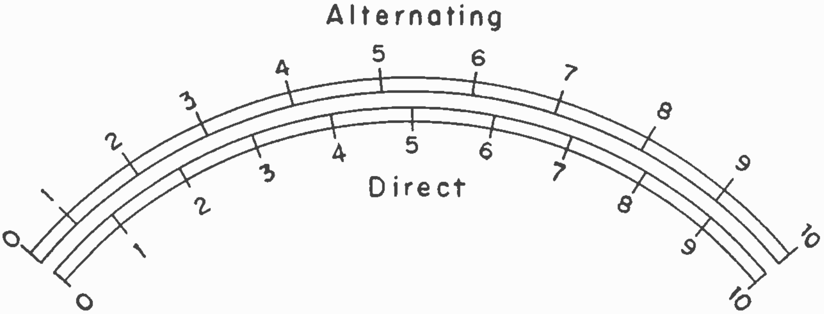


Fig. 19.—Typical alternating potential or current graduations for the scale of a rectifier meter.

for direct current and potential measurements, and is used with a rectifier for measurement of alternating quantities.

It has been mentioned that a rectifier meter will read high on direct current due to the fact that readings actually are proportional to average current although calibration is for effective value of sine wave current. It follows that the full-scale d-c current for a movement to be used in a rectifier meter should be less than the full-scale alternating current to be indicated, or less than the current that would be required for indicating a given direct potential. This comes about because the movement responds to the average value of current, but scale markings are based on effective value, which is 1.11 times the average value. The d-c movement should provide full-scale deflection with 80 to 90 per cent of the current that would be used for d-c measurements. As an example, the d-c movement for a rectifier meter to indicate up to one milliampere of alternating current should have full-scale deflection with a direct current of 0.80 to 0.90 milliampere.

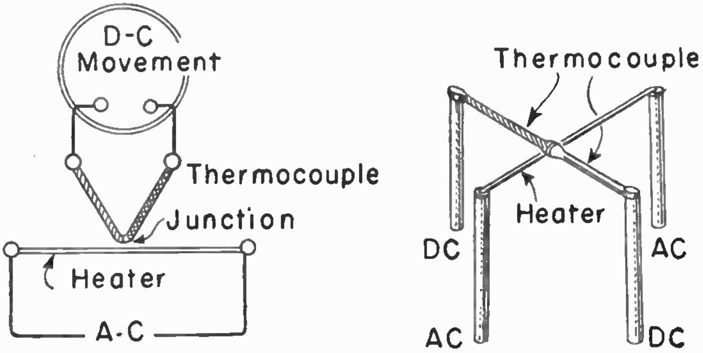


Fig. 20.—The principle of the thermocouple meter.

Thermocouple Meters.—A type of indicating meter which will operate at alternating frequencies up to several hundred megacycles makes use of the heating effect of the alternating current to produce a direct current which is measured or indicated by a moving coil permanent magnet movement. The device which produces an emf and a direct current when heated is called a thermocouple, and meters using this device are called thermocouple meters, or sometimes are called thermal meters.

The principle of the thermocouple is shown by Fig. 20. The couple itself consists of two conductors of dissimilar metals joined together at a junction, and with their outer ends connected to the d-c movement of the meter. Close to the junction, sometimes in direct contact with it, is a heater wire or strip through which flows the alternating current to be measured. Flow of current raises the temperature of the heater and of the thermo-junction. When the temperature of a junction between unlike metals is raised above the temperature at the opposite end of the circuit including the metals, an emf appears at the junction. If the thermocouple circuit is closed, as through the moving coil of a meter, direct current flows in the circuit.

The emf produced at the junction depends on the temperature and on the kinds of metals forming the couple. The power which produces heat in any conductors is proportional to I^2R, or to the current squared and multiplied by the resistance. Temperature rise is proportional to the heat produced. Therefore, the temperature rise at the thermo-junction, and the direct emf produced there, is proportional to the square of the effective or r-m-s value of alternating current in the heater. With any given kinds of metals in the couple the emf may be specified as so many microvolts per degree of temperature rise. With full normal value of alternating current in the heater wire, or the value which would cause full-scale deflection of the meter, the direct potential outputs from thermocouples are from five to ten millivolts, depending on the make and type of couple.

Among the metals having relatively large thermoelectric powers, in microvolts per degree, are antimony, bismuth, nickel, iron, and the copper-nickel alloy called constantan. Antimony and platinum give a power of about 41 microvolts per degree centigrade, with the antimony negative and the platinum positive. Copper and constantan give about 43 microvolts, with the copper positive and the constantan negative. There are various other usable combinations.

The resistances of thermocouples of various types and makes run usually between three and 12 ohms. This is the resistance that is placed across the d-c movement when the thermocouple is connected to the movement. To have maximum transfer of power from couple to movement the resistance of the movement should be equal to, or a little higher than, the resistance of the couple. This is simply the familiar matter of matching resistances or impedances for maximum power transfer.

Because heating is proportional to the square of the current, small alternating currents in the heater wire produce but little heat. To prevent rapid loss of heat and lowering of temperature in the heater, thermocouples for use on currents up to about 500 milliamperes usually are enclosed in a highly evacuated glass envelope, like a radio tube. The vacuum retards loss of heat by radiation. For larger alternating currents it is common practice to use air thermocouples, which are not enclosed. The evacuated couple does not change its d-c output as quickly as does the air type when alternating current decreases, because the vacuum retains heat and the couple continues to generate emf. Vacuum thermocouples usually are an inch or somewhat more in length, and about a half-inch in diameter. The heater wire usually is platinum or platinum alloy, only three or four thousandths of an inch in diameter.

Because heat and temperature rise in the heater, and emf and current for the d-c movement are proportional approximately to the square of the alternating current in the heater, the dial scale of the thermocouple meter is decidedly crowded at the lower end. The positions of graduations for equal increases of heater current as they would appear on a "current squared" scale are shown by Fig. 21.

The chief advantage of the thermocouple is in the accuracy of its indications at all alternating frequencies. This is because the small diameter, short, straight elements in the couple have very little inductance or distributed capacitance. If suitable precautions are used in construction and connection of a thermocouple meter, these factors of inductance and capacitance may be kept small in the whole measuring apparatus. Energy losses at very high frequencies are due also to skin effect. This loss is lessened by using non-magnetic metals in the couple, and, in some constructions, by using a tubular conductor for the heater.

Skin effect tends to make the meter read high with increasing frequency, while capacitance tends to make the readings low. With meters for alternating currents of only two or three milliamperes the indications may become lower with increasing frequency, but in most meters the error is in readings which become too high. Thermocouple meters with full-scale ranges of from two to five milliamperes are available with accuracies (full-scale errors) of not over two per cent at frequencies as high as 50 to 70 megacycles. Higher current ranges, up to 100 or 200 milliamperes may be had with equal accuracy on frequencies of 100 megacycles and even somewhat higher. Thermocouple voltmeters in which currents through the heater are as mentioned have generally similar accuracies at high frequencies.

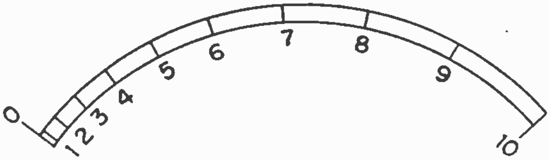


Fig. 21.—The dial scale for a meter whose indications are proportional to current squared.

Thermocouple meters indicate true effective or r-m-s a-c values regardless of the a-c waveform, this because these meters are actuated by heating effects, and effective or r-m-s values are primarily based on heating effect in conductors.

Thermocouple meters would have errors due to surrounding temperatures only were such temperatures to affect the couple or the junction more than the end of the couple circuit connected through the d-c moving coil. It is only the difference between temperatures at the two ends of the thermocouple circuit which result in emf's at the junction. If the two ends of the circuit are at the same temperature without heating current flowing in the heater element, then the temperature difference and generated emf will result only from the alternating current.

Iron Vane Meters. — For measurements at power-line frequencies, and sometimes at frequencies as high as 500 cycles, the repulsion type of iron vane meter is in general use. The principle of such a meter is shown by Fig. 22.

Inside of a hollow coil which carries the current that actuates the meter are two iron vanes. One is supported in a fixed position and remains stationary. The other has one side or edge fastened to the shaft which carries the pointer. When current flows in the coil the two vanes are magnetized. With current in one direction the upper ends of both vanes will be made north poles, and their lower ends will be made south poles. This magnetization occurs because inside the coil there are produced magnetic lines of force traveling lengthwise or in line with the pointer shaft.

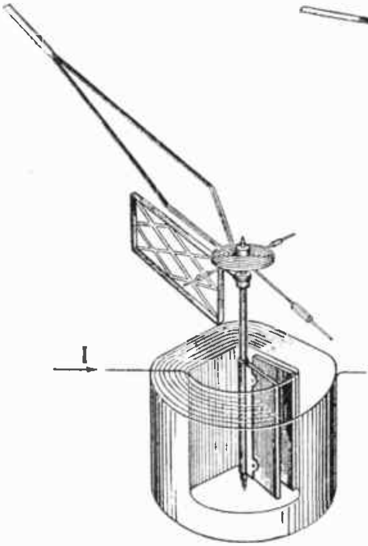


Fig. 22.—The principle of the iron-vane movement of the repulsion type. (Courtesy of Weston Electrical Instrument Corp.)

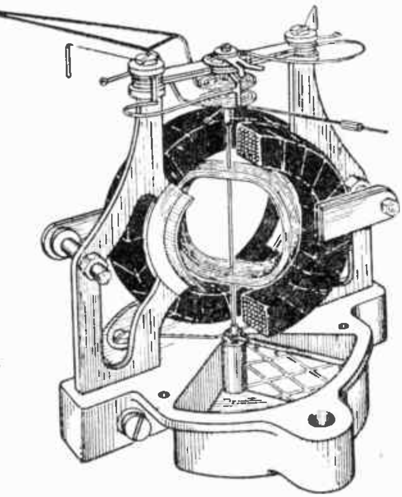


Fig. 23.—The principle of the dynamometer instrument. (Courtesy of Weston Electrical Instrument Corp.)

Since the ends of the vanes have the same magnetic polarities they repel each other and the movable vane swings away from the fixed vane to move the shaft and the pointer. Repulsion of the vanes and travel of the pointer across its scale is opposed by hair springs attached to the shaft.

When the direction of coil current reverses, the magnetic polarities at the ends of the iron vanes are reversed. But because the polarities are reversed at both ends of the vanes, there are still like poles at each end and there is repulsion just as before. With alternating current the magnetic polarities of the vanes are reversed on every half-cycle, but like poles always are together and the repulsion force depends on the strength of the current, not on its direction. Repulsion type instruments will indicate on direct current, although the readings may not be so accurate as on alternating current.

The scale of the repulsion vane meter tends to be compressed at the low readings, but for values of ten per cent and greater percentages of full-scale the indications are clear.

There are various other types of moving iron meters in which are employed the magnetic attraction or repulsion of the field of a current-carrying coil on one or more pieces of iron held in various positions and attached to the pointer shafts.

Dynamometer Meters.—Still another kind of meter designed especially for measurement of alternating currents and potentials is the dynamometer or electro-dynamometer type whose principle is shown by Fig. 23. In this instrument there are stationary and moving coils, with the moving coil carried by a pivoted shaft so that it may rotate through part of a turn. To the moving coil is attached the pointer that travels across the dial scale when this coil rotates. Rotation of the moving coil is restrained by hair springs.

The two coils are connected together so that alternating current for actuating the meter flows through them in series. When no current is flowing the coil axes are at an angle with each other. Current causes a magnetic field to appear around and inside of each coil. This field acts on the current or electron flow in the other coil to cause the conductors of the other current-carrying coil to move through the magnetic field. The action is similar to that shown by Fig. 5 for the moving coil permanent magnet meter, except that here the magnetic field is produced by current in a coil rather than by a permanent magnet. Since it is only the conductors of the suspended coil that can move in the field of the stationary coil, the suspended coil rotates. The greater the current the stronger is the force between the magnetic fields and the coil currents, and the farther the pointer is moved over its scale against the tension of the hair springs.

The capacitance between the fixed and moving coils, as well as the distributed capacitance and large inductance of the coils, makes this type of instrument unsuited for use on frequencies above a few hundred kilocycles in usual designs. Dynamometer instruments may be used for direct currents and potentials as well as for alternating currents and potentials of moderately high frequency.

The scales of dynamometer current meters and potential meters are quite compressed in the lower readings, having the general distribution of graduations shown for a current squared scale in Fig. 21.

Wattmeters.—Dynamometer instruments are in general use for measuring power in watts taken through either d-c or a-c circuits. For such use the stationary and movable coils are not in series, but are connected to separate terminals so that the stationary coil (then called the current coil) can be connected in series between the line and the load, while the moving coil (then called the voltage coil) can be connected across the load. These connections are shown by Fig. 24.

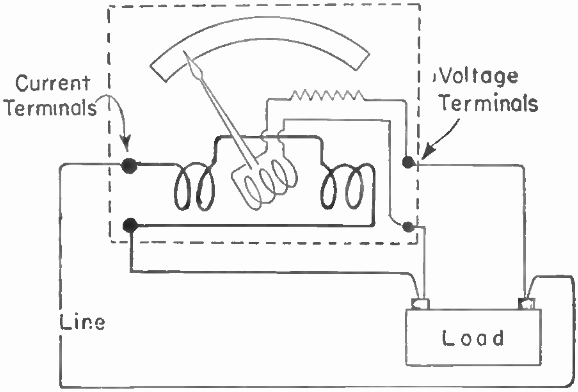


Fig. 24.—Connections of a wattmeter to the line and the load.

The current and the magnetic field of the current coil have strengths proportional to the load current. The current and field of the voltage coil are proportional to the potential difference across the power-consuming load. Then the deflection of the pointer is proportional to both amperes and volts, or to power. The scale is graduated in watts.

REVIEW QUESTIONS

1. Which of the following meters are used for direct current and which for alternating current? Permanent magnet moving coil; moving iron; rectifier; dynamometer; thermocouple.
2. Is the resistance of a meter shunt usually greater or less than the resistance of the meter itself? Is a multiplier resistance greater or less than the meter resistance?
3. In which type of meter is it desirable to have high resistance, and in which to have low resistance; voltmeter or current meter?
4. Which of the following meters is best suited to measurements at radio frequencies; moving iron, thermocouple, rectifier, dynamometer?
5. Explain how a single permanent magnet moving coil instrument may be used for measuring either currents or voltages.
6. If scale graduations of a meter are crowded at the low-value end is the meter designed for measurement of direct or alternating quantities?
7. Is the permanent magnet moving coil movement employed in any meters which measure alternating currents and potentials? If so, what are those types?
8. Explain why dynamometer meters are not well suited for measurements at very high frequencies.

Chapter 2

OPERATION AND CARE OF METERS

In order to use the type of meter best suited to whatever measurements are being made, and to employ that meter to best advantage without danger of damaging either the instrument or the apparatus being worked upon, it is necessary to understand certain of the limitations applying to measuring instruments.

The first thing to be considered is that of *accuracy* of indications. Accuracy is specified as the maximum error that may occur, as measured in a percentage of the full-scale reading. Laboratory instruments are made with accuracies as good as 1/10 of one per cent, but such types are too costly and too delicate for use other than as standards. Meters with accuracies of ½ of one per cent and of 1 per cent often are used in production testing. But most of the meters used in radio service work, when the instruments are of the moving coil permanent magnet type, have full-scale accuracies of 2 per cent. This degree of accuracy applies also to service types of thermocouple, repulsion vane, and dynamometer meters. Because of the errors to which rectifier meters are subject, their accuracies are not better than 5 per cent.

An accuracy specified as a per cent refers to that percentage of the full-scale reading, and is "plus or minus," meaning that the indication may be the specified percentage lower or higher than the true current or potential. If we consider a full-scale reading of 100 (in any units) an accuracy of 2 per cent means that the reading may be anywhere between 98 and 102 units. This is a variation of 4 units. This same variation in number of units applies anywhere on the scale. If the readings are being taken at half-scale, or at 50 on the scale, the variation still may be four units, and the reading may be anywhere between 48 and 52 when the actual value is 50. This is an accuracy of 4 per cent. Readings at quarter-scale, or at 25, then may vary between 23 and 27, which is a possible variation of 8 per cent of 25. At one-tenth scale, or at 10, the indications might be from 8 to 12, which is an accuracy of only 20 per cent.

Because of the rapidly increasing allowable error with lowered readings, meters should be chosen of such ranges that most of the important readings will be taken in the upper part of the scale. For instance, when potential differences of only 10 to 20 volts are being taken, we should not use a 150-volt meter if it can be avoided. A reading of 12 volts on such a meter, of 2 per cent accuracy, might mean a real potential anywhere between 12 and 18 volts.

Sensitivity and Power Consumption.—The sensitivity of current meters refers to the value of current which causes full-scale deflection. For instance, if there is full-scale deflection with a current of 500 microamperes, we speak of the meter as having a sensitivity of 500 microamperes.

The sensitivity of voltmeters such as used in radio ordinarily is specified in ohms per volt. The number of ohms per volt is found from dividing the total resistance of the meter, including multipliers, by the full-scale volts. For instance, if the resistance of a 100-volt meter is 100,000 ohms the sensitivity is $100{,}000 \div 100 = 1{,}000$ ohms per volt. The total resistance of a voltmeter, including multiplier, is equal to the full-scale volts multiplied by the sensitivity in ohms per volt. The sensitivity of a voltmeter, in ohms per volt, is equal also to the quotient of dividing 1,000 by the number of milliamperes for full-scale deflection of the movement. The full-scale current, in milliamperes, is equal to the quotient of dividing 1,000 by the sensitivity in ohms per volt.

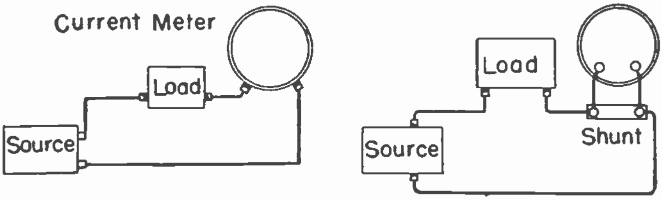


Fig. 1.—Connections for current-indicating meters.

A current meter, or the shunt for such a meter, always is connected in series with the circuit wherein current is to be measured, as shown by Fig. 1. The resistance of the meter, or meter and shunt, is added to the resistance of the remainder of the circuit. Therefore, with the meter connected, the resistance of the circuit always is more than without the meter, and the current is changed by the added resistance. The result is that the measured current always is less than the current which normally flows in the circuit.

With high resistance circuits the added resistance of the current meter will have little effect on current, and readings will give information in error by only a small amount. But if the meter resistance anywhere near approaches the resistance, or is of the same general order as the circuit resistance, the readings will be inaccurate.

It becomes plain that the less the resistance of any current meter the more suitable it is for making measurements, so far as affecting the measured circuit is concerned. For moving coil instruments of moderate price and two per cent accuracy the resistances of the movements run about as shown by the full-line curve of Fig. 2 for various full-scale ranges in microamperes. The broken-line curve shows the corresponding powers in microwatts which must be furnished from the measured circuit in order to cause full-scale deflection of the meter.

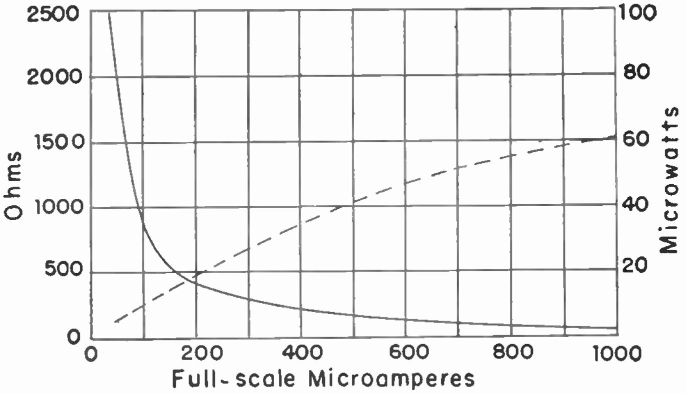


Fig. 2.—Resistances and power consumptions of meters commonly used in radio service work.

Although the resistances appear high for ranges below 200 microamperes, it will be found that such small currents almost always exist only in circuits having high resistances. Therefore, the added resistances of these low-range meters do not cause serious errors in indicated currents. The power which must be furnished from the measured circuit may cause more difficulty, since in many high-resistance radio circuits the available powers are very small at best.

A voltmeter always is connected across a "load" element between the two points where potential difference is to be measured, as shown by Fig. 3. Thus the resistance of the meter is in parallel with the resistance of the part whose potential difference is being measured, and current will divide between the measured load and the meter inversely as the two paralleled resistances. Unless the resistance of the voltmeter is high in comparison with the resistance of the measured load and other resistances in the circuit the indicated voltages may have little relation to voltages which exist without the meter connected.

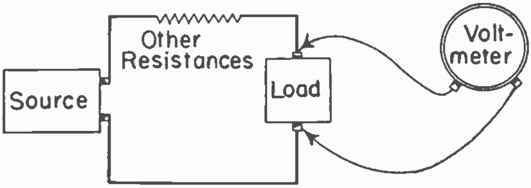


Fig. 3.—Connections for a voltmeter.

As an example of what may happen, assume that in the circuit of Fig. 3 the resistance of the load is 50,000 ohms, the total of other resistances is also 50,000 ohms, making a total circuit resistance of 100,000 ohms, and that the emf of the source is 250 volts. Then, before the voltmeter is connected, there will be a current of 2.5 milliamperes everywhere in the circuit, and drops of 125 volts across the load and across the other resistances.

Supposing that the voltmeter has a range of 250 volts and sensitivity of 1,000 ohms per volt, indicating a meter resistance of 250,000 ohms. Connecting this meter across the load causes the following things to happen.

The combined parallel resistance of meter and load becomes 41,667 ohms. Then the total circuit resistance becomes 41,667 + 50,000 = 91,667 ohms, instead of the former 100,000 ohms.

With the emf of 250 volts and circuit resistance of 91,667 ohms the total current becomes 2.73 milliamperes instead of the former 2.5 milliamperes. With this greater current the drop in the other resistances of 50,000 ohms becomes 136.5 volts instead of the former 125 volts.

Of the total current, 2.73 milliamperes, the voltmeter is taking 0.455 milliampere. This leaves 2.275 milliamperes for the load, instead of the former 2.5 milliamperes. With this load current in the 50,000 ohms resistance of the load the drop across the load becomes 113.8 volts instead of the former 125 volts, and this is the potential difference which would be indicated by the voltmeter. The meter is indicating 91 per cent of the drop that exists without the meter connected. The higher the resistance of a voltmeter the less will be the difference between its readings and the potential differences without the meter connected to the measured circuit.

In our example we have assumed that the source maintains its original emf with the increased current resulting from connection of the meter, and that our "other resistances" include the internal resistance of the source. Actually, the terminal potential of the source would change, becoming lower with the increased current.

If we figure power rates for the example we learn that there is dissipation of 0.625 watt in the circuit before the meter is connected. The meter takes 0.052 watt at the voltage it indicates. Because of the meter and the increased total current there is dissipation of 0.682 watt with the meter connected. Thus the source is required to increase its power output from 0.625 watt to 0.682 watt, an increase of about 9 per cent. Were the source not capable of furnishing the greater power, the errors caused by connecting the meter would be greater than previously computed.

In rectifier types of microammeters and milliammeters the resistance of the rectifier is combined with the resistance of the d-c movement. Consequently, rectifier current meters have much higher resistances than d-c meters of similar range. In full-scale ranges around 100 microamperes the rectifier instrument resistance will usually be three or four times the resistance of a d-c type. The ratio of resistances increases at higher current ranges until, at 1,000 microamperes or one milliampere, the resistance of the rectifier instrument may be about 20 times that of the d-c type.

Rectifier voltmeters usually have sensitivities of either 1,000 ohms or 2,000 ohms per volt, but are available also with greater sensitivities.

Rectifier instruments are used for measurement of alternating currents and potentials where only small currents and powers may be taken from the measured circuits, and where the rather large errors of the rectifier types are not too objectionable.

The resistance which a thermocouple current meter inserts in series with the measured circuit is the resistance of the heater element, since the thermocouple itself is connected to the d-c movement but not to the measured circuit. To obtain a sufficient I^2R heating effect with very small currents it is necessary that the heater have relatively high resistance, and even so the lowest current ranges ordinarily available in such meters are on the order of two or three milliamperes. In such ranges the heater resistances run between 600 and 1,000 ohms, which is ten to twenty times the resistance of the d-c movement. Ranges up to 100 milliamperes take five to twenty milliwatts of power in their heaters for full-scale deflection. All of this refers to vacuum thermocouples.

Thermocouple voltmeters must be of rather low sensitivity, in ohms per volt, to permit sufficient current to flow in the heater elements. Usual sensitivities run between 125 and 500 ohms per volt.

Thermocouple meters are used for direct indications of high-frequency alternating currents and potentials where good accuracy is required, but where considerable power may be taken from the measured circuit.

Repulsion vane alternating current meters are available in full-scale ranges as low as 10 milliamperes. Resistances are high in comparison with d-c moving coil permanent magnet types. Power consumption runs about the same in all current ranges, usually being something between $\frac{2}{10}$ and $\frac{3}{10}$ of a watt. Repulsion vane voltmeters have low sensitivities. In ranges from 1½ to 300 volts the sensitivities vary from about 3 to 80 ohms per volt, with the higher sensitivities in the higher voltage types.

Repulsion vane meters give accurate readings of actual currents in the meters and of actual voltages across the meter terminals, but the high current resistance and low voltage sensitivity limit the use of these meters to circuits where much power may be taken without upsetting normal conditions to much extent. These meters are useful for measurements in power line circuits, and for a-c heater and filament circuits which carry fairly large currents.

Dynamometer instruments, like the repulsion vane types, have excellent accuracy but have high current resistance and low voltage sensitivity. Full-scale ranges of current meters run as low as 10 or 15 milliamperes. Resistances run from 100 to more than 1,500 ohms in ranges from 100 down to 10 or 15 milliamperes. Voltmeter sensitivities run between 2 and 30 or slightly more ohms per volt. These instruments are used for the same general purposes as the repulsion vane types.

Meter Connections.—Current measuring meters, or their external shunts, always are connected in series with the part of a circuit in which current is to be measured. This requires opening the circuit, as indicated in Fig. 1. A current meter must not be connected across points in a closed circuit when there is any possibility of much potential difference between the points, or when there is appreciable resistance or impedance between the points. Such a connection might force enough current through the relatively low resistance of the meter to burn out the meter windings or coils.

Voltmeters always are connected between points whose potential difference is to be measured, as in Fig. 3. If an external multiplier is used, the multiplier resistor is to be connected directly to and in series with either of the meter terminals.

A moving coil permanent magnet d-c instrument should not be used on a circuit carrying pure alternating current or a large a-c component. The pointer will vibrate but will remain near zero, even though current through the meter may be enough to burn it out. Such meters may be used in plate circuits and other circuits where there is a relatively small a-c component as compared with the direct potential or voltage. The meter then will read the average value of current or voltage, which is the direct-current value equivalent to that of the pulsating current or voltage with the peaks smoothed out so far as the reading is concerned.

Meters which are in cases made of insulating materials, not in iron or steel cases, should be kept well separated from one another so that magnetic and electric fields of one instrument will not affect readings of others. Meters should also be kept away from transformers, chokes, and other parts around which there may be strong magnetic fields. If you are in doubt, place the meter with its dial horizontal and turn it to different positions about 90 degrees apart. Changes in reading or indication probably are due to external fields affecting the meter.

When using portable meters on a bench, do not drape the connecting leads on or over the front of the bench, where they may be caught to pull the meter onto the floor.

When using an external shunt resistor with a current meter use only the leads which are furnished with the instrument for connection between the ends of the shunt and the indicating unit. Leads of different resistance will cause errors in indications. Connections to the shunt resistor should be clean and tight, since any appreciable contact resistance might be almost as great as the resistance of the shunt itself. It is a good safety precaution to connect both ends of the shunt into the measured circuit before connecting the meter to the shunt, then later to disconnect the meter from the shunt before disconnecting the shunt from the circuit.

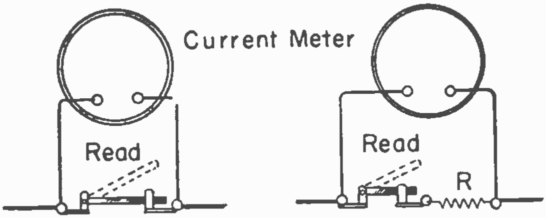


Fig. 4.—Protective devices for current meters.

It is another excellent safety measure to connect meters into circuits or to circuits only while those circuits are dead, when they are carrying no current and have no potential differences.

Delicate current measuring instruments may be protected from accidental damage as shown by Fig. 4. At the left a switch is connected in series with the measured line, and the meter is connected to the switch terminals. The switch is kept closed until connections are checked, then is opened only while current readings are taken, and again is closed and left so until the next reading. A better arrangement is shown at the right. Here there is connected in series with the switch a resistor *R* whose resistance is about one-fourth or one-fifth of the meter resistance. With the switch closed the meter will carry only one-fourth to one-fifth of the line current. If the meter now reads only one-fourth to one-fifth of its full-scale value it is safe to open the switch because the pointer will stay on scale with the full line current. If the reading is higher with the switch closed, the line current is too great for the meter being used.

Voltmeters may be protected as shown by Fig. 5. At the left there is a switch in series with one terminal of the meter. This switch is kept open until connections are checked, then is closed while taking a reading, and is opened until another reading is to be taken. At the right the protective switch is shunted by a resistor. This resistor should have resistance several times as great as the resistance of the meter, and should be of high enough wattage rating to safely dissipate the number of watts found from dividing the square of the full-scale voltmeter read-

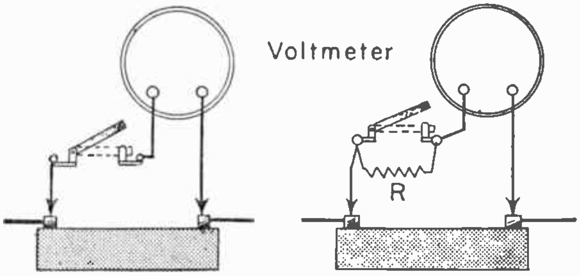


Fig. 5.—Protective devices for voltmeters.

ing by the number of ohms of resistance in the resistor *R*. For example, with a one-megohm resistor on a 250-volt meter, the square of 250, which is 62,500 would be divided by 1,000,000 to show that only about 0.063 watt need be dissipated. With the switch open, the meter should read no higher than a fraction of full-scale reading equal to the meter resistance divided by the protective resistance *R*. In the foregoing example, were the meter resistance 250,000 ohms, the reading should be no more than 250000/1000000 or ¼ scale. Then the pointer will stay on scale when the switch is closed to take a regular reading.

Wattmeters have rated maximum currents and rated maximum voltages. Neither limit may be exceeded without danger of burnout. For example, a certain wattmeter may have limits of 150 volts and 3 amperes. It must not be connected into a circuit where the potential difference is higher than 150 volts, nor the current more than 3 amperes, regardless of the power in watts.

Reading the Meters. — Unless the case of a portable testing instrument is designed to hold the meter or meters in a vertical or sloping position, all such instruments are designed and calibrated for use with the dial scale horizontal. If used in other positions the errors may be increased. Meters should not be subjected to vibration, as for example, when checking auto radios with the automobile engine running. In such situations the meter should be laid on a folded cloth or other vibration-absorbing pad.

Take readings from such positions that your line of sight is perpendicular to the dial scale, as shown by the full line arrow in Fig. 6. Then you will read the value of a scale graduation that is directly back of the pointer. If you read from a position such that your line of sight follows arrow *A* your readings will be too high on the scale, and if from the other side, arrow *B*, your readings will be too low. Such displacement errors are called errors of *parallax*. Many of the higher priced instruments have anti-parallax mirrors on the scale plate. Then you get your eye in such position that the image of the pointer is directly back of and is hidden by the pointer itself, thus insuring a perpendicular line of sight.

Before a meter carries current or is subjected to voltage, observe whether the pointer tip rests exactly at the zero graduation on the scale. Tap the meter very lightly to note whether the pointer is sluggish or sticking. If the pointer is not on zero, use the zero adjuster screw-head to bring it there before taking measurements.

Wiping the glass or plastic cover of the dial scale with a cloth may impart a strong electric charge to the cover. This charge may attract the pointer and cause it to move far from correct readings. After a cover is wiped, breathe on it to deposit a film of moisture that lets the charge dissipate. Otherwise do the wiping with a cloth that is slightly moist.

When using voltmeters fitted with test prods, hold the prods only by their insulation—never touch the metal tips. The resistance of your body is only a few thousands of ohms, and if you take hold of the metal prods or tips you are shunting the voltmeter with the relatively low resistance of your body, and readings will be greatly in error.

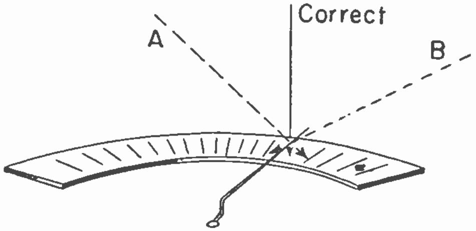


Fig. 6.—The effects of parallax when reading a meter.

When testing potential differences in high-voltage circuits guard against letting these potentials force currents through your body. One way that is fairly safe, when you are not standing on a conductive surface, is to use only one hand. Clip one meter lead to one of the points to be checked, then, holding only the insulation, touch the other prod or tip to the second point. Many workers make it a habit to keep one hand in a pocket while making high-voltage tests. A better way is to cut off the power, as by opening a line switch, before making any test connections, and then turn on the power only after connections are complete and your hands out of the way.

Many testing instruments have several ranges for currents and potentials. One such multi-range meter for measuring volts and milliamperes in several ranges is shown by Fig. 7. Unless you know positively that potential difference or current is below a certain value, and you seldom do know positively when working on defective parts, always commence by checking on the highest potential or current range of the meter. Then, if the reading is within one of the lower ranges, change to that lower range.

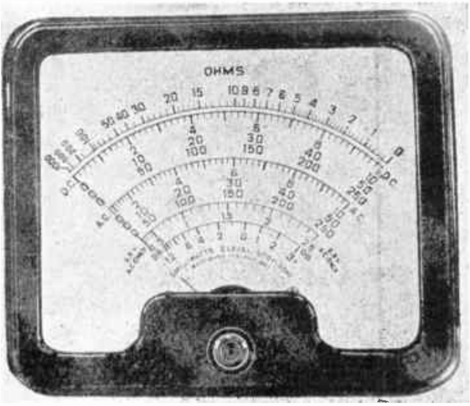


Fig. 7.—A meter with many scales for indicating various kinds and ranges of values.

When such instruments are fitted with switches for selecting one of the several ranges, form the habit of placing the selector switch at the highest range position when the instrument is put away. Then you or someone else won't be so likely to cause an expensive burnout when the instrument is used next time.

Shielding of Meters.—It has been mentioned before that meters having cases of insulating material should be kept away from strong magnetic fields, including the fields of other meters. As a general rule, a separation of six inches between small meters is enough to prevent trouble.

When meter cases are of steel or iron, instead of insulating material, the cases provide adequate magnetic shielding for all ordinary situations. When cases are of insulating material an extra cup or housing of iron or steel sometimes is placed outside of the insulating case. Such shields usually are no more than $\frac{1}{16}$ inch thick. Fig. 8 shows a section through a meter with a drawn steel cup for its case. This particular instrument has the interior of the case sealed air-tight for exclusion of dust and moisture. Terminals are brought through the bottom of the case with fused glass seals somewhat like those used for bringing leads through the glass envelopes of tubes.

When shielding is to be against electric or electrostatic fields the material of the shield should be of good conductivity. Both magnetic and electric shielding may be provided by means of a steel case (for magnetic shielding) heavily plated with high-conductivity silver (for electric shielding).

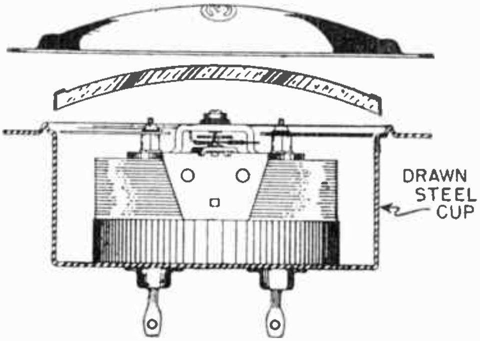


Fig. 8.—The hermetically sealed steel case of one style of Marion meter.

Meter Troubles.—The following are most common causes for errors or inaccuracy in meters and for damage to the instruments.

Overloads due to excessive current or voltage may cause damage to the working parts even if coils are not immediately burned out.

Shocks due to dropping the instruments even an inch or so, also excessive or continued vibration, will damage the pivots and their jewels to cause inaccurate indications.

Dirt, moisture, and gases which cause internal corrosion, may get inside the cases unless meters are stored in clean, dry places between periods of use.

Strong magnetic fields which cause inaccuracies may also affect the strength of permanent magnets so that later readings are in error.

Various kinds of abuse may cause bending of the pointer, or may cause the scale to get out of position or to warp, or may cause the pointer to be sluggish in action due to binding or friction between pivots and jewels. The error due to a bent pointer cannot be compensated for by the zero adjuster, because such a correction brings the moving coil away from its normal position.

The moving element may be out of balance, so that the position of the pointer undergoes considerable change when the meter is turned at various angles with the vertical position of the dial scale.

Extremely high or low temperatures may affect the accuracy of any meter. This applies especially to rectifier types, and often to thermocouple types.

Meters used at frequencies for which they are not suited may have large errors.

Waveforms differing greatly from a sine wave will affect the readings of most a-c meters except the thermocouple types.

Finally, it should be emphasized that no kind of lubrication, not even the finest watch oil, should be used on the pivot and jewel bearings of meters. Any oil will collect dirt to cause sluggishness and wear.

Testing and Calibrating.—To calibrate a meter or other instru-

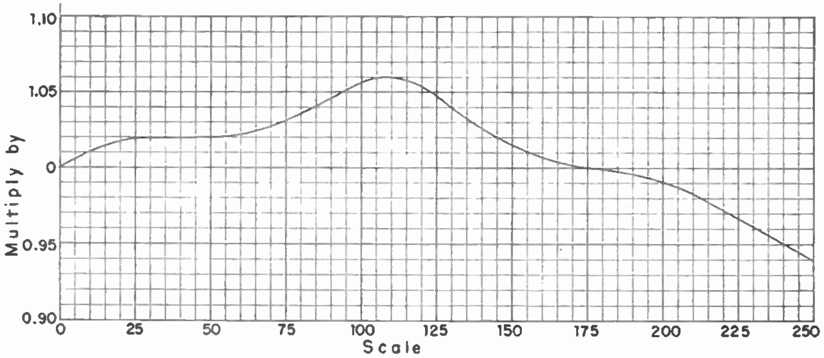


Fig. 9.—A correction curve which may be made during calibration.

ment means to check its readings against the readings of a standard instrument of known accuracy in order to determine the errors at various points on the scale of the meter being calibrated. The word calibrate is sometimes used also in referring to adjustments which are made to reduce the errors and improve the accuracy.

If a record of errors and appropriate correction factors is to be made available during future use of the calibrated instrument the record usually is made on a correction curve or calibration curve such as shown by Fig. 9. The graph shows, at its left, the factors by which indications at various points on the meter dial scale are to be multiplied in finding the true value of potential or current applied to the meter. As examples; a dial reading of 50 should be multiplied by 1.02, and a reading of 110 multiplied by 1.06. Since these readings are to be multiplied by factors greater than 1.00, the indications of the meter must be low at these points. A dial reading of 175 would require no correction. A reading of 240 would be multiplied by 0.95, meaning that the instrument here is reading too high because the correction factor reduces the indication.

A current-measuring meter; ammeter, milliammeter, or microammeter, is checked or calibrated as shown in Fig. 10. The meter being calibrated, represented at the right, is connected in series with another meter which is to be used as the standard for comparison, and with a source of current whose value may be varied over the range of the meter being calibrated. The current is adjusted to bring the pointer of the meter being calibrated to

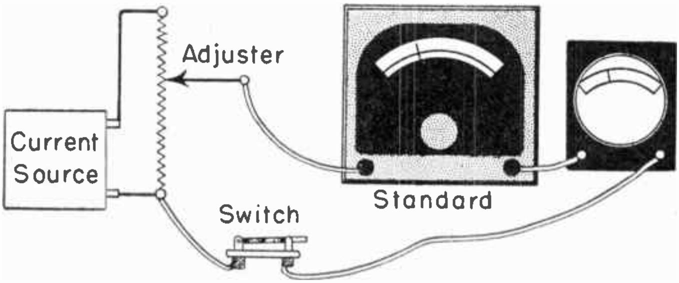


Fig. 10.—Connections for calibration of a current-indicating meter.

various points on the scale. At each point the difference between this reading and the reading of the standard is noted and recorded. A switch is provided so that, before closing the circuit for checking, the meter pointer may be adjusted to the zero position if necessary. Before the final reading at each test point, the meter being calibrated may be lightly tapped to make certain that its pointer assumes its position for that value.

A voltmeter is checked or calibrated as shown in Fig. 11, being connected in parallel with a suitable standard voltmeter, and with both meters connected across a source of adjustable voltage whose value may be varied to cover the range of the meter on test. Before the switch is closed, the meter being checked is examined for zero position of its pointer and a correction is made with the zero adjuster screw-head if necessary. The voltage is adjusted to bring the pointer of the meter on test to various points on its scale, and at each point the indication is compared with the reading of the standard. A record of the variations may be made. The meter on test may be tapped lightly before taking the final readings which are recorded.

Unless the standard, the meter on test, or both, have shielding cases they should be turned to several positions in relation to each other while both are indicating. If this turning causes the readings to vary, the magnetic fields are too close and the meters should be moved farther apart for all checks.

Meters which do not have shielding cases, and which are to

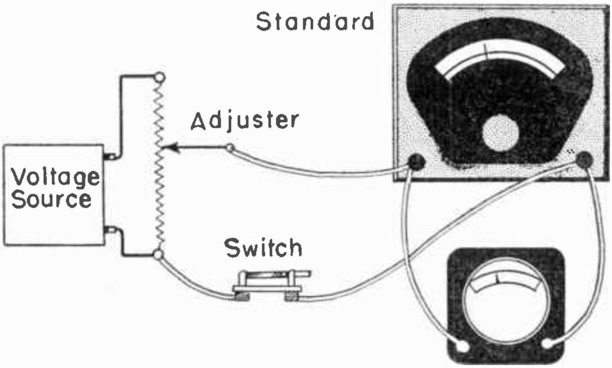


Fig. 11.—Connections for calibration of a voltmeter.

be mounted in panels or boxes of steel or iron, should be calibrated while inserted in a sheet of steel or iron of generally similar kind, of the same thickness, and with the same size of opening or recess as will be found in the final mounting. Nonmagnetic panels usually have little effect on calibration. Most meters which have iron or steel cases, which are in place during calibration, may be used in any type of panel without affecting the correctness of their indications.

Alternating-current types of meters are preferably calibrated on alternating voltages and currents, and by making comparisons with an a-c standard meter. The meters should be turned to various relative positions to note the effects, if any, of their fields on each other. The separation must be such that there is no magnetic interaction.

If an a-c standard and adjustable a-c source are not available, radio types of a-c meters may be checked on direct potentials or current with d-c standard meters. Two readings are taken at each test point, one reading with the potential or current in one direction or polarity, and the second with polarity reversed. If these two readings do not vary by more than a few per cent, their average may be taken as the alternating value and so recorded for calibration when the tested meter is a thermocouple type or a dynamometer type. Such average readings on repulsion vane meters may be less accurate than with alternating current. With rectifier meters the average of the two d-c readings will be about 1.11 times the corresponding a-c sine wave values. The averages should be multiplied by 0.90 to obtain the equivalent sine wave values. Thermocouple meters may be checked on power-line frequencies, such as 60 cycles, and the calibration used at frequencies up to several hundred kilocycles.

Meter Adjustments.—Until you have had much practical experience in adjusting or repairing the internal working parts of meters, and unless you have the highly specialized tools required for such work, the safest rule is never to remove a meter from its case and to have all internal adjustments and repairs made by those competent to handle them correctly. If you are ready to discard a certain meter, or if it is damaged beyond hope of economical repair, it will be interesting to take the instrument apart and to experiment with adjustments. Some of the difficulties involved may be realized from the statement that in many of the smaller types of radio meters of the moving coil permanent magnet type, the weight of the moving coil, its bobbin, the two hair springs, two pivots, pointer, and three balance weights comes to a total in the neighborhood of 1/100 ounce. These parts are shown, enlarged, by Fig. 12. Touching a hair spring so lightly that you cannot feel what happens will so distort the shape that an expert may not be able to straighten it for further usefulness.

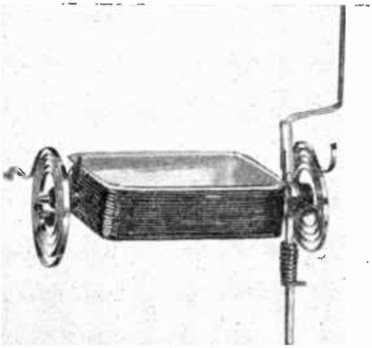


Fig. 12.—A moving coil with its hair springs.

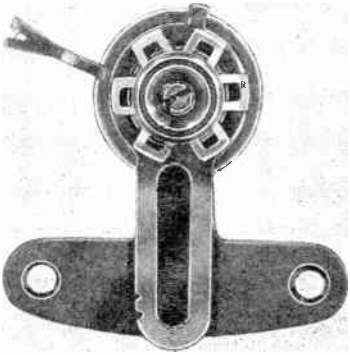


Fig. 13.—A zero adjuster with the jewel screw showing in the center.

In the majority of service type instruments the magnet and movement, also any rectifier, thermocouple, and resistance coils, are attached to the back of the case. The body of the case, in the front of which are the cover glass and zero adjuster, slips over the outside of the edge of the back and is held in place with small screws (usually three) passing through the rear cylindrical edge of the body and into the material of the back or into threaded inserts. With these screws removed, the case body and back may be carefully separated. A meter never should be opened on or near an ordinary work bench where dirt and dust, and especially iron filings, may be present. These filings fly into the spaces between moving coils and magnets, and can be dislodged only with great difficulty. Screws and other small parts should be placed in boxes or trays as removed.

A bent pointer sometimes may be flattened by carefully pressing the spade or lance and its end of the pointer against the surface of the scale plate with a small piece of rather stiff cardboard. Remaining kinks may be taken out by supporting one end of the bent section with some small tool while pressing with a similar tool at various places along the bend. This job is easier if the pointer is held by tweezers such as regularly employed in instrument repairing. The movement usually will be out of balance after the straightening, because it is difficult to restore a pointer to its original shape and position.

If the pointer moves sluggishly, or if it tends to stick in some positions, the cause may be jewel bearings which have become too tight for one reason or another. A pointer that is free will move slightly when you tap the case gently before the instrument is opened, and the pointer will deflect to some extent when you hold the instrument in your hands and rotate it around the axis of the moving coil. With the instrument case removed it should be possible to make the pointer move across its scale by blowing lightly on the pointer.

In most meters, but not all, the jewels are in the inner ends of screws whose outer slotted ends may be seen at the ends of the moving coil. One such jewel screw is visible in the center of the zero adjuster washer pictured in Fig. 13. Fig. 14 shows a somewhat different construction, wherein the jewel screw is held against turning by a hexagon lock nut. Adjustment is made by loosening the lock nut a part of a turn while holding the jewel screw stationary, then holding the lock nut stationary while

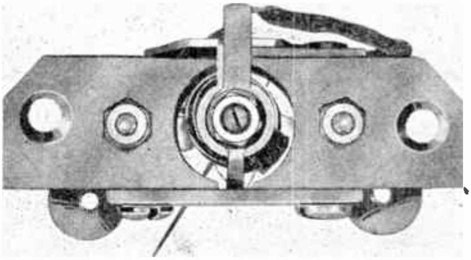


Fig. 14.—A jewel screw held against turning by means of a lock nut.

turning the jewel screw with the screwdriver, then holding the jewel screw stationary while tightening the lock nut.

The easiest way to make readjustment of a jewel bearing is to first loosen the jewel screw until the pointer is very free in its movement. One outward turn of the jewel screw should do this. More turning may let the pivots slip completely out of the depressions in one or both bearings. Then blow lightly on the pointer while slowly tightening the jewel screw until you can note the least perceptible binding of the pointer. Then back the jewel screw out by about one-third to one-half turn and lock it in this position. This adjustment should give the necessary freedom and slight end play to insure free movement of the pointer.

The weight of the pointer, which extends in one direction from the axis of the moving coil, is balanced in most instruments by three additional weights carried on arms which extend outward from the axis as shown at the left in Fig. 15. At the right is a picture showing part of the pointer extending upward, the "tail weight" on its arm extending downward, one of the "cross weights" on its arm extending to the right, and the left-hand cross arm on which there is no weight but on which one might be used.

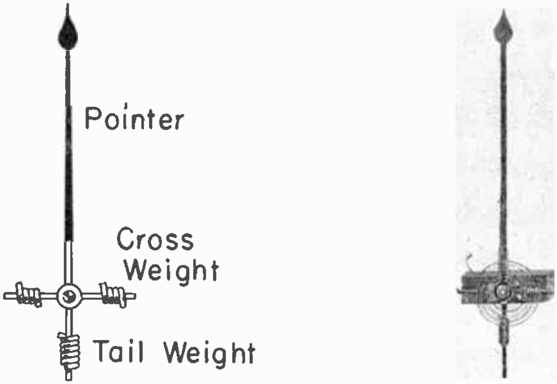


Fig. 15.—Balance weights and arms. The pointer extends upward.

The balance weights are small spirally coiled wires which fit snugly over the balance arms. The spiral turns of the weights give them the properties of an internally threaded cylinder which may be "screwed" back and forth on the arm to move the weights closer to or farther from the coil axis. The weights are easily moved, after plenty of experience, by grasping them with the tweezers while the tweezers are held almost in line with the weight arms. When the tips of the tweezers are held so that they catch on one end of the spiral, turning tends to slightly loosen the turns of the weight so that it moves easily in one direction. Catching the other end slightly loosens the turns for moving in the opposite direction. This is an operation easier to perform after a few trials than to describe.

The first step in balancing is to support the meter with its back and scale plate horizontal while moving the zero adjuster arm to bring the pointer directly over zero on the scale. In this position the unbalanced masses have least effect on pointer position, and the adjuster has maximum effect.

Next, hold the meter so that the back and scale plate are vertical, and tilt the instrument to one side so that the zero point on the scale and the normal zero position of the pointer are about as shown at the left in Fig. 16. Adjust the tail balance weight to bring the pointer exactly on zero of the scale. Continue holding the meter so that the scale and back are vertical, and tilt it to bring zero and the normal pointer position into the relations shown at the center. Adjust the cross balance weights, or the one cross weight when only one is used, to bring the pointer directly over zero on the scale.

The pointer should now stand at zero when the meter is held in its normal position as shown at the right in Fig. 16. However, to secure correct balance, it usually will be necessary to repeat the operations previously described, in the order described, to make the slight re-adjustments needed for good balance.

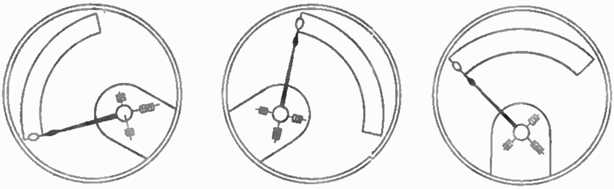


Fig. 16.—Positions in which a movement is balanced.

If the slot or fork in the front zero adjuster is not vertical, or is not on a line between the center of the scale and the axis of the moving coil, place the meter in a horizontal position, move the front zero adjuster into the vertical position mentioned, and set the rear zero adjuster to bring the pointer to zero on the scale.

To reach shunt and multiplier resistors or coils which are mounted within the meter case it is necessary to remove the scale plate, and usually the magnet as well. In some designs the movement, magnet, and scale plate may be separated from the back as a unit, leaving the movement (through the hair spring connections) connected to the resistors or coils through flexible leads of some length. The scale plate usually is held in place by two small screws or nuts, which may be taken off to allow sliding the plate from between the pointer and magnet, with the greatest of care to avoid bending the pointer.

If voltmeter multiplier coils have too much resistance, making the meter read too low, turns or parts of turns may be taken off the coil or coils to get a correct reading at full scale. Only a little wire should be removed at one time. If the resistance is too low, making the meter read high, it is necessary to put in a new coil having more resistance, or to replace a fixed resistor of any type. Internal shunt coils for current meters may be similarly adjusted or replaced. Too much shunt resistance makes the meter read high, while too little shunt resistance makes the meter read low.

Meter calibration often is corrected by varying the strength of the permanent magnet through the operations of magnetizing and demagnetizing. Magnetic strength is increased by magnetizing when the readings are too low and when the pointer should move farther over its scale for a given current in the moving coil. This work is done with magnetizers consisting of strong electromagnets actuated from direct current.

After the magnetic strength has been increased, the magnet is replaced in the meter and a calibration test is made by the methods shown in Figs. 4 and 5. If the magnetization has been more than enough, as it always should be, the magnet then is partially demagnetized until indications are correct. Demagnetizing is done with an electromagnet actuated by alternating current. The demagnetizer, attached to a handle and supplied with current through a flexible cord, is brought near the gap of the permanent magnet on the meter. Indications of the pointer will decrease. The demagnetizer must be handled carefully, both as to position and time of application, to avoid bringing the indications too low. This would call for re-magnetizing and starting all over again.

The effective strength of the permanent magnet is adjusted in some meters by use of a magnetic shunt which diverts more or less of the magnetic field from the space in which the moving coil rotates. The principle is shown by Fig. 17. The shunt is a piece of soft iron, usually tapered at one end. The farther the shunt extends across the gap between magnet poles, the more of the magnetic flux will pass through the shunt and the less through the space where the moving coil rotates. This will lower the pointer position and scale indication for any given potential or current being measured. Moving the shunt out of the gap will raise the indications.

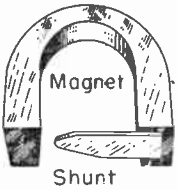


Fig. 17.—Principle of the magnetic shunt.

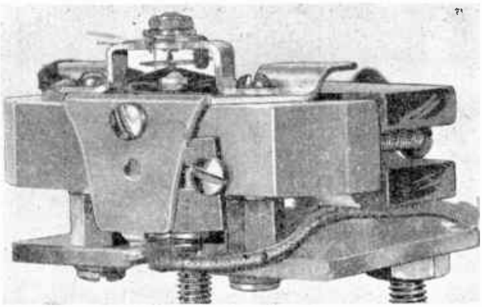


Fig. 18.—A magnetic shunt in place on a meter (Beede instrument).

Fig. 18 shows a movement and permanent magnet with a magnetic shunt. The right-hand end of the shunt may be seen extending from the movement frame. The shunt is held in its adjusted position by a screw passing through a slot in the shunt and into one of the pole pieces.

REVIEW QUESTIONS

1. Is it necessary to open the measured circuit when using a voltmeter?, when using an ammeter or other current meter?
2. When the accuracy of a meter is specified as a certain percentage, does this percentage apply everywhere on the scale? If not, where does the percentage apply?
3. What is the total internal resistance of a voltmeter whose sensitivity is 5,000 ohms per volt and whose full scale reading is 100 volts. What is the resistance of a 500-volt meter having sensitivity of 1,000 ohms per volt?
4. When a voltmeter is connected across a load does voltage across the load increase or decrease? Does current in the load increase or decrease?
5. Explain how you would determine whether a meter is being affected by magnetic fields in the space around the meter?
6. When a resistor is used to protect a current meter is the resistor connected in series or in parallel with the meter? How is a resistor connected for protection of a voltmeter?
7. If the pointer of a meter becomes bent would you correct it by changing the zero adjustment?
8. When calibrating a voltmeter is this meter connected in series or parallel with the standard voltmeter. Which connection is used for calibrating a current meter?

Chapter 3

MEASUREMENTS WITH DIRECT CURRENTS AND LOW FREQUENCIES

Many measurements of the properties of radio circuits and devices may be made with relatively simple equipment and with energy furnished by sources of direct or low-frequency alternating potentials and currents. Properties thus measured include resistances of conductors and insulation, approximate values of inductance and capacitance, reactances or impedances, and power consumption. These measurements will indicate the performance to be expected in circuits operating with direct currents, with power line a-c frequencies, and, in many cases, with audio frequencies. Methods of checking high-frequency performance are described in another chapter.

Resistance Measurements.—The following tests are of ohmic resistance, which is the resistance to flow of direct or low-frequency alternating currents where the only energy losses are due to heating, and not to the presence of inductance, capacitance, and such things as skin effect, which cause additional losses at high frequencies.

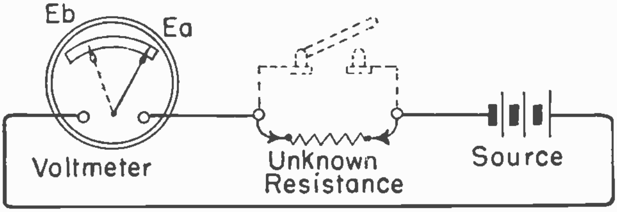


Fig. 1.—Measuring an unknown resistance with a voltmeter.

Resistance may be measured with a d-c voltmeter of known resistance and any source of direct potential, such as dry cells, with the connections of Fig. 1. The source is of such potential difference as may be measured by the meter without the pointer going off scale. The voltmeter, the unknown resistance, and the source are connected in series. A switch may be arranged to short circuit the unknown resistance. Two voltage readings are taken; one (*Ea*) without the unknown resistance and with the meter connected directly across the source, and the other (*Eb*) with the unknown resistance in series.

Designating the voltmeter resistance as *Rm* and the two voltage readings as *Ea* and *Eb*, either of the following formulas may be used to determine the value of the unknown resistance.

$$\text{Unknown resistance} = \frac{\text{Rm}}{\text{Eb}} \times (\text{Ea} - \text{Eb})$$

$$\text{Unknown resistance} = \text{Rm} \times \left(\frac{\text{Ea}}{\text{Eb}} - 1\right)$$

As an example, supposing that we have a voltmeter whose resistance is 50,000 ohms, and that the two voltage readings are 45 and 29. Using these values in the first formula we have,

$$\text{Unknown resistance} = \frac{50000}{29} \times (45 - 29) = 1725 \times 16 = 27{,}600 \text{ ohms}$$

With the second formula we have,

$$\text{Unknown resistance} = 50000 \times \left(\frac{45}{29} - 1\right) = 50000 \times (1.552 - 1)$$

$$= 50000 \times 0.552 = 27{,}600 \text{ ohms}$$

It is assumed that the potential difference furnished by the source does not change appreciably between the two readings. The range or full-scale of the voltmeter makes no difference in taking the measurements, although better accuracy may be expected if the reading without the unknown resistor in series is well toward the high end of the scale.

The same principle may be employed with a current meter; ammeter, milliammeter, or microammeter, as shown by Fig. 2. To one of the meter terminals is connected a protective resistor of such value that the pointer will stay on scale when the meter is directly in series with this protective resistor and the source, without the unknown resistance in the circuit. For an ammeter the ohms for the protective resistor are found by dividing the volts of the source by the full scale amperes of the meter. For a milliammeter divide the full-scale milliamperes into 1,000 times the source volts, and for a microammeter divide the full-scale microamperes into 1,000,000 times the source volts. One reading (*Ia*) is taken without the unknown resistance in circuit, and a second (*Ib*) with the unknown resistance connected in series.

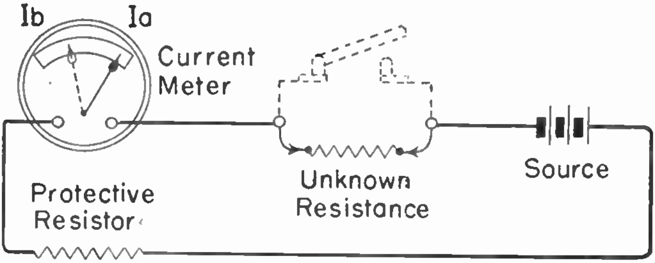


Fig. 2.—Measuring a resistance with a current meter.

Designating the meter resistance by *Rm*, the protective resistance by *Rp*, and the two current readings by *Ia* and *Ib*, either of the following formulas may be used to determine the unknown resistance.

$$\text{Unknown resistance} = \frac{\text{Rm} + \text{Rp}}{\text{Ib}} \times (\text{Ia} - \text{Ib})$$

$$\text{Unknown resistance} = (\text{Rm} + \text{Rp}) \times \left(\frac{\text{Ia}}{\text{Ib}} - 1\right)$$

As an example, supposing that we have a 1-milliampere meter whose internal resistance is 60 ohms, that we use one dry cell (about 1.5 volts) and a protective resistor of 1,500 ohms. Assume that the two current readings are 0.95 milliampere and 0.60 milliampere. By placing these values in the first formula we have,

$$\text{Unknown resistance} = \frac{60 + 1500}{0.60} \times (0.95 - 0.60)$$

$$= \frac{1560}{0.60} \times 0.35 = 2600 \times 0.35 = 910 \text{ ohms}$$

The second formula will be found to give the same answer, 910 ohms. Were we to neglect the resistance of the meter, and work with only the protective resistance value in the formulas, the answer would come to 875 ohms. The error, 4 per cent, is the same as the percentage which the meter resistance forms of the protective resistance. If we use a higher protective resistance to lessen the error when neglecting meter resistance, the readings will be lower on the scale, where the accuracy of readings is less on a percentage basis, and nothing will be gained. If you don't know the meter resistance, and thus must neglect it, add about 5 per cent to the computed resistance to get an approximately correct value.

A well known method of measuring resistance calls for measuring current through the unknown with a current meter, measuring potential drop across the unknown with a voltmeter,

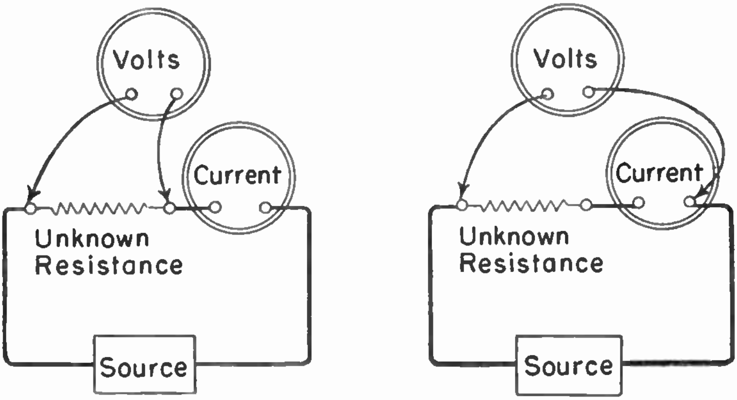


Fig. 3.—Measuring resistance with a voltmeter and a current meter.

and dividing the potential drop by the current to determine the unknown resistance. The two possible connections of the meters are shown in Fig. 3.

At the left the voltmeter is connected only across the unknown resistance, and correctly measures the potential drop. But the current meter will indicate the sum of the currents in the unknown resistance and in the voltmeter, since these latter two are in parallel with each other, and each is carrying current. If you know the resistance of the voltmeter, divide its full-scale volts by this resistance to find the full-scale current for this meter. Then divide the indicated volts by the full-scale volts, and with the fraction thus obtained multiply the full-scale voltmeter current. The result will be the current value which should be subtracted from the reading of the current meter to find the current in the unknown resistance. Dividing the indicated voltage by this correct value of current will give the resistance of the unknown.

At the right in Fig. 3 the voltmeter is connected across both the unknown resistance and the current meter. Now the current meter reads the correct value of current in the unknown, but the voltmeter is indicating the drop across both the unknown resistance and the current meter. If you know the resistance of the current meter, multiply it by the indicated current to find the drop across this meter. Then subtract the computed drop from the voltage read on the voltmeter to find the drop across the resistor alone.

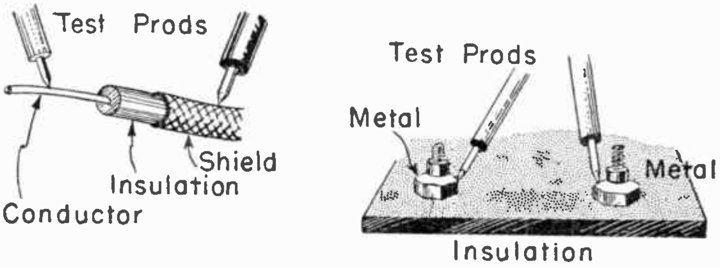


Fig. 4.—Checking the resistance of insulation.

If you make no corrections, greater accuracy will be secured on small unknown resistances with the arrangement at the left, and on large resistances with the arrangement at the right. Always make sure that the current meter will not be burned out. Divide the source potential, in volts, by the smallest possible resistance in the unknown. The result, amperes, must be less than the full-scale range of the current meter in *amperes*.

The test methods illustrated by Figs. 1 and 2 may be used for checking the approximate resistance of insulation, or for making rough comparisons of the effectiveness of insulations. The test prods, represented by arrowheads in Figs. 1 and 2, are applied on opposite sides of the insulation in ways such as illustrated by Fig. 4. At the left a check is being made of resistance of insulation between the conductor and outer metallic shield of a cable. At the right a check is being made of resistance between two metal terminals or other metal inserts in an insulating support.

For insulation tests the voltage of the source should be about equal to the normal working voltage of the tested apparatus, or higher. The accuracy of this method is not so very great, because the second reading (Eb or Ib) will be near the lower end of the meter scale where the percentage errors may be large.

Polarity Tests.—A convenient way to determine which of two points is positive and which negative with reference to the other is to connect to the points a d-c voltmeter of range high enough for the existing potential difference. With the positive terminal of the meter connected to the positive point in the tested circuit, and negative to negative, the voltmeter pointer will move up on its scale. With reversed connections the pointer will go off scale to the left of zero.

Polarity of two exposed wires or leads may be checked by dipping them into a glass of water in which has been dissolved about a half-teaspoonful of table salt, or a little vinegar. The wire on which more bubbles appear is negative with reference to the other wire. If equal quantities of bubbles appear on both wires, the circuit is carrying alternating current. Do not touch the wires together under the water, since this might cause a short circuit.

Polarity may be checked with a small neon glow lamp provided it is possible to determine which of the lamp terminals connects to which of the two plates. On direct current only the plate connected to the negative will glow. On alternating current both plates will glow.

Neon lamps are available in sizes taking from $\frac{1}{25}$ to 3 watts on

115-volt circuits. This means a range of currents from 350 microamperes to 26 milliamperes to light the lamps to full brilliancy. Small sizes of these lamps will show a noticeable glow on five or ten microamperes. Glow is due to ionization of the neon gas. Ionization does not commence until the potential difference between plates is about 85 to 95 volts. Thus the glow will not commence on direct potential until such voltage is reached. The corresponding peaks of alternating potential occur with effective a-c potentials of 60 to 67 volts for starting the glow. The glow does not stop until the applied potential is well below the starting potential.

Circuit Testers.—There are several simple types of apparatus for checking short circuits, accidental grounds, open circuits, and abnormally high resistance. Such testers may be grouped in two general classes. In one class the tester consists only of an indicator for potential or current. This indicator may be a voltmeter, a neon lamp, a small incandescent lamp, or a headphone. The other class includes testers consisting of any of the indicators just mentioned and a self-contained power supply, which ordinarily is one or more dry cells. The indicator and power supply are connected in series with test leads or prods.

The power supply for a voltmeter may be a battery giving about half-scale deflection. Incandescent lamps of the pilot lamp or flash lamp variety require one to six dry cells, or an equivalent battery, depending on the rated lamp voltage. Headphone operation may be with one or more dry cells. A neon lamp would require a 90-volt B-battery, consequently is seldom used in a self-contained tester.

An open-circuited point may be located with an indicator alone as shown by Fig. 5. With the line switch turned on to energize the circuit the tester is connected between various points as at the left. Between points where there is no open circuit, but where the circuit is closed, as at *A* and *C*, the tester gives no indication. When across an open point, as at *B*, there is an indication. This assumes that there is but one open point in the circuit.

With the method shown by the right-hand diagram one side of the tester is connected near the beginning of the circuit and left so. The other side of the tester is connected successively to points farther and farther from the first connection. No indication will be given with all connections up to the open point, while indications will be given on all points beyond the open. If there is more than one open point, indications will commence after the last open is passed. With this last fault corrected, the testing is begun over again to locate the next open, and so on.

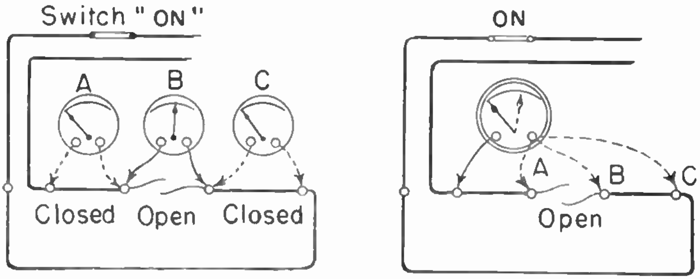


Fig. 5.—Testing for open-circuited points with a test indicator.

Points of abnormally high resistance are located with the same methods used for locating opens. The indicator will show more current where there is low resistance than where resistance is too high.

Short circuits and accidental grounds (a form of short) may be located with only an indicator as shown by Fig. 6. The circuit

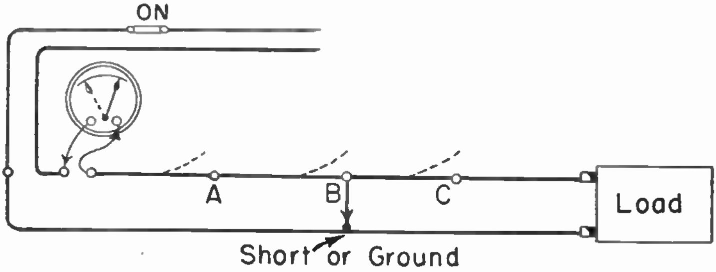


Fig. 6.—Locating shorts and accidental grounds with a test indicator.

is opened near its beginning and the indicator connected in series. The line switch is turned on to energize the circuit, but the indicator will limit the current which may flow through the short. As successive points in the circuit then are opened, leading away from the indicator connection, the indications will become zero at each disconnection until the one following the shorted or grounded point. With this and following points disconnected, the indicator will show current flow.

Open circuits may be located with a self-contained circuit tester as at the left in Fig. 7. The line switch is turned off and the tester is connected across two points as near as possible to the beginning of the circuit. The tester will give no indication until the open circuit has been corrected, after which it will indicate current flow. Abnormally high resistance is located in similar fashion; the tester giving a low indication until the fault is corrected, then giving a full normal indication.

Short circuits and accidental grounds may be located with a self-contained tester as at the right in Fig. 7. The line switch is turned off and the tester connected across two points near the beginning of the circuit, as shown. As successive points leading away from the test connections are opened, the indication will drop to zero at each disconnection until the short or ground has been passed. Thereafter the indication will remain high for all disconnections. As shown by the diagram, the load may be dis-

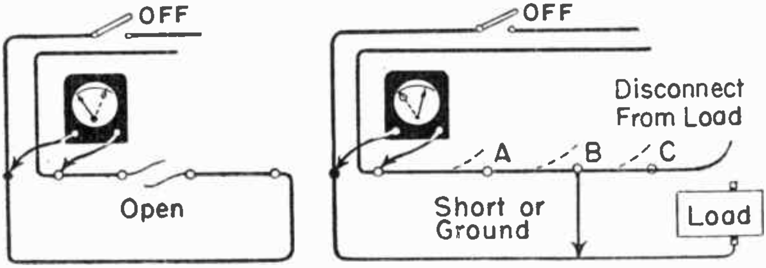


Fig. 7.—Locating circuit troubles with a self-contained tester.

connected at either of its terminals so that current through the load will not cause false indications in case the load current is comparable with that through the short or ground.

If a neon lamp is used as the indicator in a d-c circuit or with self-contained d-c supply, and if there is a capacitor in the tested circuit, the lamp will flash and then go out as the capacitor charges provided the capacitor is not leaky and is not of the electrolytic type. There will be enough continued current through an electrolytic to keep the lamp glowing regardless of the polarity of the capacitor, and if other types of capacitors are shorted or leaky the lamp will continue to glow.

A headphone will give an audible click when connected to a closed circuit, even though the circuit has very high resistance. There will be a click also when the circuit contains a capacitor, unless the capacitance is very small and takes almost no charge with the applied potential. Experience with a headphone tester allows identifying degrees of resistance and large or small capacitances by the loudness or faintness of the clicks.

A self-contained ohmmeter, described in another chapter, is one of the most satisfactory circuit testers. The ohmmeter is used like a voltmeter type of self-contained tester, but indications are of resistances in ohms between the points to which the test leads are attached.

Capacitance Measurement. — Approximate values of capacitance may be determined by use of an a-c voltmeter and an a-c milliammeter, or by the use of an a-c voltmeter alone. The measurements really depend on impedance and reactance, but may be translated into capacitance values quite easily.

One method of making capacitance measurements is shown by Fig. 8. Alternating current is supplied from an a-c line through a transformer. The transformer may be omitted if desired, but then the apparatus being tested must be completely disconnected from the power line to avoid possibility of burnouts. The connections are such that, with the switch opened, the current meter indicates electron flow to the capacitor being tested. It is assumed that the resistance of the meter is negligible in comparison with the reactance of the capacitor, so that the meter does not affect the value of current. When the switch is closed, the voltmeter indicates the potential difference across the capacitor.

Impedance is equal to volts divided by amperes. The resistance in a capacitor is small, so the capacitive reactance may be taken as equal to the impedance. By taking a standard formula for capacitive reactance, and making various substitutions and conversions, we arrive at a formula for microfarads of capacitance in terms of milliampere and voltage readings, and the applied frequency.

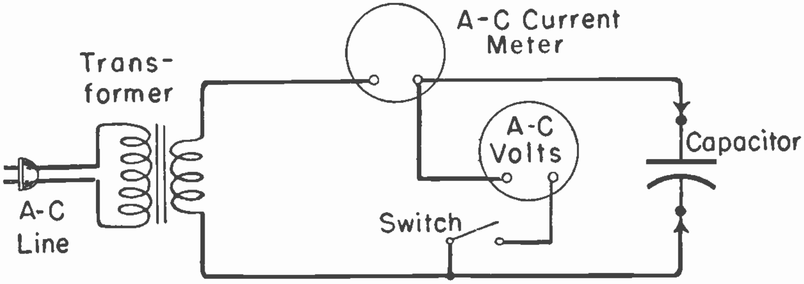


Fig. 8.—Measuring capacitance by means of an a-c current meter and voltmeter.

$$\text{Mfds} = \frac{159.155}{\text{cycles}} \times \frac{\text{milliamperes}}{\text{volts}}$$

For a frequency of 60 cycles the first factor on the right becomes 2.6526, or, close enough for the accuracy of the meters, becomes 2.65. Then we have,

$$\text{Mfds} = 2.65 \times \frac{\text{milliamperes}}{\text{volts}}$$

For a frequency of 50 cycles the factor is 3.18, and for 25 cycles is 6.37. It may be noted that the frequencies of large power and lighting systems are held within very close limits; the accuracy being better than that of most service oscillators; and better than that of meters ordinarily used.

As an example, supposing that the applied frequency is 60 cycles, and that the meter readings are 44 milliamperes and 115 volts. Using these values we have,

$$\text{Mfds} = 2.65 \times \frac{44}{115} = 2.65 \times 0.383 = 1.053$$

Fig. 9 shows an arrangement which permits checking for shorted and open-circuited capacitors, as well as for capacitance. The three-way single-pole switch should be of a spring type normally held closed in position *A*, where the current meter and tested capacitor are short circuited by the switch, and where applied voltage is indicated by the voltmeter. With the switch at *B* the capacitor, milliammeter, and voltmeter are in series on the supply. The high resistance of the voltmeter prevents excessive current. If the voltmeter reads full line or transformer voltage, the capacitor is shorted. If the voltmeter reads zero the capacitor is open circuited. If neither fault is present, the switch is moved to position *C*, which shorts out the voltmeter and leaves the milliammeter and capacitor in series for a current reading. Capacitance is determined from current and voltage readings, and the known frequency, by using the formulas already given.

The tapped secondary of the transformer may be used to apply various voltages. The same thing may be accomplished by a tapped primary, or by an adjustable resistor in series with the primary. The larger the capacitance tested the less should be the applied voltage, in order to keep the current within the range of the milliammeter and to prevent heating the tested capacitor.

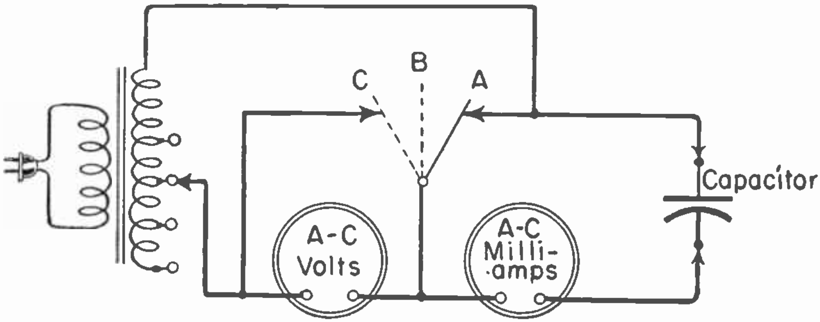


Fig. 9.—A capacitance tester which checks for opens and leaks in capacitors.

Small capacitances require high voltages to get readable current indications. The applied voltage must not be more than $\frac{7}{10}$ of the maximum d-c working voltage of the capacitor, which means a-c peaks or full d-c working voltage. When using various applied voltages it is convenient to have a multi-range voltmeter whose ranges may be selected for the voltage being used.

Capacitance may be measured by connecting the capacitor in series with an a-c voltmeter and a source of alternating current. Because of the reactance or impedance of the capacitor, the meter reading will be lower than when the capacitor is not in the circuit. It is possible to compute scale readings in microfarads when knowing the resistance of the meter, the readings with and without the capacitor in series, and the applied frequency. The formula is complicated, involving multiplication, division and subtraction of squares, and extraction of a square root. It is easier to make tests with known capacitances and mark the scale from the readings obtained.

Fig. 10 shows a capacitance scale above the scale for a rectifier type of a-c voltmeter having a full-scale range of 150 volts and a resistance of 1000 ohms per volt, or 150,000 ohms total. The scale applies when the line voltage is 117. Capacitance readings become very crowded near this applied voltage. They can not be carried to the zero end of the scale, because this end of the scale on a rectifier meter becomes crowded. If an iron vane or dynamometer voltmeter were used, with its current-squared

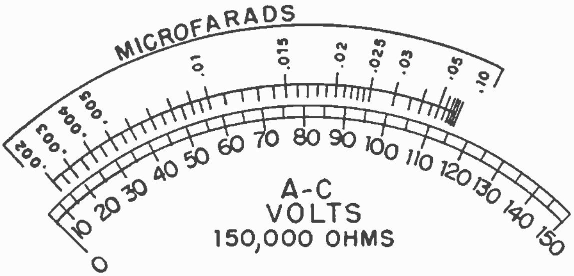


Fig. 10.—A capacitance scale on a rectifier type a-c voltmeter having a range of 150 volts and sensitivity of 1,000 ohms per volt.

scale, the lower end would be so crowded as to bring capacitance values close together. The less the meter resistance the greater may be the capacitances measured, and the higher the meter resistance the smaller may be the measured values. With other factors unchanged, indications for given capacitances are inversely proportional to the meter resistance.

Electrolytic capacitors may be measured with the arrangements of Figs. 8 and 9, but the applied alternating potential must be kept low, around 3 volts, to prevent excessive reverse current through the tested capacitor. Electrolytics of the usual polarized types, designed for use in d-c circuits such as used for filters, normally operate with a large direct potential difference (a polarizing voltage) and a relatively small alternating component. When no polarizing voltage is applied during the test, the alternating current or potential difference should be small. The testing voltage should be applied to the capacitor only long enough to take the readings. Electrolytics normally have small leakage currents in the reverse direction. Small leakages indicated during tests do not indicate a defective capacitor.

Inductance Measurement.—Inductances of iron-cored chokes, loud speaker fields, and transformer windings may be measured by employing the same principles used for capacitance measurements. That is, the indications depend on impedance and reactance, but may be translated into units of inductance, such as henrys.

Inductors have wire windings, in which there may be quite a bit of resistance. Filter choke resistances usually are between 100 and 600 ohms, while speaker field resistances commonly are between 500 and 2,500 ohms. These resistances, in combination with the reactances, may so affect the impedance that meter readings are not proportional to inductive reactance and inductance. Impedance is equal to the square root of the sum of the squares of the reactance and impedance.

It so happens that when we use a testing frequency of 60 cycles, unless the resistance is more than 55 times the number of henrys of inductance the impedance will not exceed the inductive reactance by more than one per cent. Then measurements resulting from impedance may be translated into equivalent inductances with only about one per cent error. As an example, supposing that we are going to measure a choke of about 20-henry inductance. Multiplying 20 by 55 gives 1,100, so unless the choke resistance exceeds 1,100 ohms we may make computations with no corrections and have but slight error.

Chokes and other inductors often are used in circuits where the unit carries direct as well as alternating current. The direct current, if of usual values, partially saturates the iron core and reduces the inductance below that which would exist with only alternating current. The Weston Electrical Instrument Corporation gives the circuit of Fig. 11 for testing the inductance of inductors while they carry direct current. Resistors *R* and *R* are used for regulating the direct and alternating currents from their respective sources. The d-c source may be a radio d-c power supply, and the a-c source the secondary of a transformer. Capacitor *C* keeps direct current out of the a-c voltmeter, which is a rectifier type. The capacitance at *C* should be large enough so that its capacitive reactance is not more than 1/10 of the voltmeter resistance. Direct current is adjusted to the value with which the inductor will operate in service. Current and voltage readings are taken on the a-c meters and used for computing inductance of the inductor.

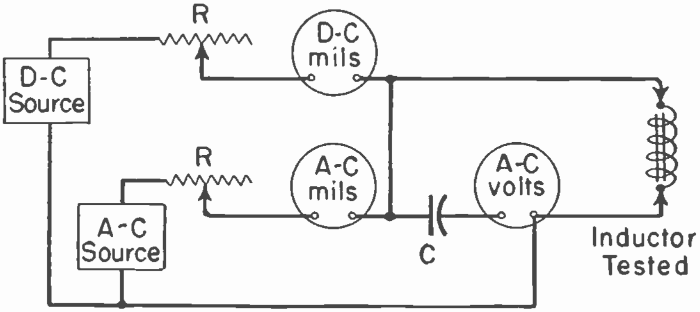


Fig. 11.—An inductance testing circuit with which direct current is put through the inductor during measurement.

The arrangement of Fig. 8 may be used for inductance measurement when the inductor is to carry no direct current, connecting the inductor to be tested in place of the capacitor shown in the diagram.

The formula for inductance in henrys, when the applied frequency is 60 cycles, is,

$$\text{Henrys} = 2.65 \times \frac{\text{volts}}{\text{milliamperes}}$$

For 50 cycles the first factor on the right becomes 3.18, and for 25 cycles is 6.37. The formulas for capacitance and inductance differ only in that current is divided by voltage for capacitance, and voltage is divided by current for inductance.

Power Measurement.—In a direct-current circuit the power in watts may be found from multiplying the number of amperes of current in the load by the number of volts potential drop across the load. Connections for a current meter and a voltmeter are shown by Fig. 12, both meters being of d-c types for d-c circuits.

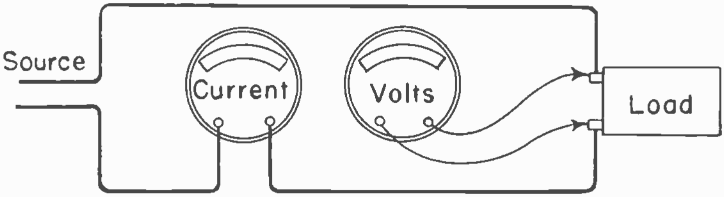


Fig. 12.—Connections for computing power used in a load.

If operation is with alternating current, and if the circuit and the load have neither inductance nor capacitance whose reactances are more than two or three per cent of the ohmic resistance of circuit and load, effective a-c amperes may be multiplied by effective a-c volts, both as measured by ordinary a-c meters, to find the power consumption in watts.

If there are appreciable inductive or capacitive reactances, the product of a-c amperes by a-c volts will be volt-amperes, not watts. The power in volt-amperes is greater than the power in watts. The number of volt-amperes would have to be multiplied by the power factor of the circuit to determine the number of watts. The greater the net reactance as compared with the ohmic resistance the smaller is the power factor fraction. The power factor fraction is equal to the cosine of the angle of lag or lead of alternating current with reference to alternating voltage. Power factor may be found also from dividing the ohms of ohmic resistance by the ohms of a-c impedance.

Impedance may be found from dividing the effective volts drop by the effective amperes of current, as measured in Fig. 12. The ohmic resistance may be measured by using direct current with methods described earlier. Since power is dissipated only in the ohmic resistance of a circuit, and in neither the inductance nor capacitance, the approximate watts of power may be found from multiplying the square of the effective a-c amperes by the ohms of ohmic resistance.

Temperature Measurement. — Because the resistance of conductors commonly used for winding coils increases with rise of temperature it is possible to determine the average rise of temperature inside of a coil by measuring the resistance of the coil at two temperatures. As an example, assume that a coil winding has not been carrying current for a time long enough that the coil temperature is the same as the room temperature, which we shall take as 70° F. Let the resistance of the coil at this temperature be 200 ohms. After carrying current for some time the temperature will rise throughout the coil, and the coil resistance will increase, say to 220 ohms. The approximate internal rise of temperature in the winding may be found from this formula.

$$\text{Temperature rise, °F.} = \frac{\text{hot resistance} - \text{cold resistance}}{0.0022 \times \text{cold resistance}}$$

Placing the assumed values in the formula gives,

$$\text{Temperature rise, °F.} = \frac{220 - 200}{0.0022 \times 200} = \frac{20}{0.44} = 45.45°$$

Then the higher temperature will be equal to the original temperature plus the rise, or 70° + 45.45° = 115.45°

This formula assumes that the coil is wound with annealed copper wire. The factor 0.0022 is the temperature coefficient of resistivity per Fahrenheit degree for such wire. If some other kind of conductor is used, its temperature coefficient may be substituted, being sure that the coefficient is per Fahrenheit degree when temperatures are measured in Fahrenheit degrees. For centigrade temperature measurements the coefficients per centigrade degree would be used.

REVIEW QUESTIONS

1. When measuring an unknown resistance with a 100,000-ohm voltmeter the voltage is 85 without the resistance and 17 with the resistance. Use the formula in this chapter to determine the unknown resistance.
2. Explain how an unknown resistance is measured by using a current meter.
3. When using the voltmeter-ammeter method of resistance measurement, how are the meters connected for measuring low resistances? how connected for high resistances?
4. When using a voltmeter to locate an open circuit will there be a meter reading when bridging parts which are not open or parts in which there is an open?
5. Is capacitance measured by using a source of direct current or one of alternating current?
6. If electrolytic capacitors are tested without a polarizing voltage should the applied alternating voltage be high or low?
7. Describe how resistance of a choke or inductor affects measurements of the inductance; will apparent inductance be more or less than true inductance?
8. Is the inductance of a choke coil the same whether or not the coil is carrying direct current?

Chapter 4

MEASUREMENTS AT HIGH FREQUENCIES

Measurements of the performance and properties of circuits which are to operate at high frequencies have to be made at these frequencies if indications are to represent conditions which actually will exist. High-frequency performance is affected by the following factors.

Reactances of small inductances become high, and of large capacitances become low. Consequently, we deal with inductances and capacitances much smaller than those used at low frequencies. Because all conductors possess inductance, and because there are capacitances between all separated conductors, we find that coils have appreciable capacitance as well as inductance, and that capacitors have appreciable inductance as well as capacitance. The effects of inductance and capacitance exist throughout entire circuits, rather than being concentrated in coils and capacitors as in low-frequency circuits. The inductances and capacitances of test connections, of instruments, of tools and benches, and of your own body, often are greater than the circuit inductances and capacitances with which you are primarily concerned. While we are used to thinking of electron flow (current) as being uniform throughout a single conductor, and of potentials as having steady decreases, the standing waves which may exist at high frequencies cause quite different distribution of both currents and potentials.

With high-frequency methods to be described we may measure self-inductance and mutual inductance, capacitance of capacitors and also distributed capacitances, high-frequency resistances resulting from the several kinds of losses due to these frequencies, and the frequencies of signals.

Resonance Method.—The high-frequency measurements which have been mentioned may be made by resonance methods, employing a circuit which may be tuned to resonance while energized by high-frequency energy from an oscillator. The principle is shown by Fig. 1. The coil in the resonant circuit is *L*. The variable tuning capacitor is *C*. Energy is introduced through the pickup coil which is coupled, adjustably, to a coil of the oscillator. The tuning capacitor should be a "low-loss" type, usually with ceramic insulation. It should be shielded, with the shield connected to the rotor plates, and the shielded side should be grounded. Small transmitter capacitors are suitable.

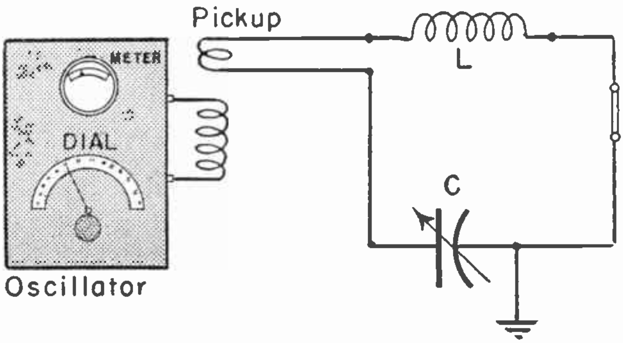


Fig. 1.—How the tuned high-frequency testing circuit is energized from an oscillator.

The capacitance of *C* and inductance of *L* and the pickup combined will depend on the frequency band to be used. If the standard broadcast band is used, the product of maximum capacitance of the capacitor and the total inductance of *L* and the pickup, in micro-microfarads and microhenrys, should be 83,740. To lessen the effects of distributed capacitances, which cannot be controlled or adjusted, it is desirable to use a rather large tuning capacitance, at least more than 300 mmfds. The tuning dial should be of the vernier type, and should have no appreciable backlash.

The oscillator may be of any service type available, or a simple one may be constructed with the circuit shown by Fig. 2. Any triode tube may be used. The capacitance of the tuning capacitor *Ct* and the inductance of the grid coil are chosen to suit the frequency band used. If the standard broadcast band is to be used, these parts may be of the broadcast receiver types. The feedback coil in the plate circuit should have one-third to one-half as many turns as the grid coil, and, preferably, should be adjustably coupled to the grid coil as a means for regulating the strength of oscillations. The pickup coil is the one shown in Fig. 1.

When oscillations commence, and again when they stop, there are changes of grid current and of plate current. These currents, and their changes, may be shown by a grid meter of 200 to 500 microampere range and by a plate meter of such milliampere range as will cover two to three times the normal maximum value of plate current for the tube used. Both meters are of the moving coil permanent magnet type. The grid meter should be bypassed with capacitor *Ca* of at least 0.1 mfd capacitance, and the plate meter by capacitor *Cb* of 1.0 mfd or greater capacitance.

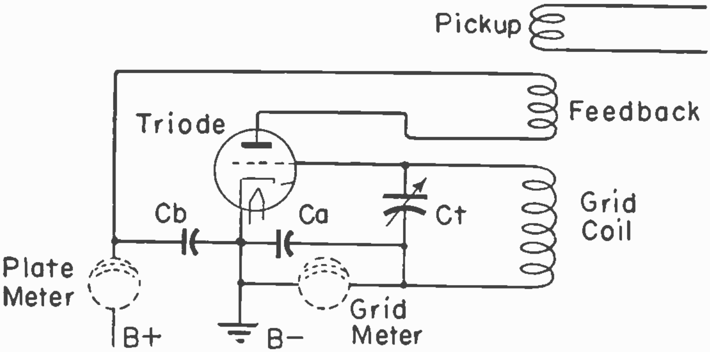


Fig. 2.—A simple oscillator with tickler feedback.

Both grid current and plate current will be relatively high while oscillation continues, and both will drop at the instant in which oscillation ceases. Couplings are adjusted so that tuning the resonant circuit of Fig. 1 to the oscillating frequency of the oscillator will absorb enough energy into the resonant circuit to stop the oscillations, as indicated by decrease of meter reading. By loosening the pickup coupling until oscillations cease through the least possible movement of the resonant circuit tuning dial it will be known that the oscillator and the resonant circuit are tuned approximately to the same frequency. Either a plate meter or a grid meter may be used, but both are not needed. Indications of the grid meter are sharper than those of the plate meter, but there is more danger of burning out the grid meter with incorrect adjustments, or with too rapid change of coupling.

Resonance measurements are, in general, based on comparisons of unknown inductances, capacitances, and resistances with standards. The standard of capacitance sometimes is the tuning capacitor of the resonant circuit, and of inductance is the tuning coil in this circuit. Resistances may be inserted in the circuit by opening the link shown at the right-hand side in the resonant circuit of Fig. 1.

All connections and leads should be as short and straight as possible, and their relative positions and separations must not be altered during successive steps of a measurement. The tuning coil should not be close to any metal parts, and should have the

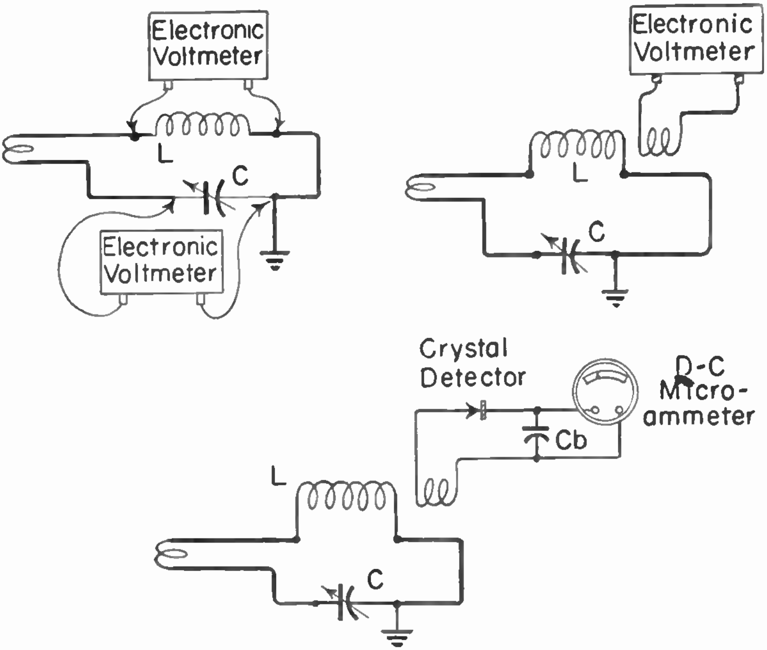


Fig. 3.—Various types of resonance indicators connected to or coupled to the tuned testing circuit.

least possible insulation or dielectric material in its magnetic field.

It is important that coupling of the resonant circuit to the oscillator be kept loose enough that tuning and other changes in the resonant circuit during measurements do not change the oscillator frequency. Change of frequency is indicated by changes of readings on the meters of Fig. 2. When there is such a change during the tests, the coupling should be loosened to get the original readings on the meters. This precaution insures also that there is minimum change of emf induced in the coupled resonant circuit.

Resonance Indicators.—When the testing circuit is tuned to resonance at the operating frequency of the oscillator there is maximum high-frequency current in the testing circuit. If this current is measured, resonance is indicated by maximum indication. The most generally satisfactory resonance indicator is an electronic voltmeter used in any of the ways shown at the top of Fig. 3. The voltmeter may be connected across either the coil L or the tuning capacitor C, as shown at the left. Or, as shown at the right, a coil of a few turns may be connected to the voltmeter and this small coil coupled more or less closely to the tuning coil L. With any of these arrangements resonance is indicated by maximum voltage as indicated by the meter.

An electronic voltmeter consists essentially of a tube operated like a rectifier, or a detector with an indicating meter in its plate circuit. If this voltmeter tube has a control grid, the grid is biased sufficiently negative to prevent flow of grid current. The voltage to be measured is applied to the grid circuit, which is so arranged that the greater the applied voltage the greater will be the change of plate current and of the meter indication. Thus, while taking negligible power from the measured circuit into the grid circuit, there is ample power in the plate circuit to give readable indications with very small measured voltages, and at very high frequencies as well as low ones. Electronic voltmeters are described in detail in another chapter.

At the bottom of Fig. 3 is shown a method of using a crystal detector and a d-c microammeter for a resonance indicator. A fixed crystal such as is available at radio supply stores is satisfactory. The bypass capacitor *Cb* should be of 0.001 mfd capacitance. The meter range preferable should be 100 or 200 microamperes, but may be greater if only high ranges are available. The microammeter shows maximum deflection when the testing circuit is tuned to resonance.

A thermocouple meter may be used for a resonance indicator in any of the ways shown by Fig. 4. At the left the meter is connected to a small coil which is coupled to the tuning coil *L*. At the center the meter is connected across a few of the turns of the tuning coil. At the right the meter is in series with the resonant circuit, between *L* and *C* and on the shielded and grounded side of *C*. The thermocouple is relatively insensitive as compared with the electronic voltmeter or crystal.

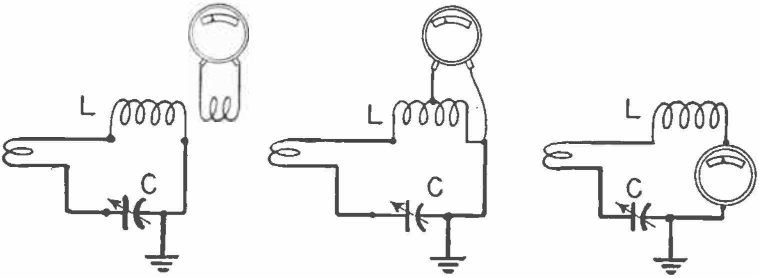


Fig. 4.—Connections of a thermocouple meter used as a resonance indicator.

Note that when there is any choice of positions for resonance indicator connections, the indicator always is placed in or at the grounded side of the tuned circuit.

Unless the tuned circuit has very little high-frequency resistance, the current will remain rather large through quite a range of frequency on both sides of the true resonant frequency, and the point of resonance will have to be determined by careful reading of the indicator. This is the same as saying that the resonance curve has a rather broad top unless the high-frequency losses are small. To avoid the difficulty of reading true resonance, it is possible with some kinds of measurements to work not at the resonant frequency, but at a frequency far enough removed from resonance that there is a steady increase or decrease of the indication as tuning capacitance or inductance is varied.

Instead of tuning exactly to resonance, as at the peak of the current curve in Fig. 5, we might tune to a frequency at *A* or at *B*. Having observed the reading of a resonance indicator, it would be much easier to return later to exactly the same reading were we working at *A* or *B* rather than at the peak, for at these points removed from resonance there would be relatively great change of indication for small changes of frequency. However, when working at resonance there is the advantage, for some measurements, that inductive and capacitive reactances cancel. This is not true when working off resonance, and more care is necessary to avoid large changes in emf induced in the tuned circuit as the tuning is varied. Such changes are reduced by maintaining constant reading of a grid or plate meter in the oscillator.

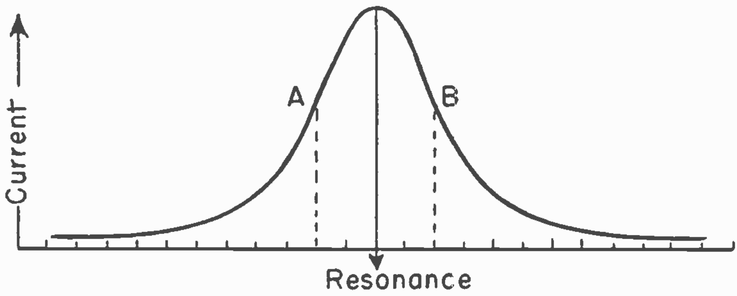


Fig. 5.—There is greater variation of current with frequency slightly off resonance than at resonance.

Inductance Measurement.—One method of measuring inductances is shown by Fig. 6. The method depends on the fact that, for any given frequency, the product of inductance and capacitance remains the same—if inductance is reduced, capacitance must be increased, and vice versa.

A coil of known inductance is connected into the testing circuit, and the circuit is tuned to resonance at the oscillator frequency. The capacitance of the tuning capacitor is noted. Then the coil of unknown inductance is substituted for the first coil, the circuit is again tuned to resonance at the same frequency, which should not have changed in the oscillator, and the new tuning capacitance is noted. Then we use the formula,

$$\begin{matrix}\text{Unknown}\\ \text{inductance}\end{matrix} = \begin{matrix}\text{known}\\ \text{inductance}\end{matrix} \times \frac{\text{capacitance with known inductance}}{\text{capacitance with unknown inductance}}$$

As an example, assume a known inductance of 200 microhenrys, for which the tuning capacitance is 125 mmfds, and a second capacitance setting of 80 mmfds with the unknown inductance in the circuit. Using these values, we have,

$$\begin{matrix}\text{Unknown}\\ \text{inductance}\end{matrix} = 200 \times \frac{125}{80} = 200 \times 1.563 = 312.5 \text{ microhenrys}$$

The unknown inductance will be in the same units as the known inductance, in this case microhenrys. Note that it is not necessary to know the resonant frequency, just so long as both inductors can be tuned to the same frequency.

If the frequency of the oscillator now is changed, and the measurements repeated, the computed unknown inductance will be found to differ from the first value. This results from the fact that the computed inductance is *apparent inductance* rather than true inductance. The apparent inductance of a coil depends on its true inductance and its distributed capacitance. The distribu-

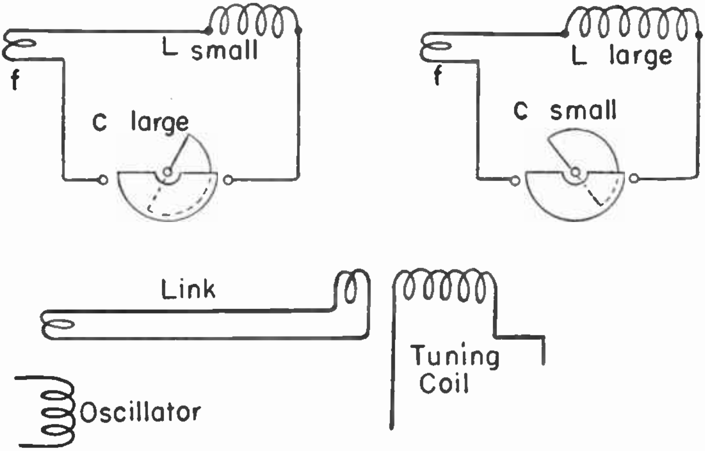


Fig. 6.—Inductance measurement by substitution.

ted capacitance is a relatively fixed quantity, not varied by adjustments of the tuning capacitor. The distributed capacitances of both the known and unknown inductors affect the computed result. If the known inductor has the greater distributed capacitance, the computed unknown inductance will be too high, and if the relative values of distributed capacitances are reversed, then the computed unknown inductance will be too low in relation to the true inductance.

With the pickup coil in series with the measured inductor the two inductances add to form the total inductance in the circuit, and the inductance of the pickup should be subtracted to find the inductance of the measured unit. This complication may be avoided by taking the energy through a link circuit as shown at the bottom of Fig. 6. The link consists of two small coils, one coupled to the oscillator and the other coupled to the tuning coil or measured coil in the resonant circuit. With loose coupling the pickup then has little effect on measured inductance. The link coupling simplifies computations whenever inductances are factors in the formulas.

Another method for measuring an unknown inductance is shown by Fig. 7. The tuning capacitor C must be calibrated in microfarads or micro-microfarads, and the tuned resonant frequency must be known in kilocycles or megacycles. Connections to the coil of unknown inductance are arranged so that it may be disconnected from the tuned circuit for the first test, then connected in parallel with the regular tuning coil for the second test.

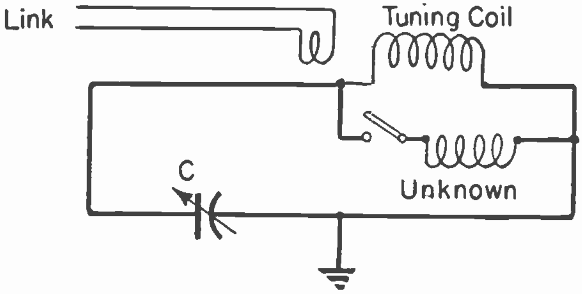


Fig. 7.—Inductance measurement with coils in parallel.

With the unknown coil out of the circuit tune to resonance at a known (oscillator) frequency and note the exact value of tuning capacitance. With the unknown coil in parallel with the regular tuning coil again tune exactly to the same frequency and note the value of tuning capacitance. The second capacitance will be the greater because the coils in parallel have less effective inductance than either one alone. Then use this formula

$$\begin{array}{c}\text{Unknown}\\ \text{inductance,}\\ \text{microhenrys}\end{array} = \frac{25\,330\,000\,000}{(\text{kilocycles})^2 \times (\text{second C, mmfds} - \text{first C, mmfds})}$$

As an example, assume a testing frequency of 1,000 kilocycles, a first capacitance (with one coil) of 250 mmfds and a second capacitance (with both coils) of 320 mmfds. These values in the formula give,

$$\begin{array}{l}\text{Unknown L}\\ \text{microhenrys}\end{array} = \frac{25\,330\,000\,000}{1000^2 \times (320 - 250)} = \frac{25\,330\,000\,000}{1\,000\,000 \times 70}$$

$$= \frac{25\,330\,000\,000}{70\,000\,000} = 361.9 \text{ microhenrys}$$

If frequency is measured in megacycles the factor above the line is divided by one million and becomes 25,330.

To determine the inductive reactance at the resonant frequency the portion of the formula below the line on the right-hand side is the same as for inductance, but the number above the line is made 159 155 000 000. The computed reactance will be in ohms. With the same capacitance values and frequency as in the preceding example, the inductive reactance will be approximately 2,271 ohms.

Capacitance Measurements. — Standard capacitors used for capacitance measurements may be of the air dielectric type, like the usual tuning capacitors, or of the mica or ceramic dielectric type. Unless paper dielectric capacitors are constructed for low inductance their inductances may upset measurements made with them. Fixed mica capacitors, if of good quality and of capacitances not more than about 1,000 mmfd or 0.001 mfd may be used without much error up to frequencies of about 2,000 kilocycles. Units of small capacitance, to about 100 mmfd, may be so used up to about 7,000 or 8,000 kilocycles. Fixed capacitors must be kept free of dust and moisture between terminals. Spaces between plates of air capacitors may be freed of dust by using a pipe cleaner; taking care not to bend the plates of a calibrated unit.

Capacitances which affect the measurements include capacitances between all connecting wires, shields, frames, and grounded objects. These capacitances are lessened by using bare (uninsulated) wire connections of small diameter. Variations of the capacitances during steps of a test are reduced by keeping all connections in the same relative positions as changes are made, and by not changing the lengths of any of the connections. Long, fixed leads are preferable to short ones which may be moved about. When two air-dielectric capacitors are used in the same tuned circuits, as in measurements by comparison, the two rotors should be connected together and to ground.

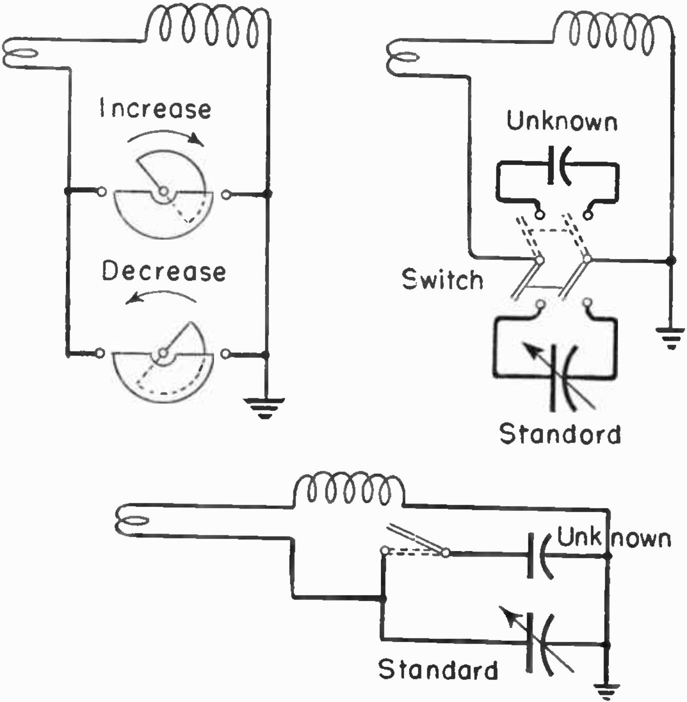


Fig. 8.—Three methods for measuring capacitance.

Three methods of measuring unknown capacitances are shown by Fig. 8. At the upper left the unknown capacitance is connected in parallel with a standard capacitor calibrated in capacitance values. Adjust the capacitance of one unit to near its maximum value, and the other to near its minimum. Set the oscillator frequency to cause an indication of resonance. Now change the capacitance of the standard by some measured value, such as 10 or 20 mmfd. Vary the capacitance of the unknown until there again is resonance at the oscillator frequency, which should not have changed. The change of capacitance in the unknown is equal to the change of capacitance previously made in the standard. This is a method used for calibrating variable capacitors of unknown capacitance.

When the standard has been varied to the limit of its capacitance in one direction, a new oscillator frequency may be used to permit an additional series of comparisons, using a higher frequency if the adjusted capacitance has become minimum, or a lower frequency if it has become maximum.

At the upper right in Fig. 8 the standard and unknown capacitances are compared by alternately switching them into the tuned circuit. With the double-pole double-throw switch closed to the terminals of the unknown unit the oscillator is tuned to a frequency at which resonance is indicated. Then the switch is closed on the standard capacitor and this unit is adjusted to again cause a resonance indication at the same frequency. The capacitance of the standard capacitor now is the same as that of the unknown. If the unknown is a variable capacitor, its capacitances at various settings may be measured by comparing it with the standard at each setting. The lengths and shapes of leads from the switch to the two capacitors should be alike or symmetrical, so that both sets of connections may have the same capacitances. If only one or two checks are to be made the throwover switch may be omitted and the two capacitors connected successively to the same set of leads coming from the tuning and pickup coils.

At the bottom of Fig. 8 the unknown capacitance is placed in parallel with the standard calibrated capacitor and a switch is connected in series with the unknown so that it may be cut into or out of the circuit. With the unknown switched out of the circuit the standard capacitor is adjusted to some capacitance near its minimum and the oscillator is tuned to cause an indication of resonance. Then the unknown is switched into the circuit and the standard again is tuned to cause a resonance indication at the unchanged oscillator frequency. The difference between the two capacitances at which the standard has been set in the two tests is the capacitance of the unknown unit.

Distributed Capacitance.—One method of determining the distributed capacitance of a coil or other circuit element is shown by Fig. 9. The unit whose distributed capacitance is to be measured is connected into the resonant testing circuit instead of the regular tuning coil. The oscillator then is tuned to a frequency less than half of its maximum frequency range, and the capacitor in the testing circuit is adjusted to cause a resonance indication at this frequency. The value of tuning capacitance is noted. We shall call this capacitance *C1*. Then the oscillator is tuned to twice the first frequency. For instance, were the first frequency to be 600 kc the second would be made 1,200 kc. The capacitor in the testing circuit then is adjusted to cause a resonance indication at this higher frequency, and the value of tuning capacitance is noted. We shall call it *C2*. Now the two measured capacitances are used in the following formula for distributed capacitance.

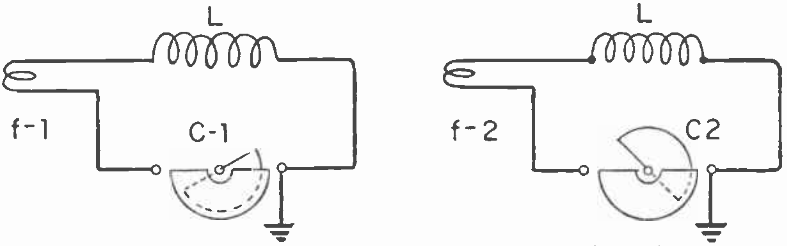


Fig. 9.—The testing setup for measurement of distributed capacitance.

$$\text{Distributed capacitance} = \frac{C1 - (4 \times C2)}{3}$$

Supposing that measured capacitance *C1* is 215 mmfd and that *C2* is 48 mmfd. With these values placed in the formula we have,

$$\text{Distributed capacitance} = \frac{215 - (4 \times 48)}{3} = \frac{215 - 192}{3} = \frac{23}{3}$$
$$= 7.67 \text{ mmfd.}$$

The distributed capacitance will be in the same units as the measured tuning capacitances, which in this case are micro-microfarads.

The second measurement of tuning capacitance may be made by leaving the oscillator tuned to the original frequency, then tuning the testing circuit to the second harmonic frequency. Oscillators of types generally used in these tests produce not only the frequency to which they are tuned, called the fundamental frequency, but many higher frequencies which are exact multiples of the fundamental. These multiples are called harmonic frequencies or harmonics. When an oscillator is tuned to 500 kilocycles, as an example, it will produce and emit frequencies of 500, 1,000, 1,500, 2,000, 2,500 and still greater numbers of kilocycles, all of which are exact multiples of the 500-kc fundamental.

A little earlier we discussed measurement of inductances, or self-inductances; all of the computed values being those for apparent inductance. If the apparent inductance is computed for two frequencies, and the corresponding tuning capacitances are noted, it becomes possible to compute the distributed capacitance from these values used in the following formula. For the higher tuned frequency the apparent inductance is denoted by $L1$ and the tuning capacitance by $C1$. For the lower tuned frequency the apparent inductance is $L2$ and the tuning capacitance $C2$.

$$\text{Distributed capacitance} = \left(\frac{\text{L1}}{\text{L2}} - 1\right) \times \frac{\text{C2} \times \text{C1}}{\text{C2} - \text{C1}}$$

The distributed capacitance will be in the same units as the measured tuning capacitances.

As an example, assume that when tuned to a higher frequency, such as 1,500 kc, the apparent inductance $L1$ is 125.0 microhenrys and the tuning capacitance $C1$ is 90.1 mmfds, and that when tuned to a lower frequency, such as 1,000 kc, the apparent inductance $L2$ is 117.9 microhenrys and the tuning capacitance $C2$ is 200.0 mmfds. With these values in the formula we have,

$$\begin{aligned}\text{Distributed capacitance} &= \left(\frac{125.0}{117.9} - 1\right) \times \frac{200 \times 90.1}{200 - 90.1} \\ &= (1.06 - 1) \times \frac{18020}{109.9} = 0.06 \times 164 \\ &= 9.84 \text{ mmfd.}\end{aligned}$$

If the distributed capacitance has been computed, its value may be used together with that of apparent inductance and tuning capacitance for the higher frequency to determine the true inductance, as follows.

$$\text{True inductance} = \frac{\text{L1}}{1 + \dfrac{\text{distributed capacitance}}{\text{C1}}}$$

If this formula is used with values employed in preceding examples the true inductance will be found as 114.5 microhenrys for the coil having distributed capacitance of 9.84 mmfd.

High-frequency Resistance.—The high-frequency resistance of any conductor, or of the conductors in any piece of apparatus, is the value of a resistance which, if used in the circuit, would cause the same total energy loss or dissipation as results from skin effect, eddy currents, dielectric losses, emf's induced in other circuits, and everything else that happens at high frequencies and not at low frequencies.

When resistors are used as standards for comparison or substitution these standards must have but little increase in energy loss at high frequencies. Adjustable resistors such as found in high quality decade resistance boxes are satisfactory at frequencies as high as 50 to 100 kilocycles, but single straight wires are used at higher frequencies. The higher the frequency the less must be the diameter of these wires, and the lower their d-c resistance the smaller must be their diameter for use at high frequencies. For examples, at 3,000 kc copper wire should be no larger than number 42 gage (0.0025 in. diam.) and Manganin no larger than 28 gage (0.0126 in diam.)

Since high-frequency resistance increases with frequency, the high-frequency resistances measured and computed exist only for the frequency used during tests.

One method of measuring high-frequency resistance is shown by Fig. 10. It is called the *substitution method.* This way of making measurements is not particularly accurate, but it is rapid and fairly satisfactory for getting approximate values. The part having the unknown resistance is connected in series with the regular testing circuit. The circuit is tuned to resonance, and the reading of the resonance indicator is noted. Now the unknown is taken out of the circuit and the resistance standard inserted in its place. This may be done with a double-pole double-throw switch. The circuit is again tuned to resonance at the original oscillator frequency, and the resistance standard is adjusted to obtain the same reading on the resonance indicator as before. The adjusted resistance of the standard is assumed equal to the high-frequency resistance of the unknown at the frequency employed.

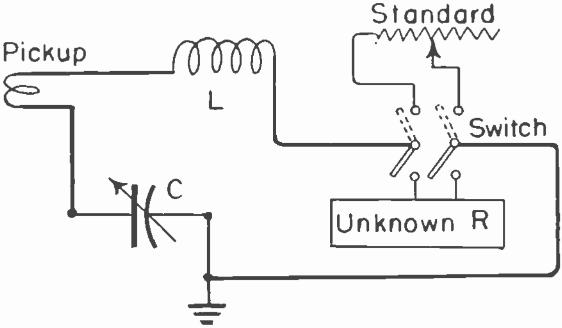


Fig. 10.—High-frequency resistance measurement by substitution.

Because addition of resistance of a tuned circuit broadens the resonance peak, results may be more accurate if the substitution is used with off-resonance indications as explained in connection with Fig. 5. When this is done the oscillator current, as shown by a grid or plate meter, should be the same for both measurements. If the current changes it should be readjusted by varying the coupling for feedback in the oscillator or by varying the oscillator plate voltage. Otherwise the difference between induced emf's will cause larger errors.

Another method, called the *resistance variation method,* is shown by Fig. 11. Here the standard resistance remains in series with the tuning coil, pickup coil, and tuning capacitor of the resonant testing circuit. It is arranged that the unknown resistance may be cut into series with the testing circuit, or the circuit closed with the unknown omitted. The resonance indicator must be of such type that its indications are of current in the tuned circuit, or are directly proportional to current. The indicators shown at the upper left in Fig. 3 and at the right in Fig. 4 give suitable readings.

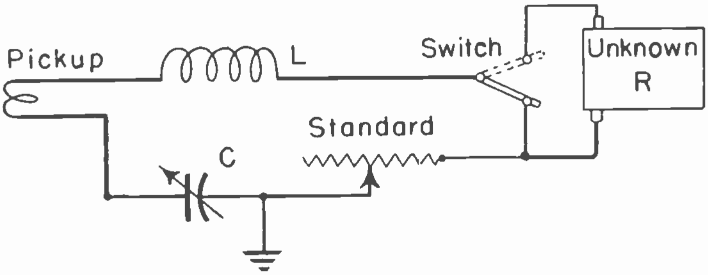


Fig. 11.—Measuring high-frequency resistance by resistance variation.

Resistances of the tuned testing circuit are computed under two conditions; first with the unknown resistance in the circuit, second with the unknown out of circuit. The first resistance will be the higher. The difference between the two resistances is assumed to be the high-frequency resistance of the unknown at the frequency employed.

Make the first resistance measurement thus: With the unknown resistance in the circuit, set the standard at its zero or minimum resistance, tune to resonance, and note the reading of the indicator in either volts or current. Then increase the resistance of the standard, keeping the circuit tuned to resonance, and note the reading of the indicator with this greater resistance in use. Then the circuit resistance is found with the following formula, in which the values are indicated by the listed letter symbols.

Ra Lower resistance of standard, in ohms, when set at zero or minimum.
Rb Higher resistance of standard, in ohms.
Ia Indicator reading, voltage or current units, when standard has zero or minimum resistance.
Ib Indicator reading, same units as before, when standard has higher resistance.

$$\text{Circuit resistance} = (\text{Rb} - \text{Ra}) \times \frac{\text{Ib}}{\text{Ia} - \text{Ib}}$$

For example, assume that the standard resistance is increased from 3 ohms to 5 ohms, and that the corresponding readings of the resonance indicator are 8.6 volts and 2.3 volts. These values in the formula give,

$$\text{Circuit resistance} = (5 - 3) \times \frac{2.3}{8.6 - 2.3} = 2 \times \frac{2.3}{6.3} = 0.73 \text{ ohm}$$

This, of course, is the resistance of the circuit as it would exist without any standard resistance in series.

Now the unknown resistance is placed in series, as by moving the switch of Fig. 11 to its upper position. The tests are repeated while keeping the circuit tuned to resonance at the original fre-

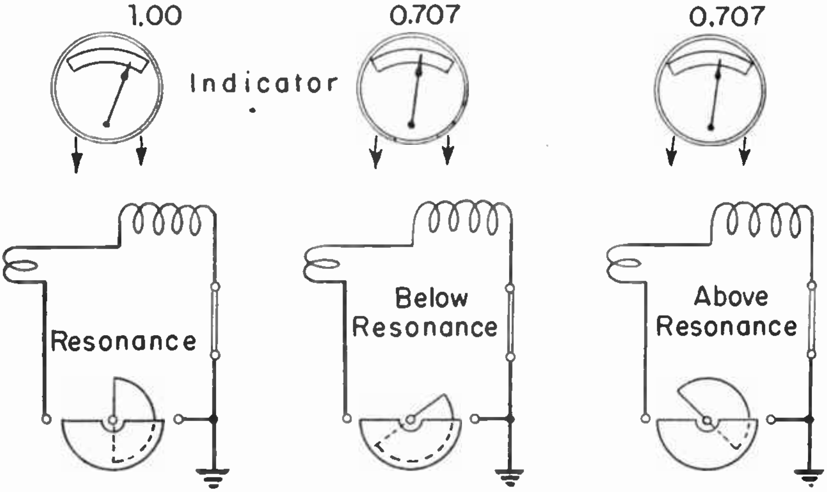


Fig. 12.—High-frequency resistance measured by reactance variation.

quency, and with no change of current in the oscillator. That is, we take readings of the resonance indicator in voltage or current units with some low value of resistance in the standard, and then with a higher value of resistance in the standard. These new values are used with the same formula to determine the circuit resistance with the unknown in series. Subtracting the earlier circuit resistance, without the unknown, from this circuit resistance with the unknown will give the high-frequency resistance of the unknown for the frequency being used.

Still another way of measuring high-frequency resistance is called the *reactance variation method.* This method is considered better than the resistance variation method at frequencies higher than 1,000 kilocycles, although for lower frequencies the values determined may be less accurate with reactance variation than with resistance variation. The reactance variation method depends on tuning to resonance and noting the value of tuning capacitance, than detuning by changing the tuning capacitance, which varies the reactance of the tuned circuit.

The reactance variation method is illustrated by Fig. 12. The resonance indicator must be of a type which will indicate currents or potential differences with accurate relative values. This would mean either an electronic voltmeter across the tuning coil or capacitor, or else a thermocouple meter in series with the circuit. The high-frequency resistance of the tuned circuit is determined under two conditions; with and without the unknown resistance in series. The difference between circuit resistances is taken as the high-frequency resistance of the unknown. The unknown may be cut into and out of the circuit at the link shown at the right on diagrams in Fig. 12.

The first step is to tune the circuit to resonance at the frequency applied from the oscillator, to note the oscillator frequency, the reading of the resonance indicator, and the precise value of tuning capacitance. Next, the tuning capacitance is increased, which would tune the circuit to a frequency below resonance, until the reading on the indicator becomes exactly 0.707 times its reading at resonance. The new value of tuning capacitance is noted. The oscillator frequency and current must remain constant for all steps in the test. Finally, the tuning capacitance is decreased, tuning to a frequency above resonance, until the indicator again reads 0.707 times its reading at resonance. The value of tuning capacitance is noted.

Now we determine the average change of tuning capacitance, from resonance, which is required to reduce the indicator reading. That is, we subtract the resonance capacitance from the detuned capacitance below resonance to get one difference, then subtract the detuned capacitance above resonance from the resonance capacitance to get the other difference. The average of these differences will be used in computation.

The high-frequency resistance of the circuit may be computed from the following formula, in which the letter symbols have these meanings.

kc Oscillator frequency, in kilocycles.
Cr Tuning capacitance at resonance, in micro-microfarads.
Cd Average of differences between resonant capacitances and detuned capacitances required to reduce the indicator reading to 0.707.

$$\text{High-frequency resistance, ohms} = \frac{159\,155\,000 \times \text{Cd}}{\text{kc} \times \text{Cr}^2}$$

As an example, assume that we are working with an oscillator frequency of 1,000 kc, that the tuning capacitance at resonance is 140 mmfd, and that the average of the detuning in opposite directions amounts to 7 mmfd. These values in the formula give,

$$\text{High-freq. ohms} = \frac{159\,155\,000 \times 7}{1000 \times 140^2} = \frac{1\,114\,100\,000}{1000 \times 19600} = 56.8 \text{ ohms}$$

Parts such as coils and capacitors may be tested for high-frequency resistance by substitution or by variation of either resistance or reactance. When a coil to be tested is connected in series with a tuning coil already in the testing circuit, be sure that there is no coupling and no mutual induction between the two coils. How the emf is induced in the testing circuit, by coupling with the oscillator, may make a difference in results. If you are testing a coil, such as the secondary of a transformer, with which emf is induced directly in this coil while in normal operation, it is best to couple the tested coil to the oscillator through a link so that the testing emf is induced in the testing coil. If the tested coil is something like a choke, with which emf is not induced in the coil when in normal operation, it is best to induce the testing emf into another part of the circuit, as by coupling the regular tuning coil to the oscillator. Make sure that the oscillator has coupling with only one of the coils in the testing circuit, not some coupling with both.

Frequency Measurement.—The instrument most often used for measuring high frequencies is commonly called a *wavemeter*, because originally used for measurement of wavelengths. The same instrument sometimes is called an *absorption frequency meter*, because it absorbs power from the circuit whose frequency is being measured. The wavemeter or absorption frequency meter consists primarily of a series circuit made up of a coil and a variable tuning capacitor as shown by Fig. 13. The tuning capacitor is operated by an accurately calibrated vernier dial whose graduations may be read directly in frequencies or wavelengths, or which may have arbitrary numbers used in connection with a calibration curve or graph which relates these numbered settings to frequency or wavelength.

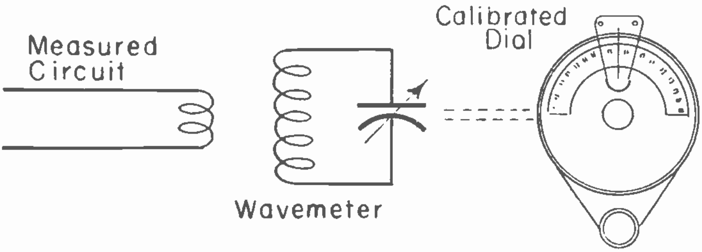


Fig. 13.—The principle of the wavemeter or absorption frequency meter.

The coil of the wavemeter is brought close enough to the circuit whose frequency is to be measured so that there is loose coupling. Emf is induced in the wavemeter circuit by the alternating magnetic field around the measured circuit. When the wavemeter circuit is tuned to resonance at the frequency of the measured circuit the reactances of the wavemeter circuit cancel, and there are maximum current and potential in this circuit. If the condition of resonance can be determined accurately, the reading of the wavemeter dial then will give the frequency at which the measured circuit is operating.

If an oscillator has a current meter in its grid or plate circuits, the oscillating frequency may be checked as shown by Fig. 14. The coil of the wavemeter, which ordinarily is mounted outside of the housing that encloses the capacitor, is brought near the oscillating circuit and the wavemeter tuning is varied until the oscillator meter dips in its indication. The meter then is absorbing power from the oscillator. The meter is moved farther and farther from the oscillator circuit, while varying the meter tuning, until the least possible variation of the wavemeter dial causes the oscillator meter to dip. Then the oscillating frequency may be read from the wavemeter.

As shown at the right in Fig. 14, there is maximum absorption of power at resonance, for then there is maximum induced current in the meter circuit, and power to keep this current flowing is proportional to the square of the current. Absorption decreases either side of the resonant frequency, but, if the wavemeter is held close enough to the oscillator for fairly close coupling, oscillation will be stopped over a fairly wide frequency range. The coupling is loosened, by moving the wavemeter away from the oscillator, to get as close as possible to the resonant peak.

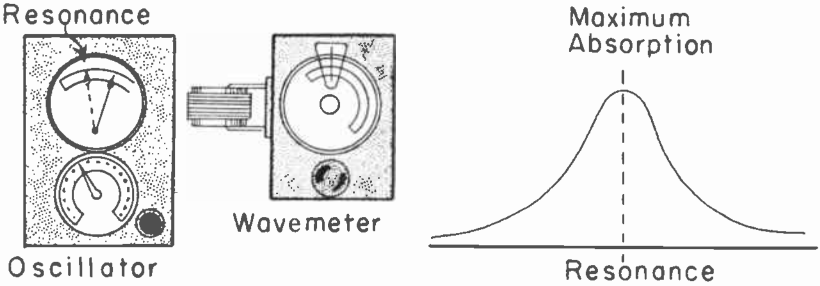


Fig. 14.—Oscillation in the oscillator is stopped at and near resonance.

If a headphone bypassed with a small capacitor can be connected in the plate circuit of the oscillator, as sometimes is the case, a click will be heard in the phone when the wavemeter is tuned below resonance, and there will be another click when tuned above resonance. By loosening the coupling the clicks can be brought close together. When as close as possible, the resonant frequency may be taken as half way between the wavemeter settings for the two clicks.

Wavemeter Resonance Indicators.—Resonance at an applied frequency may be indicated in the wavemeter itself in various ways. One method uses a small flash-lamp bulb in series with the wavemeter circuit. Such an indicator will operate only when the measured circuit is capable of furnishing a considerable amount of power. Then the lamp will glow most brightly at resonance. Wavemeters with lamp indicators usually are arranged so that the lamp may be removed and the meter circuit closed around the socket. Then the meter may be used with the "reaction" method of resonance indication described in connection with Fig. 14.

Fig. 15 shows two methods of using headphones and a crystal detector as a resonance indicator coupled to the wavemeter circuit. The crystal, which may conveniently be of the fixed type, and the headphone are in a series circuit. At the left this indicator circuit contains also a small coil inductively coupled to an auxiliary coil in the wavemeter circuit. At the right there is direct coupling by means of a wire conductor. Sometimes the results are better with a small bypass capacitor connected across the phones.

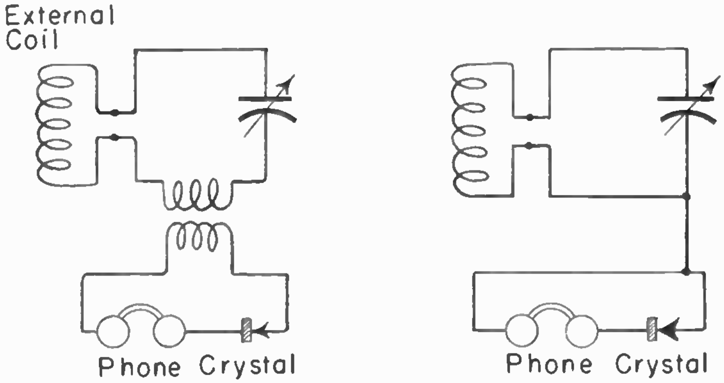


Fig. 15.—Crystal detectors used as resonance indicators for wavemeters.

Any resonance indicator coupled to the wavemeter circuit takes power from that circuit and makes the tuning broader. The meter must be calibrated with the indicator coupled, because inclusion of the indicator lowers the resonant frequency for any given setting of the tuning capacitor in comparison with the frequency when the indicator is not coupled.

With either of the arrangements shown by Fig. 15 the headphone might be replaced with a d-c microammeter. The terminals of the microammeter should be bypassed with a fixed mica capacitor of about 0.001 mfd capacitance.

The resonance indicator may employ a rectifying tube and a microammeter in a circuit which becomes essentially a simple electronic voltmeter. One such arrangement is shown by Fig. 16. The external coil and tuning capacitor *C* form the wavemeter circuit. The tube is a battery-filament type, used because it may be operated with small self-contained battery. A triode may be used with plate and control grid tied together so that the tube acts as a rectifier. Capacitors *Ca* and *Cb* are bypasses for the meter and the filament power supply. The filament rheostat is *R*, the filament battery is *B*, and the battery switch is marked *Sw*. The microammeter reads proportionately to potential difference across the tuning capacitor, since it is this potential difference that causes direct current to flow in the tube circuit. Any electronic voltmeter might be connected across the terminals of the tuning capacitor in a wavemeter to act as a resonance indicator.

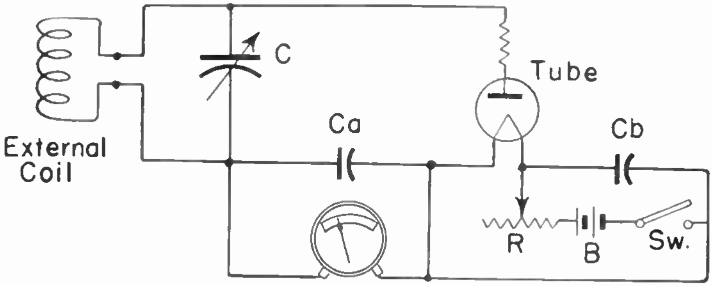


Fig. 16.—A wavemeter with tube rectifier and current meter in the resonance indicator.

With any indicator whose readings are proportional to current or potential difference in the wavemeter circuit, frequency may be accurately determined as follows: First tune the wavemeter for maximum indication, and note the value of this indication. Then tune to two points, one above and the other below resonance, at which the indication decreases by the same amount. Adjust the coupling to get these two points fairly close together. Then the true resonant frequency may be assumed to lie midway between the frequencies indicated by the wavemeter when the indication is reduced to equal values either side of resonance.

Wavemeter Calibration.—The frequency range of wavemeters is extended by making the tuning coils of plug-in type and providing different coils for various frequency bands. Tuning capacitors of ordinary design permit using a single coil for tuning over a frequency range of three to one or somewhat more. For instance, one coil might permit tuning from 1,000 to somewhat more than 3,000 kilocycles. But because the frequency ranges must overlap, to avoid the possibility that some frequencies may not be handled, the effective ratio is only about two or two and one-half to one per coil.

A wavemeter with any one coil in position may be calibrated for frequency readings if access can be had to a circuit which is oscillating at a known frequency. Any receiver having a detector which oscillates or which may be made to oscillate at some received frequency will permit calibration. The oscillator circuit of a superheterodyne receiver may be used provided the intermediate frequency is known, and it is known whether the intermediate is above or below the received radio frequency. Then the intermediate frequency may be added to or subtracted from the received radio frequency to determine the oscillator frequency.

The wavemeter is brought near the oscillating circuit of the receiver just as it is brought near an oscillator in Fig. 14. The wavemeter is tuned as the coupling is loosened until oscillation is stopped throughout the least possible movement of the wavemeter dial. Midway between readings at which oscillation stops and starts again, the wavemeter is tuned to the oscillator frequency of the receiver. With a superheterodyne receiver the oscillator stops when the audible signal from the loud speaker stops, and oscillation resumes when the audible signal reappears.

Heterodyne Frequency Meter.—A heterodyne frequency meter consists of a calibrated oscillator producing known frequencies which are heterodyned with other frequencies to be measured in such manner that the two frequencies may be made alike and both read from the frequency meter dial.

The principle of the heterodyne frequency meter is shown by Fig. 17. An unknown frequency which is to be measured induces emf's and current in a detector. At the same time there is introduced into the detector circuit an emf from the oscillator of the frequency meter. The two frequencies combine in the detector to produce a third frequency equal to the difference between the first two. The action is like that of combining the signal frequency and the oscillator frequency in the mixer or converter of a superheterodyne receiver to produce the intermediate frequency by heterodyne action, or by "beating" of the original frequencies with each other.

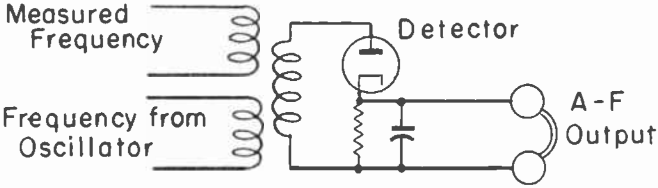


Fig. 17.—Basic principle of the heterodyne frequency meter.

As the oscillator frequency is adjusted to bring it closer and closer to the frequency to be measured, the difference becomes smaller and smaller. The difference frequency or beat frequency becomes audible in the headphone of Fig. 17. The audio note becomes lower and lower until, when the two incoming frequencies are alike, there is zero beat, no difference frequency, and silence in the phone. Then the adjusted oscillator frequency is the same as the frequency being measured.

Fig. 18 shows the principal parts of a complete circuit adapted for a heterodyne frequency meter. The oscillator section consists of the triode with its grid-plate circuit tuned to the known frequency by capacitor *C*. Many other types of oscillator might be employed instead of the Hartley type shown here. In the plate circuit of the oscillator is a current meter, *M*. Potentials at the oscillator frequency are fed through coupling capacitor *Cc* to one of the control grids of a pentagrid tube being used here as an electron coupled mixer.

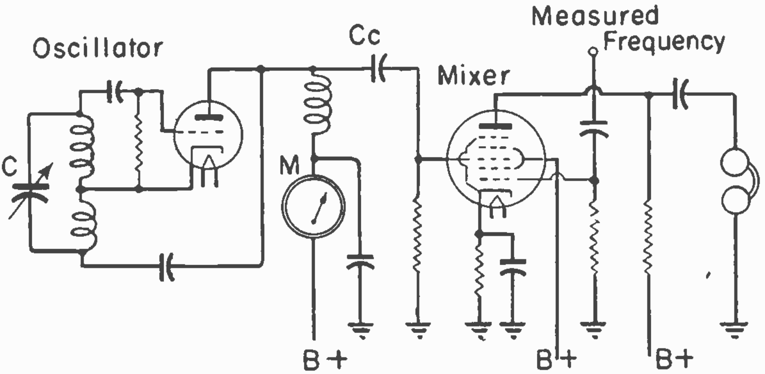


Fig. 18.—Principal parts of a heterodyne frequency meter circuit.

The frequency to be measured is applied to the other control grid of the mixer tube through the connection shown. Between this connection and the ground of the frequency meter might be connected any coupling device, such as a small coil to be brought near any apparatus whose operating frequency is to be determined. The electron stream passing from cathode to plate in the mixer tube goes first through the grid carrying the frequency to be measured, then through the grid carrying the oscillator frequency, hence the rate of electron flow is affected by both these frequencies and in it appears the difference frequency or beat frequency. The two frequencies, or their potentials, are electron coupled in the tube.

The beat frequency which appears in the plate circuit of the mixer passes through the headphone at the right, and when this frequency is in the audio range it may be heard. Tuning the oscillator to a point at which no audible note is heard, in between points at which there is a note, makes the oscillator frequency equal to the applied unknown frequency. The headphone shown in the diagram often is replaced by an audio-frequency amplifier to increase the sensitivity of indications. This amplifier may actuate phones or a loud speaker.

REVIEW QUESTIONS

1. Is grid current greater when a tube is oscillating or not oscillating? How about plate current under the two conditions?
2. In making resonance measurements should coupling be loose or close between the oscillator and the measured circuit?
3. What devices or instruments may be used for resonance indicators?
4. When the apparent inductance as measured at one frequency differs from that at a different frequency, what property or effect in the inductor causes the difference?
5. For capacitance measurements is the standard capacitor preferably of the paper, electrolytic, air, or mica dielectric type?
6. Would carbon or wire-wound resistors make suitable standards of resistance at radio frequencies? If neither is desirable, describe a satisfactory standard.
7. Describe briefly the principles of measuring high-frequency resistance by the substitution method, the resistance variation method, and the reactance variation method.
8. What is the common name of the instrument or device most often used for measurement of high frequencies.

Chapter 5

MEASUREMENTS WITH BRIDGES

Just as the tuned resonant circuit is a means for measurement of many kinds of electrical properties at frequencies extending as high as several hundreds of megacycles, so the balanced bridge circuit is a means for measuring such properties at frequencies extending from zero (direct current) through the power and audio ranges and into the lower radio frequencies. The bridge circuit, like the resonant circuit, may be arranged for the measurement of resistance, reactance, impedance, inductance, capacitance, or frequency.

You will recall that four essential parts are used in making measurements with resonant circuits. These parts include (1) the source of energy, (2) an indicator, (3) an adjustable standard such as a variable capacitor, and (4) the unknown whose value is to be measured. For measurements with the bridge circuit we require parts performing somewhat similar functions; (1) a source of energy, (2) an indicator, (3) an adjustable standard, and (4) the unknown whose value is to be measured.

But in the bridge circuit we have a fifth part which tells the number of times that the unknown value exceeds the standard, or the fraction of the standard value which exists in the unknown. In this part lies a great advantage of the bridge method, for with only a single standard it becomes possible to measure values as great as hundreds of times the standard and as small as a few thousandths of the standard value. This additional part consists of the "ratio arms." Fig. 1 shows controls for the standard and for the ratio arms, also the indicator, on the panel of a bridge designed for measurement of resistance.

When using a bridge we compare the unknown quantity with a standard whose value is known. This is true also of resonance methods. But the computations required with the bridge method are generally simpler than those for resonance methods. In fact, when a bridge is designed to make measurements of only one kind of electrical quantity, it is not difficult to provide dials which read directly in that quantity.

Many commercial bridges are arranged especially for measuring a single electrical quantity, such, for example, as capacitance. In such an instrument there would be self-contained parts including a source of energy, a suitable indicator, one or more capacitance standards, and a dial for direct reading of measured capacitances. Special purpose bridges save much time, because few if any computations are called for, and they decrease the probability of error.

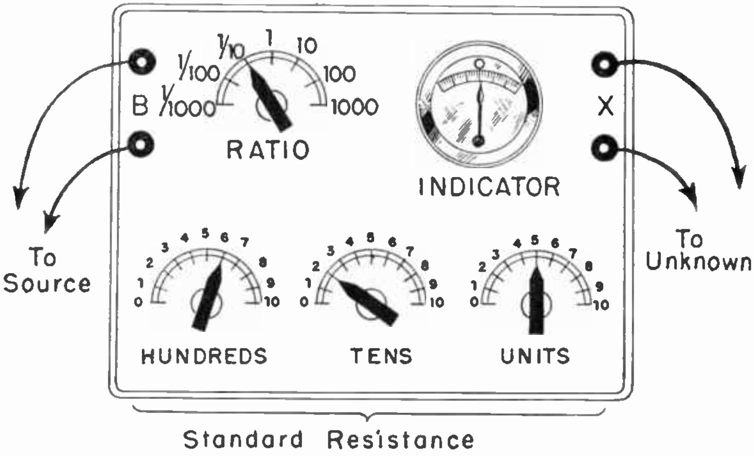


Fig. 1.—The panel controls of a resistance bridge.

In contrast with the single-purpose bridge we may use separate parts which may be quite easily assembled into a bridge for making any kind of measurement. One of the separate units might consist of the ratio arms. Others might be a direct-current source and an audio-frequency source. We would need also a d-c indicator and an a-f indicator, together with standards of resistance, capacitance, and inductance. With these parts it would be possible to make up a resistance bridge, various capacitance bridges, various inductance bridges, or a bridge for measuring audio frequencies.

From what has been said so far it becomes apparent that, when we speak of bridge measurements, we are not referring to any single instrument, but rather to a general method for making measurements of many kinds. The original bridge circuit, which has been known for more than one hundred years, is arranged for measurement of resistance. It is called the *Wheatstone bridge*, after the man who popularized its use. Because the principles employed in all bridge circuits are the same as those of the Wheatstone bridge, or are modifications of these principles, it is this type which we shall examine first.

Resistance Bridge Principles.—Fig. 2 is an introduction to the basic principle of the resistance bridge. In diagram *1* we have resistances connected in parallel across a source furnishing 8 volts potential difference. There are steady drops of potential through both the upper and lower lines of resistance. If the resistance in each line is divided into four equal parts, the potentials at the several points of division will be as shown; 8 volts, 6 volts, 4 volts, 2 volts, and zero volts.

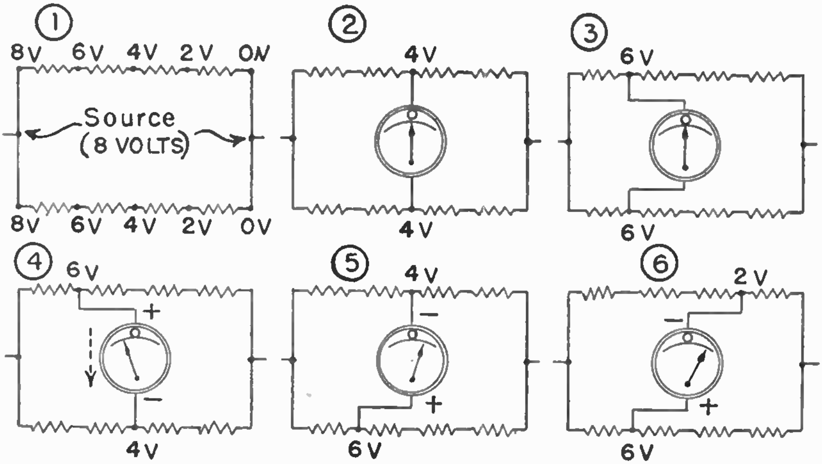


Fig. 2.—Indicator readings and potentials in the elementary bridge circuit.

In diagram *2* we have connected between two points having 4-volt potentials a current meter of the zero-center type. Both ends of the meter are connected to equal potentials, there is no *difference* of potential applied to the meter, consequently there will be no current in the meter and the meter will indicate zero. In diagram *3* the meter is connected between two points having 6-volt potentials. Again there is no difference of potential across the meter, and the reading will be zero.

In diagram *4* the upper end of the meter is connected to a point which is at a 6-volt potential, and the lower end is connected to a 4-volt point. Now there is a difference of potential across the meter and current will flow through the meter to cause a deflection of the pointer. We assume that the relative potentials, or the polarity, applied to the meter cause current in such direction as to deflect the pointer toward the left.

In diagram *5* the upper end of the meter is connected to a 4-volt point, and the lower end to a 6-volt point. Again the meter is subjected to a difference of potential, but the polarity is opposite to that of diagram *4*. This means an opposite direction of current through the meter, and an opposite deflection of the pointer. In diagram *6* the meter is connected between 2 volts and 6 volts, top and bottom. The potential difference now is greater than in diagram *5*, but the polarity is the same, and so the pointer deflects still farther to the right.

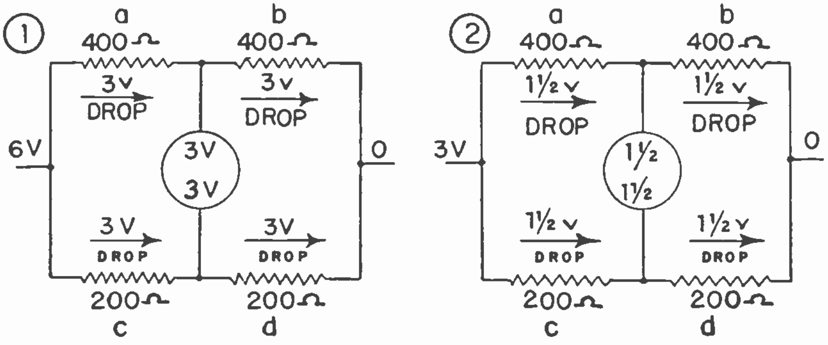


Fig. 3.—Voltage drops which cause equal potentials across the indicator.

The zero-center current meter, which is our indicator, will show zero current whenever equal potentials are applied to its two terminals. If the potentials are not equal there will be a reading on the meter, and the direction of pointer deflection will depend on which of the potentials is the greater.

In Fig. 3 we have a parallel circuit with two resistances in the upper line and two in the lower line, and have a current indicator between junctions of upper and lower resistances. In diagram *1* each of the upper resistances is 400 ohms, and each of the lower resistances is 200 ohms. The applied potential difference is 6 volts. Because the two upper resistors are of equal value there will be equal voltage drops in them, and each drop will be half of the total applied voltage, or will be 3 volts. Because the two lower resistors are of equal values there are equal voltage drops in them, and each drop will be half of the applied voltage, or will be 3 volts. Then the potentials at both junctions will be 3 volts. These equal potentials applied to the meter or indicator cause no current to flow in the meter or indicator, and it will read zero.

In diagram *2* we have retained the same values of resistance throughout the circuit, but the total potential difference applied from the source now is 3 volts instead of the former 6 volts. Again there are equal voltage drops in the equal halves of upper and lower lines, there are equal potentials at both ends of the indicator, no current in the indicator, and a zero reading.

If resistances are such as to cause zero reading of the indicator with one applied voltage, the reading will remain at zero with any other voltage applied from the source.

In diagram *1* of Fig. 4 the two resistances in each line, upper and lower, no longer are equal in value. At *a* we have 200 ohms, and at *b* have 600 ohms. The potential drops must be proportional to the resistances. The fraction of the overall potential drop that appears in each resistance must be the same as the fraction of the total resistance which is represented by that resistance. The total resistance of *a* and *b* is 800 ohms. Then the fraction for *a* is $^{200}/_{800}$ or ¼, and in *a* the drop must be ¼ of the overall potential difference, 6 volts, or must be 1½ volts. The fraction for *b* is $^{600}/_{800}$ or ¾, and in *b* we have ¾ of 6 volts, or 4½ volts.

Applying the same reasoning to the lower resistances, *c* and *d*, whose total resistance is 400 ohms, we have the fraction 100/400 or 1/4 for *c*, and have 300/400 or 3/4 for *d*, and have the same relative voltage drops in *c* and *d* as in *a* and *b*. A drop of 1½ volts through *a* and also through *c* leaves 4½ volts potential at both the upper and lower junctions, leaves 4½ volts at both terminals of the indicator, and the reading is zero.

In diagram *2* of Fig. 4 the values of resistance have been changed. Computing the drops as proportional to the resistances, just as was done for diagram *1*, we find drops of 4½ volts in both *a* and *c*, have 1½ volts of the total 6-volt applied potential remaining at both junctions, and again have zero reading of the indicator.

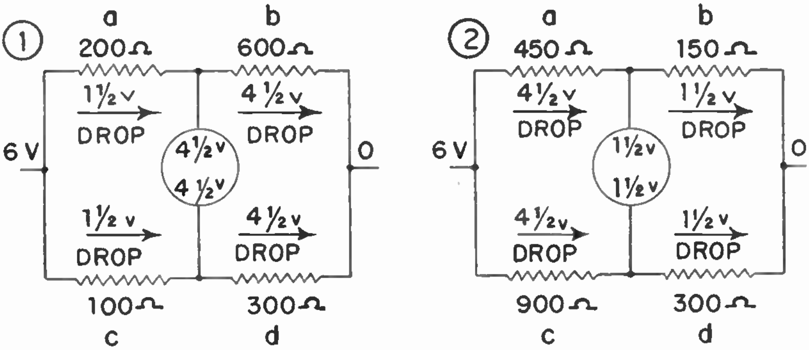


Fig. 4.—Voltage drops with unequal resistances in the bridge elements.

We observe that any relative value of resistances which give two equal voltage drops across *a* and *c*, and another two equal voltage drops across *b* and *d*, will cause the indicator to read zero with any total potential difference applied form the source. The diagrams of Figs. 3 and 4, and all but diagram *1* of Fig. 2, show bridge circuits. The *bridge* is the line containing the indicator, which is the line connected between the upper and lower junctions of the resistances. When the relative values of the four resistances (*a*, *b*, *c* and *d* in Figs. 3 and 4) are such that no current flows in the bridge and the indicator, the bridge is said to be *balanced.* All measurements are made with the bridge balanced, and with the indicator reading zero. We are not concerned with readings either side of zero, for we always adjust either two or three of the resistances to obtain a zero reading.

Measurement of Resistance.—In Fig. 5 we have put the bridge circuit at work in measuring some resistances which are assumed to be originally of unknown values. The resistances which we have called *a* and *b* are similarly lettered in these new diagrams. The resistance which we have called *c* is now marked "Standard." The resistance which we have called *d* now is the unknown resistance which is to be measured. The unknown is connected between terminals marked *X* in Fig. 5. The letter *X* always stands for an unknown quantity when used in mathematical work.

Resistances *a*, *b*, the standard, and the unknown, are called the *arms* of the bridge. Arms *a* and *b* are called the *ratio arms.* In most bridges it is possible to change or adjust the relative values of the ratio arms, and usually it is possible to adjust the value of the standard arm. Adjustment of the ratio arms in Fig. 5 is made by a three-way switch connected to the upper terminal of the meter and to points between resistances which form the ratio arms. The standard resistance is shown as a rheostat whose slider may be moved to include more or less of the rheostat resistance in the bridge circuit.

In diagram *1* the ratio arms, *a* and *b*, are adjusted to have equal resistances, with 400 ohms in each arm. The "unknown" is shown as having resistance of 150 ohms. With the two ratio arms of equal resistances, the standard and the unknown must be made of equal resistances in order to balance the bridge. This is the same as saying that, to have equal potentials at both terminals of the indicator, there must be equal drops of potential in arm *a* and the standard, and equal drops in arm *b* and the unknown. The obvious way to attain this condition is to adjust the standard resistance until the indicator reads zero, then to read the resistance of the standard. The standard must be some type of adjustable resistance which is accurately calibrated and graduated in units of resistance.

In diagram *2* of Fig. 5 there is a different unknown resistance. The two ratio arms still are of equal resistance values, each containing 400 ohms of resistance. The ratio of the resistances in these arms then is $^{400}/_{400}$, which is the same as $^1/_1$ or is a one-to-one ratio. Whenever the ratio arms are set for a one-to-one ratio, meaning that their resistances are of any equal values, the resistance of the unknown will be equal to the resistance to which the standard is adjusted. That is, when we have a one-to-one ratio of the ratio arms, we must also have a one-to-one ratio of the standard to the unknown. The ratio of the standard to the unknown always must be the same as the ratio of arm *a* to arm *b* in order to balance the bridge. Since the standard in diagram *2* is shown as adjusted to a value of 450 ohms, the unknown resistance must be 450 ohms.

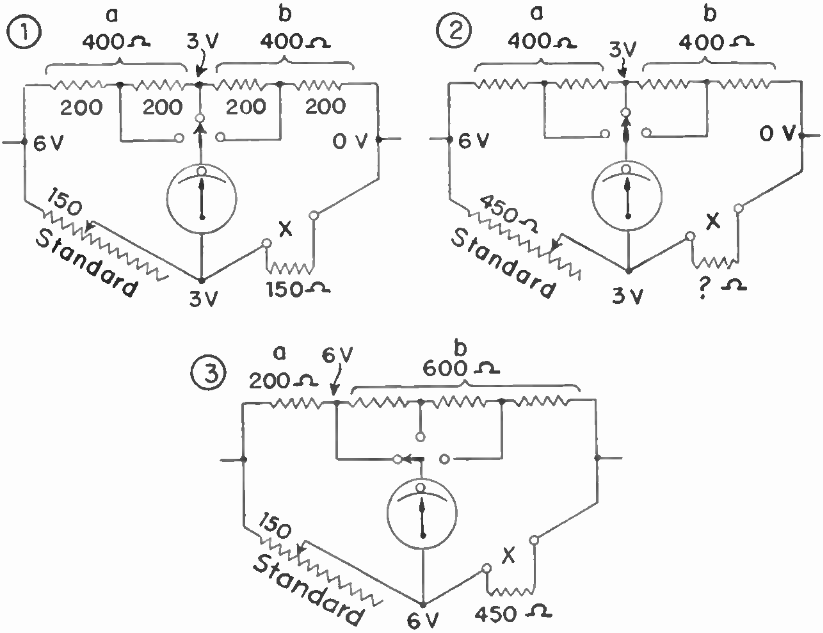


Fig. 5.—Ratio arms, standard arms, and unknown arms on a bridge circuit.

In diagram *3* the ratio-arm switch has been moved to a position such that the resistance in arm *a* is 200 ohms, and in arm *b* is 600 ohms. Now the ratio a/b is $^{200}/_{600}$ or is $\frac{1}{3}$. Then the ratio of the standard to the unknown will have to be made $\frac{1}{3}$ when the bridge is balanced. We adjust the standard to whatever value balances the bridge and makes the indicator read zero. Then the value of the standard resistance is proportional to 1, and that of the unknown is proportional to 3, because our present ratio is $\frac{1}{3}$. The diagram shows the standard set at 150 ohms. Then the unknown resistance must be 3 times this standard resistance, or must be 450 ohms.

Bridge Formulas or Equations.—In discussions of bridges the fundamental circuit often is shown as in Fig. 6, with the arms called *a*, *b*, *c* and *d*, with the indicator between two opposite junctions, and with the source between the other two opposite junctions. If *a* and *b* are taken as the ratio arms, *c* the standard, and *d* the unknown the formula for determining the unknown value is,

$$d = c \times b/a \qquad \text{or} \qquad \text{Unknown} = \text{standard} \times b/a$$

You will find that these formulas work out correctly when applied to any of the preceding diagrams on which resistance values are shown in numbers of ohms. If you enjoy experimenting with proportions and ratios begin with the equal ratios

$$a/b = c/d \qquad \text{from which,} \qquad a \times d = b \times c$$

When you have worked out all the various modifications of these equations it will become clear that,

1. Any two adjacent arms may be the ratio arms (a/b, a/c, b/d, c/d) but two opposite arms cannot be the ratio arms. The ratios may be written either side up (a/b can be changed to b/a, etc.) but inverting the ratio will interchange the standard and the unknown in the resulting formula.

2. Any one arm may be taken as the standard, either adjacent arm may be taken as the unknown, and then the two remaining arms will be the ratio arms.

3. When any two adjacent arms are taken as ratio arms, either of the remaining arms may be the standard, and the other will be the unknown. Which is standard and which is unknown will depend on how the ratio is written or on which ratio term is above the line in the ratio fraction.

Ratio Arms.—The ratio arm resistances and the control adjustment often are designed so that the value of the standard may be multiplied by various numbers or various fractions to determine the value of the unknown. Fig. 1 shows a ratio adjustment which, when turned to various positions, allows multiplying the adjusted standard value of fractions of 1/1000, 1/100 or 1/10, or by the whole numbers 1, 10, 100 or 1,000.

Fig. 1 shows also a form of standard resistance consisting of three sections, each with ten values of resistance. These are called *decade resistances* or resistors. The left-hand decade is for 100's of ohms, and may be set for 100, 200, 300, etc. The center decade is for 10's, and may be set for 10, 20, 30, etc. The right-hand decade is for units of 1 ohm each. Resistances in the three decades are in series, to form the total resistance for the standard. With the settings shown we have 6 hundreds at the left, 2 tens at the center, and 5 units at the right. Then the total is 600 ohms plus 20 ohms plus 5 ohms, or is 625 ohms for the standard. The ratio is set at 1/10, which means to multiply the standard by 1/10. Then 1/10 of 625 ohms is 62.5 ohms, which is the resistance of the unknown with the adjustments of Fig. 1 and with the indicator at zero. Were the ratio set at 1/1000, with the same standard resistance, the unknown would be 1/1000 of 625 ohms, or 0.625 ohm. Were the ratio set at 1,000 the standard would be multiplied by 1,000, and the unknown resistance would be 625,000 ohms.

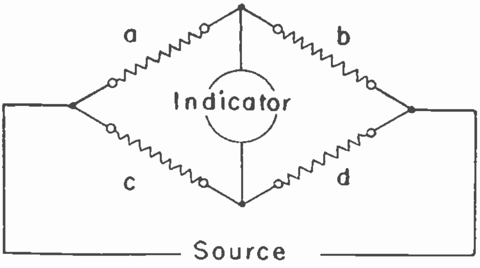


Fig. 6.—The fundamental bridge circuit.

The smallest unknown resistance which could be measured with the bridge of Fig. 1 would be equal to the smallest ratio (1/1000) multiplied by the smallest standard (1 ohm), and would be 0.001 ohm. The greatest unknown would be measured with a ratio of 1,000 and the maximum standard resistance of 1,000 + 100 + 10 = 1,110 ohms, and would be 1,110,000 ohms or 1.11 megohm.

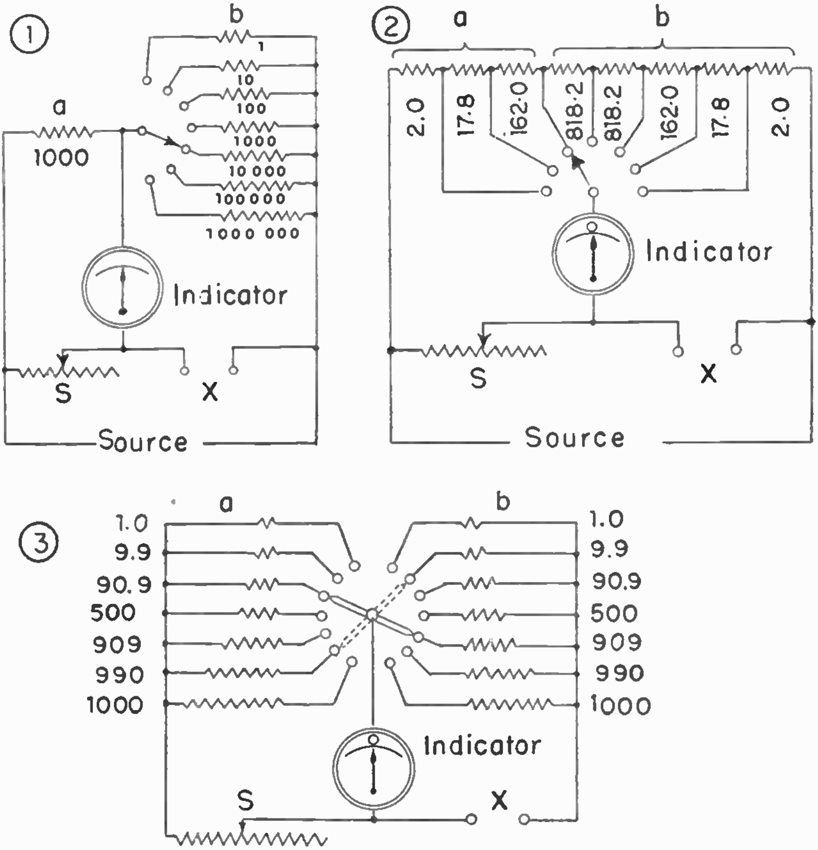


Fig. 7.—Connections and resistance values for ratio arms.

Fig. 7 shows several ways of switching resistors in ratio arms to obtain ratios from 1/1000 to 1,000. In diagram *1* the *a* arm consists of a single 1,000-ohm resistor, and in the *b* arm are seven resistors varying from 1 ohm to 1,000,000 ohms as shown. Any one of the *b* resistors is brought into the circuit by means of a 7-point selector switch. With the switch at the top the ratio a/b is 1000/1, or is 1,000. With the switch in the position shown the ratio is 1000/10000, or 1/10. With the switch at the bottom the ratio is 1000/1000000, or 1/1000.

In diagram *2* the ratio resistors are arranged in a single series string, with values in ohms as shown. Junction points between these resistors may be connected to the indicator through a 7-point selector switch. With the switch in the position shown the total resistance in the *a* arm is 2.0 + 17.8 + 162.0 = 181.8 ohms. The total resistance in the *b* arm is 818.2 + 818.2 + 162.0 + 17.8 + 2.0 = 1818.2 ohms. Resistance in the *a* arm is 1/10 of that in the *b* arm, so in this position of the switch the effective ratio for the bridge is 1/10. With the switch all the way to the left the ratio is 2/1998, or practically 1/1000. With the switch all the way to the right the ratio is inverted, and is 1998/2 or practically 1,000. At the center position the ratio is 1000/1000 or is 1-to-1.

In diagram *3* the upper end of the indicator is connected to the rotor of a selector switch with which the contact ends of the rotor rest on two contacts at once, one being at the left and the other at the right. Thus the two connected resistors, one at the left and the other at the right, form the *a* and *b* arms for a given switch position. Resistance values are shown on the diagram. With the switch in the full-line position the ratio a/b is 90.9/909, which is a ratio of 1/10. With the switch in the broken-line position the ratio a/b is 990/9.9, which is a ratio of 100/1 or 100. The complete series of ratios extends from 1/1000 to 1,000.

Slide Wire Bridge.—Instead of employing the conventional resistors for the ratio arms it is possible to use a single fairly long piece of high-resistance wire, such as Manganin wire, for this part of the bridge. Fig. 8 shows one arrangement of parts for such a slide wire bridge. The resistance wire is stretched alongside a scale divided into 100 equal parts. A key carrying a knife-edge contact may be slid along a support so that the contact may be pressed against the resistance wire anywhere along the length of that wire. The portion of the wire on the left of the contact then forms the *a* ratio arm, and the portion on the right forms the *b* ratio arm. The standard and unknown arms, and the indicator, are connected as usual.

With the scale carrying a double set of graduations, as shown, the value of the *a* arm is read from the upper graduations and the value of the *b* arm is read from the lower ones. With the key depressed to make contact at the position shown, the ratio is 40/60. The standard resistance is shown here as having four steps, 1, 10, 100 and 1,000 ohms. The standard selector switch is set to place 10 ohms in this arm. The unknown resistance, connected at *X*, then is found by multiplying the standard (10 in this example) by the ratio (40/60 in this example). With settings shown the unknown resistance would be equal to 10 × 40/60, which is 10 × 2/3, or is 6.67 ohms. Various modifications of this type of bridge are in use. Variations in resistance along the slide wire, and difficulty in making precise readings of the ratio fraction, make this type of bridge less accurate than other forms.

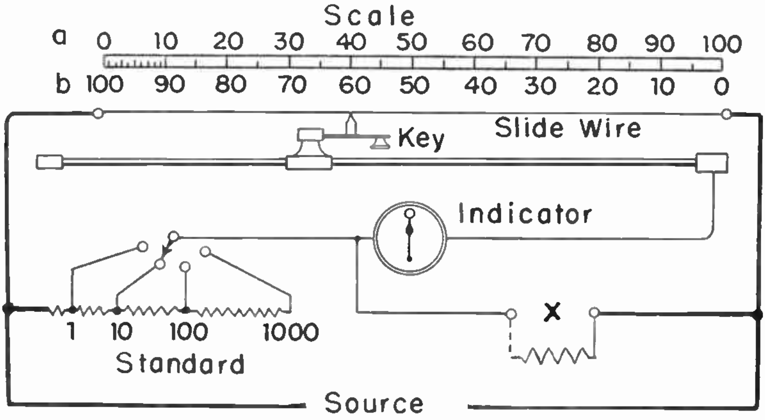


Fig. 8.—Connections for one type of slide wire bridge.

Indicator for D-c Bridge.—The indicator which shows balance when current in the bridge arm is zero usually is a direct-current galvanometer for the d-c type of resistance bridge. A *galvanometer* is any instrument which indicates the presence or absence of current in a circuit, usually without indicating any exact quantity. For the bridge galvanometer we need a zero-center instrument, because the direction of pointer deflection will show whether the unknown resistance is more or less than the standard resistance. The zero-center galvanometer often is called a *null indicator.*

Sensitive galvanometers may have full-scale deflections, either way from zero, with currents of from 10 to 50 microamperes. For less accurate readings of unknown resistances the galvanometer may have full-scale deflection with as much as a half milliampere or one milliampere. The more sensitive the galvanometer, or the less the current for any given deflection, the greater the accuracy with which resistances may be determined. Accuracy of resistance determination is increased also by using more applied voltage from the source, for this causes greater detector deflection for any given unbalance of the bridge.

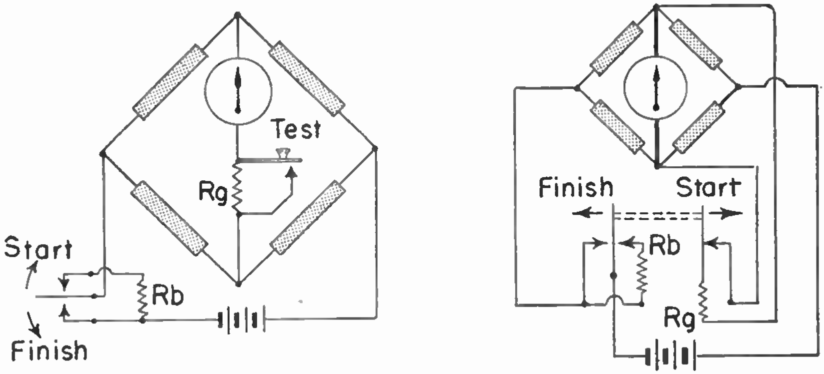


Fig. 9.—Methods of keeping excessive potential differences from the indicator.

If the resistance of the unknown differs widely from that of the standard, as often will be the case when beginning a test, a very sensitive galvanometer would be thrown off scale and the pointer and movement might be damaged. Consequently, it is necessary to protect the galvanometer from excessive current until the bridge is brought nearly into balance. If a battery is used as the source, a switch may be arranged to apply the potential difference from only one cell for beginning the test, then more cells may be cut in as the bridge approaches balance.

There always should be a key or other type of switch of the momentary contact variety which keeps open the battery circuit, the galvanometer leads, or both, except during readings of the indicator. Then the indicator is not likely to be damaged while connections are being made and changed.

Two ways of protecting the galvanometer are shown by Fig. 9. In the left-hand diagram there is a double-throw switch in the battery line, so arranged that resistor *Rb* is in series with the battery when the switch is in the "Start" position, and that the battery is connected directly to the bridge with the switch in the "Finish" position. Approximate balance is made with the resistor in series, and exact balance with the battery connected directly. There is a resistor *Rg* in series with the galvanometer, this resistor being cut out when the test key is pressed. The resistance at *Rg* might be from three to ten times the resistance of the galvanometer, thus permitting a deflection of one-third to one-tenth the amount which will occur when the key is pressed.

In the right-hand diagram there is a resistor *Rb* in series with the battery on the "Start" position of a double switch having both sections operated together by one control. This battery resistor is cut out with the switch in the "Finish" position. The other section of the switch controls resistor *Rg*, which is a shunt for the galvanometer. In the "Start" position this shunt resistor is across the galvanometer, and is open circuited in the "Finish" position.

Operating the Bridge.—The pointers of sensitive galvanometers often are locked in position by a clamp which must be released before tests can be made. The clamp usually is plainly marked, and is released by turning a knob, button, or lever. If the galvanometer pointer does rest exactly on zero with no current in the instrument, set the pointer correctly by means of the zero adjuster.

Some bridges have two key switches, one marked as controlling the battery, the other as controlling the indicator. Form the habit of closing the battery key first, then the galvanometer key, and of opening the galvanometer key before the battery key. This will prevent "inductive kicks" from subjecting the galvanometer to high potentials and currents when testing coils or other inductive elements in the unknown position.

Time will be saved and accuracy promoted by taking the steps in operation of a bridge in an orderly manner. The following procedure applies in general to all bridges of usual construction.

1. If the approximate value of the unit to be measured is known, adjust the standard, or the standard and the ratio, for this approximate value. Otherwise set the ratio at 1.0, or make both ratio arms of the same value and at about the middle of their range, and adjust the standard to the middle of its range.

2. Close switches or keys in the positions which will give least deflection on the indicator. This would be the "Start" positions in Fig. 9, or whatever positions give least sensitivity. Note whether the indicator pointer swings to the left or to the right.

3. Vary the ratio in either direction and again close the keys. If the indicator swings still farther in the original direction, vary the ratio oppositely to the preceding change. Find the ratio with which there is the least deflection of the pointer when the keys are closed.

4. Vary the standard in either direction and close the keys. If this causes a deflection greater than in the preceding test, vary the standard in the opposite direction. Find the setting of the standard which permits the least deflection.

5. Shift the controls or key switches to their high sensitivity positions, which would be the "Finish" positions of Fig. 9. Make a final adjustment of the standard which gives the least deflection as the key is closed and opened.

6. The value of the unknown now is found by multiplying the value of the standard by the ratio.

The greatest accuracy is attained with the ratio at 1.0 or at one-to-one, and the accuracy decreases with greater or smaller ratios. When the ratio arms are separately adjustable it is desirable that their resistances be as nearly as possible the same as the standard and unknown resistances. When measuring very small resistances be sure to make good clean, tight connections. Otherwise the contact resistances may cause large errors.

ALTERNATING-CURRENT BRIDGES

Bridge methods are applied to the measurement of capacitance and inductance by employing a source of alternating potential and current, and by using circuits in which the response is to capacitive and inductive reactances whose effects are translated into the corresponding values of capacitance and inductance. Since the source furnishes alternating potential the balance indicator must be of a type which is actuated by such potentials.

To prevent undesirable couplings the several elements of a-c bridges may be enclosed within individual shields, and an overall shield may line the case of the instrument. The shield is grounded when this is convenient during operation. The control shafts for capacitors and resistors are connected to the shield. All of the resistors used in a-c bridges should be so constructed that they have but small inductance and small distributed capacitance.

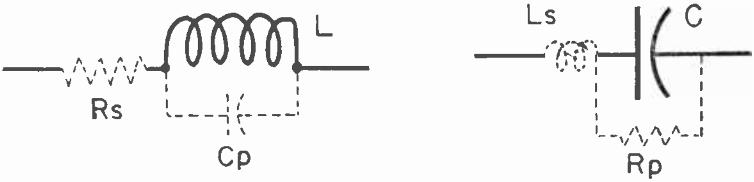


Fig. 10.—Factors which affect measurements of inductance and capacitance.

When we are measuring an inductance, as represented by its symbol, *L*. in Fig. 10, the accuracy of the results will be affected by the fact that the coil possesses resistance as well as inductance, the resistance being effectively in series with the inductance as shown by *Rs*. The coil has also more or less self-capacitance which, with connections used in bridge circuits, is effectively in parallel as shown by *Cp*. When measuring a capacitance, as *C* of Fig. 10, accuracy will be affected by inductance of the conductors, which is effectively in series as shown by *Ls*, and also by the resistance, which is effectively in parallel with the capacitance as at *Rp*.

At the rather low frequencies used for most bridge measurements the small capacitance of coils and the small inductance of capacitors have minor effects, but in order to obtain a balance when using resistors in other arms of the bridge it is necessary to compensate for the series resistance of coils and for the parallel resistance of capacitors. The compensating adjustments are one of the chief differences between d-c bridges and a-c types.

To determine measured values of laboratory accuracy we would have to make allowances and computations for everything shown by Fig. 10 and, in addition, for the series inductances and parallel capacitances of all the resistors and other conductors in the apparatus. In view of the accuracy tolerances in commercial capacitors and inductors used in radio receivers, it is not necessary to make such corrections unless greater than usual precision is required.

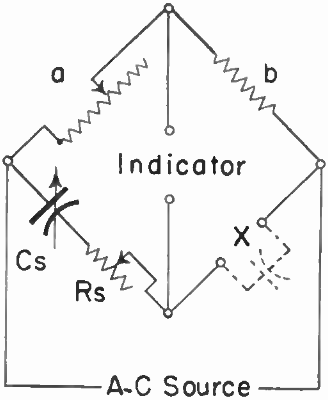


Fig. 11.—A series resistance type of capacitance bridge.

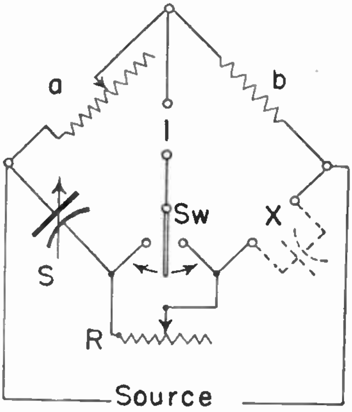


Fig. 12.—The balancing resistor may be placed in either of two arms.

Capacitance Bridges.—Fig. 11 shows the elementary circuit of a type of capacitance bridge which is in general use. The ratio arms are *a* and *b*. Arm *a* is shown as being adjustable, although either or both of these arms might be of the variable resistance type. At least one of the adjustable resistors ordinarily would be a decade type. In the standard arm we have a calibrated variable capacitor *Cs* in series with which is an adjustable resistor *Rs*. The unknown capacitance is connected at *X*. Because *Rs* is in series with the standard capacitance this bridge often is called a *series resistance* capacitance bridge.

In balancing the bridge the adjustable resistor *Rs* is set to balance the resistance component of the unknown capacitance, the necessity for which was explained in connection with Fig. 10. The standard capacitor *Cs* is adjusted to balance the capacitance of the unknown unit. When the standard capacitor is a variable air-dielectric type its maximum capacitance may be about 500 mmfd. In some bridges of this general style the standard is a fixed capacitor, often of about 0.05 mfd capacitance, and all balancing adjustments are made with the resistors. When only one ratio arm is adjustable the ratio of maximum to minimum resistance is about 1,000 to 1, with a maximum resistance usually running between 20,000 and 100,000 ohms.

The value of unknown capacitance is found from this formula, assuming that the bridge has been balanced with both *Cs* and *Rs* set for minimum response of the indicator.

$$\begin{matrix}\text{Capacitance}\\ \text{at X}\end{matrix} = \begin{matrix}\text{standard}\\ \text{capacitance}\end{matrix} \times \frac{\text{resistance a}}{\text{resistance b}}$$

The unknown and standard capacitances will be in the same units, microfarads or micro-microfarads. It should be noted that this formula involving capacitance is very different from one that would be used with a resistance bridge having the same relative positions of the arms. For capacitance we have the ratio a/b, but were the measurement of resistance the ratio would be b/a.

Fig. 12 shows a form of series resistance bridge in which the balancing resistor *R* may be placed in series with either the standard or the unknown capacitance by means of the switch

Sw in series with the indicator. With this switch thrown to the right, resistor *R* is in series with standard capacitor *S*, and when thrown to the left the resistor is in series with the unknown capacitor. In order to permit a balance, resistor *R* will have to be placed in series with whichever of the two elements, standard or unknown, has the smaller resistance of its own. When balance cannot be attained with *R* in one arm it is switched over into the other arm.

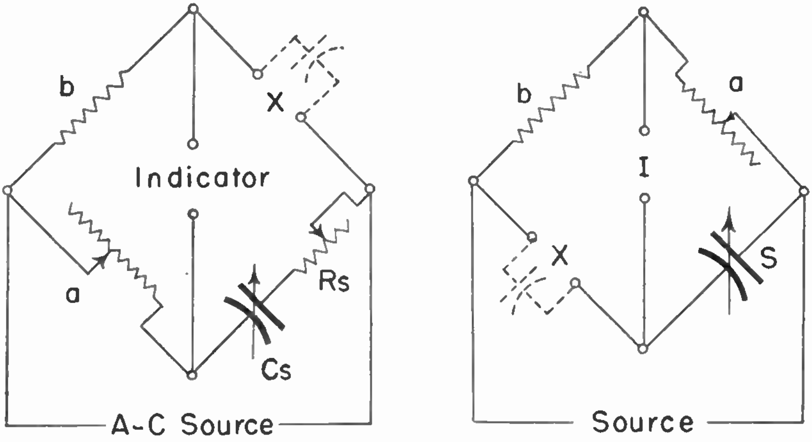


Fig. 13.—Circuit diagrams for capacitance bridges.

Another form of the series resistance bridge is shown at the left in Fig. 13. Comparison of this diagram with the one in Fig. 11 will show that the only difference between the two is an intercharge of connections of the source and the indicator to the bridge arms. In Fig. 13 the two ratio arms, *a* and *b*, are across the indicator, while in Fig. 11 these two arms are across the source. The four arms of the bridge, and their relations to one another, are exactly the same in both diagrams. The formula for capacitance that is used with the bridge of Fig. 11 applies without any alteration to the bridge at the left in Fig. 13.

The connections of the source and the indicator may be interchanged with any of the bridges without affecting the principles of the bridge and without making it necessary to change the formula which gives the unknown quantity. Which of the two possible connection arrangements is used depends on which will give the greater sensitivity, or on which will give the greater deflection of the indicator with a given potential from the source and the same degree of unbalance between standard and unknown elements.

At the right in Fig. 13 is still another circuit arrangement for the same general type of bridge, but here there is no resistor in series with the standard, and the bridge cannot be called a series resistance type. Rather it is just the simplest kind of capacitance bridge, with resistances in both ratio arms, *a* and *b*, and with capacitances in both the standard and the unknown arms. Here there is no provision for balancing the resistance of the unknown, although there can be a balance for capacitance of the unknown.

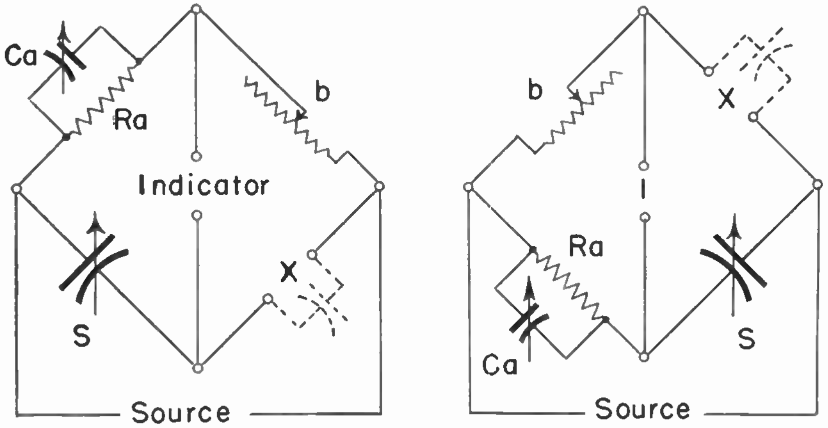


Fig. 14.—A Schering bridge for capacitance measurement.

In Fig. 14 is shown a *Schering* type of capacitance bridge. The left-hand diagram shows the ratio arms, *Ra* and *b*, connected across the source, while the right-hand diagram shows the same ratio arms connected across the indicator. The distinguishing feature of this type of bridge is that the resistive component of the unknown capacitance, connected at *X*, is balanced by adjustable capacitance of capacitor *Ca* which is in parallel with resistor *Ra*. The standard is a calibrated variable capacitor *S*. Either *Ra* or *b* might be made the adjustable ratio arm, or, of course, both of these resistors might be made adjustable.

The range of capacitance values which may be measured with bridges of the types shown most often runs from a minimum of 1/10 to 5 micro-microfarads to a maximum of 100 to more than 1,000 microfarads.

Small values of capacitance sometimes are measured with a *substitution method*, as follows: The two ratio arms are made of equal values, across the terminals for the unknown is connected a capacitor whose value is known with small error or tolerance, and the bridge is balanced by adjusting the standard capacitor. Then the unknown, whose capacitance is to be measured, is connected in parallel with the capacitor already connected to the terminals for the unknown. The bridge again is

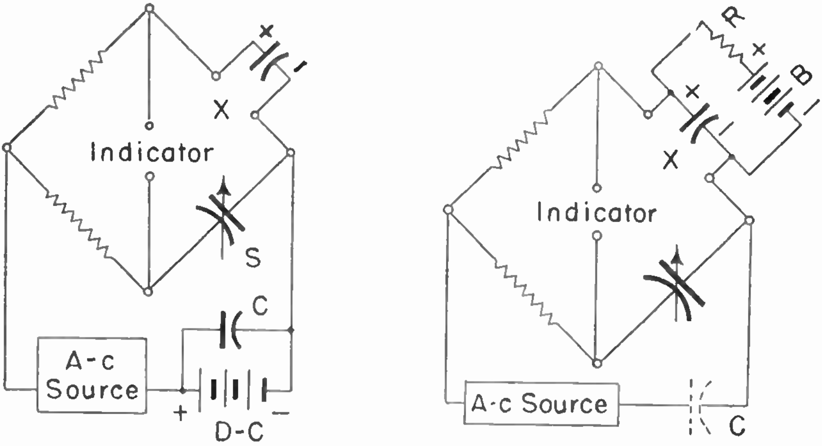


Fig. 15.—Testing electrolytic capacitors on capacitance bridges.

balanced by adjustment of the standard capacitor. The difference between the second and first capacitance settings of the standard is equal to the capacitance of the unknown.

The capacitance of electrolytic capacitors may be measured with capacitance bridges, while applying a polarizing voltage to the capacitor on test, by methods such as shown by Fig. 15. In the left-hand diagram the source of polarizing direct potential, shown as a battery, is connected in series with the a-c source. The d-c source is bypassed by a capacitor *C* having a capacitance of several microfarads, or whatever capacitance is required to have but small reactance at the frequency furnished by the a-c source. The electrolytic capacitor is connected between the X (unknown) terminals of the bridge in the usual manner, but with due regard to the polarities of the d-c source and this capacitor.

In the right-hand diagram the polarizing voltage from *B* is applied right at the electrolytic capacitor, which is connected between the *X* terminals of the bridge. In series with the d-c source must be a resistance whose value is several hundred times the reactance of the electrolytic capacitor at the frequency being used on the bridge. Otherwise the d-c source would provide a low resistance in the *X* arm of the bridge. In series with the a-c source is connected a capacitor *C* whose capacitance is several microfarads. This capacitor is used only during tests of electrolytic units. Note that with either of the polarizing arrangements shown, one of the ratio arms, of the resistance type, is in such a position as to permit action of the direct polarizing potential through the *X* arm of this ratio arm as they are connected across the a-c source. The right-hand arrangement may be adapted to other bridge connections provided the polarizing potential does not reach the indicator.

Inductance Bridges.—An inductance of unknown value may be measured against a calibrated adjustable inductance in the common type of ratio arm bridge with the arrangement shown by Fig. 16. The ratio arms are *a* and *b*. Either or both may be adjustable to provide various ratios. The standard calibrated adjustable inductor is *Ls*. In series with the standard inductor is an adjustable resistor *Rs* which is used to balance the resistance of the measured inductor, which is connected between the *X* (unknown) posts of the bridge. When both *Ls* and *Rs* have been adjustable for zero or minimum response of the indicator we use the formula,

$$\begin{array}{c}\text{Unknown}\\ \text{inductance}\end{array} = \begin{array}{c}\text{standard}\\ \text{inductance}\end{array} \times \frac{a}{b}$$

The fraction a/b is the ratio provided by the ratio arms. The unknown and standard inductances will be in the same unit; microhenrys, millihenrys, or henrys.

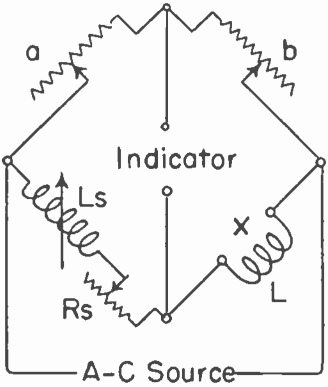


Fig. 16.—An inductance bridge of the ratio arm type.

The ratio arm bridge for inductance measurements requires an accurately calibrated variable inductor for the standard, or else several fixed inductors of known values which may be inserted in the standard position. Inductors are not so easily calibrated as are variable capacitors. Consequently there have been devised a number of types of bridge in which an unknown inductance may be measured by comparison with a standard capacitor rather than a standard inductor. In all of these bridges the value of measured inductance is proportional to the product of capacitance and resistance in the other three arms. Since the unknown value is computed by multiplication rather than with a ratio, these bridges cannot be called ratio arm types. Usually they are called by the names of the men who first devised the connections used in the several types.

Fig. 17 shows the principle of the *Maxwell* inductance bridge. The only difference between the two diagrams is the interchange of connections from the source and to the indicator. With either set of connections the current from the a-c source takes one path through resistance arm *a* and the unknown inductance at *X*, and another parallel path through the standard (*Cs* and *Rs*) and the resistance arm *b*.

The standard arm contains a calibrated variable capacitor *Cs*, in parallel with which is an adjustable resistor *Rs*. Capacitor *Cs* is used to balance the inductance of the unknown, and resistor *Rs* is used to balance the resistance of the unknown. It is necessary, in obtaining a balance, to manipulate *Cs* and *Rs*, also one or the other of the resistances at *a* or *b*. In some of these bridges *Cs* consists of two or more fixed precision capacitors, any one of which may be switched into the arms to provide certain multiplying factors, and either *a* or *b* have their control dials calibrated to read directly in henrys, millihenrys, or microhenrys.

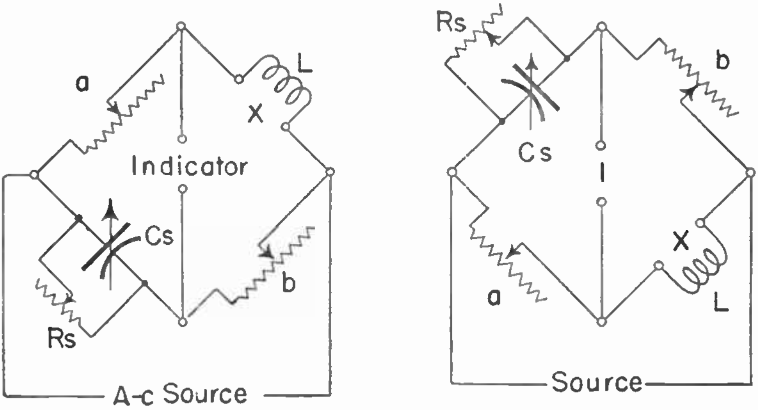


Fig. 17.—The Maxwell bridge for measurement of inductance.

When the bridge of Fig. 17 is correctly balanced for inductance of the unknown, by adjusting *Cs*, and for resistance of the unknown, by adjusting *Rs*, we may compute the inductance, the resistance, and the Q-factor of the unknown unit by using these formulas.

$$\begin{array}{c}\text{Unknown } L,\\ \text{microhenrys}\end{array} = \begin{array}{c}Cs \text{ in}\\ \text{microfarads}\end{array} \times a \text{ in ohms} \times b \text{ in ohms}$$

$$\begin{array}{c}\text{Unknown } L,\\ \text{microhenrys}\end{array} = \begin{array}{c}Cs \text{ in}\\ \text{micro-microfarads}\end{array} \times \frac{a \text{ in ohms} \times b \text{ in ohms}}{1\,000\,000}$$

$$\begin{array}{c}\text{Unknown } L,\\ \text{henrys}\end{array} = \begin{array}{c}Cs \text{ in}\\ \text{microfarads}\end{array} \times \frac{a \text{ in ohms} \times b \text{ in ohms}}{1\,000\,000}$$

$$\begin{array}{c}\text{Unknown } R,\\ \text{ohms}\end{array} = \frac{a \text{ in ohms} \times b \text{ in ohms}}{Rs \text{ in ohms}}$$

$$\begin{array}{c}\text{Q-factor}\\ \text{of unknown}\end{array} = \frac{Cs \text{ in mfd} \times Rs \text{ in ohms} \times \text{testing frequency, cycl}}{159\,155}$$

Fig. 18 shows the principle of the *Owen* bridge for measurement of inductance. Here again the unknown arm *X* is opposite the standard arm *S*, thus allowing comparison of the inductance at *X* with the capacitance at *S*. The standard, shown here as a variable capacitor, may be replaced with a fixed capacitor or with several precision fixed capacitors which are switched into the arm one at a time.

In the *a* arm there is an adjustable resistor, which may be a decade type, and in the *b* arm there is an adjustable capacitor *Cb* in series with an adjustable resistor *Rb*. The unknown inductance (or really its reactance) is balanced by adjustment of *Rb*, and the effect of resistance in the unknown inductor is balanced by adjustment of *Cb*. The inductance formulas for the Owen bridge are like those for the Maxwell bridge if we use for *Cs* in the formulas the capacitance of *S* in Fig. 18, and use for *b* in the formulas the resistance of *Rb* in Fig. 18.

The principle of the *Hay* bridge for measurement of inductance is shown by Fig. 19. Once more the standard and unknown arms are opposite each other. The inductor to be measured is connected between the *X* (unknown) posts. In the opposite standard arm there is a variable capacitor *Cs* in series with an adjustable resistor *Rs*. Arms *a* and *b* are resistors, either or both of which may be adjustable. The unknown inductance is balanced by adjustment of *Cs*, and the resistance of the unknown inductor is balanced by adjustment of *Rs*. This type of bridge is quite generally used for measurement of coils whose inductive reactance is ten or more times their effective resistance at the testing frequency, or for work with coils having Q-factors greater than 10 at the testing frequency.

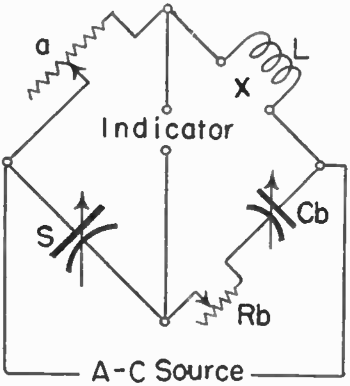


Fig. 18.—The Owen bridge for inductance measurement.

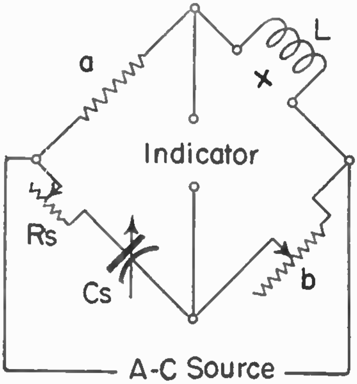


Fig. 19.—The Hay bridge for inductance measurement.

When computing inductance from values of resistance and capacitance taken on the Hay bridge it is necessary to consider the frequency of the operating potential applied from the a-c source. For the formula which follows the meanings of letter symbols are,

Lx	Unknown or measured inductance, microhenrys.
a	Resistance of a arm, ohms.
b	Resistance of b arm, ohms.
Cs	Capacitance of capacitor Cs, microfarads.
Rs	Resistance of adjustable resistor Rs, ohms.
f	Operating frequency or applied frequency, megacycles.

$$\mathrm{Lx} = \frac{\mathrm{a} \times \mathrm{b} \times \mathrm{Cs}}{1 + (6.2832 \times \mathrm{Cs} \times \mathrm{Rs} \times \mathrm{f})^2}$$

If *a* and *b* are taken as 100 ohms each, *Rs* as 10 ohms, *Cs* as 0.001 mfd., and *f* as 1 megacycle, it will be found that the inductance *Lx* comes to about 9.96 microhenrys.

Sources for A-c Bridges.—Various types of alternating-current bridges are designed for operation at frequencies ranging from the 60 cycles, taken through a transformer from a power and lighting line, up to as high as 50 or more megacycles supplied by a radio-frequency oscillator. Buzzer oscillators and tuning fork oscillators often are used at frequencies between 500 and 2,000 cycles. For audio frequencies up to 10,000 or more cycles the source often is a beat-frequency type of oscillator. For radio frequencies the source may be a modulated r-f oscillator. Higher frequencies are desirable for testing small capacitances and large inductances in order that the reactances of these units may be kept low enough to permit bridge currents and potential differences sufficient for actuating the indicators.

Indicators for A-c Bridges.—The indicator for use with a-c bridges often is one or a pair of high-impedance or high-resistance headphones connected between the indicator terminals shown on preceding diagrams. When headphones are used the source must provide a frequency within the range of clearly audible sounds, which, for most people, extends only from 200 to 5,000 cycles. Balancing adjustments are made so that there is minimum sound from the phones.

When measuring small capacitances or large inductances the small potential differences at the indicator terminals make headphone detection quite difficult unless the source furnishes high power. Sensitivity may be increased as shown in Fig. 20. Here there is connected between the indicator terminals and the phones an audio-frequency transformer, with the high-impedance winding connected across the indicator terminals, and the low-impedance winding to the phones. The transformer should have a shield between its windings, so that the shield may be grounded. The impedance of the winding on the phone side should match the impedance of the phones as nearly as possible at the frequency used for testing.

Headphone indicators are not satisfactory where there is much surrounding noise. For this reason it is common practice to use for the indicator a rectifier type a-c voltmeter or microammeter, or else an electronic voltmeter, although neither of these is as sensitive as the phones when working in quiet places. Of course, if the source potential is not at audio frequencies, or is not modulated with audio frequencies, some form of visual indicator must be used instead of headphones.

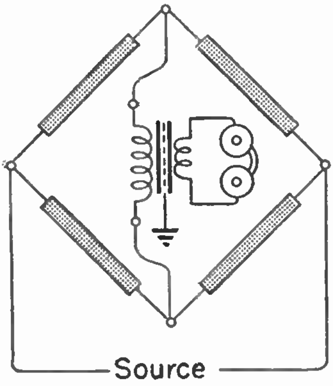


Fig. 20.—Headphones connected to a step-down transformer.

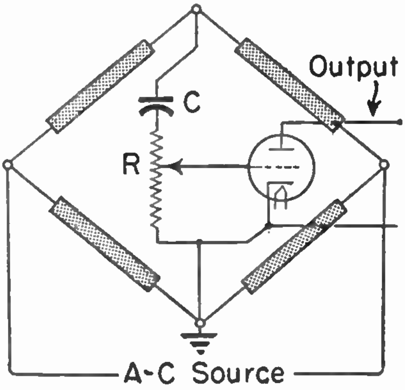


Fig. 21.—An amplifier tube in the indicator circuit.

The alternating potential differences appearing between the indicator terminals of the bridge may be amplified with one or more stages of amplification designed to operate at the testing frequency. Connection to the first amplifier tube is shown by Fig. 21. In the bridge arm are connected in series the blocking capacitor C and a volume-control type of voltage divider R. The slider is connected to the amplifier control grid, and the bottom of the resistor to the tube cathode. Required sensitivity is obtained by slider adjustment. In the plate circuit of the first or following amplifier tubes may be a d-c current meter acting as the visual indicator. Electron-ray tubes often are used for the visual indicator of amplifier output.

Operation of A-c Bridges.—There are so many general types of a-c bridges, and so many modifications of each type, that it would be impossible to give general instructions for operation which would apply to all of these instruments. The instructions which accompany the particular bridges should be followed.

In general, the first step is to set the standard and the ratio arms or else the multiplier arms as nearly as possible for the approximate value of unknown capacitance or inductance, then place the source in operation or connect it to the bridge, and observe the indicator. Then the standard, usually a variable capacitor, is adjusted for minimum response of the indicator. Next, the adjustment should be made on the element which balances the resistance effect of the unit being measured. With some bridges these two adjustments have no effect on each other, while with other types it is necessary to work back and forth between the two adjustments until there is minimum or zero response of the indicator. With the bridge thus completely balanced the measured capacitance or inductance is determined from direct readings of the dials or else is computed from appropriate formulas.

REVIEW QUESTIONS

1. May the ratio arms of bridges be formed of resistances, inductances, capacitances, or combinations of these elements?
2. What indicators are suitable for direct-current measurements, and what for alternating-current measurements with bridges?
3. The fundamental bridge formula is a/b = c/d, with a and b the ratio arms, c the standard, and d the unknown. What is the formula for the unknown, in terms of the other values?
4. Mention the principal parts of a slide-wire bridge and show how they are connected.
5. Are bridge readings inherently more accurate with high ratios, low ratios, or ratios near one-to-one between the standard and the unknown?
6. In simple types of bridges with resistance ratio arms would a capacitor be measured with the standard a resistance, a capacitor, or an inductor? What type of standard would be used when measuring an inductor?
7. Explain some of the methods for compensating for resistance of capacitors and inductors when making bridge measurements.
8. Describe one method for increasing the sensitivity or accuracy of null point determination with bridges operated from an alternating-current source.

Chapter 6

ANALYZERS AND MULTIMETERS

The measuring instrument which probably is used more often than any other in radio servicing is variously called an analyzer, a multimeter, or a volt-ohm-milliammeter. This instrument consists of a sensitive current meter of the moving coil permanent magnet type mounted on a case within which are resistance networks connected to selector switches or pin jacks which permit using the meter in various ways.

One type of analyzer is pictured in Fig. 1. This particular instrument is designed for measurement of either direct or alternating potentials in volts, direct currents in milliamperes and amperes, resistances in ohms and megohms, and a-f output in

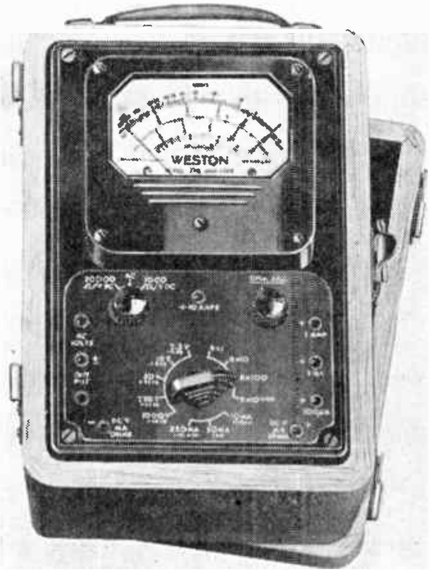


Fig. 1.—A Weston analyzer for measuring d-c and a-c volts, d-c milliamperes and amperes, decibels, and resistance, with several ranges for each kind of measurement.

decibels. By placing test leads in certain pin jacks it is possible to select the kind of value to be measured; potential, current, resistance, or output. The central rotary selector switch allows choosing any one of the several ranges which are available for measuring the different values. The upper left-hand switch determines the sensitivity for direct potential measurements, either 1,000 or 20,000 ohms per volt, and makes necessary connections for alternating potential measurements. The upper right-hand switch makes a preliminary adjustment for the measurement of resistance.

The sensitivity of the meter movement in the analyzer illustrated is 50 microamperes. The movement is suitably shunted for making current measurements, is used with suitable multiplier resistances for direct potential measurements, is used with an instrument rectifier for measurements of alternating potential and of output, and with suitable shunt and series resistances, and a self-contained battery, for measurement of resistance.

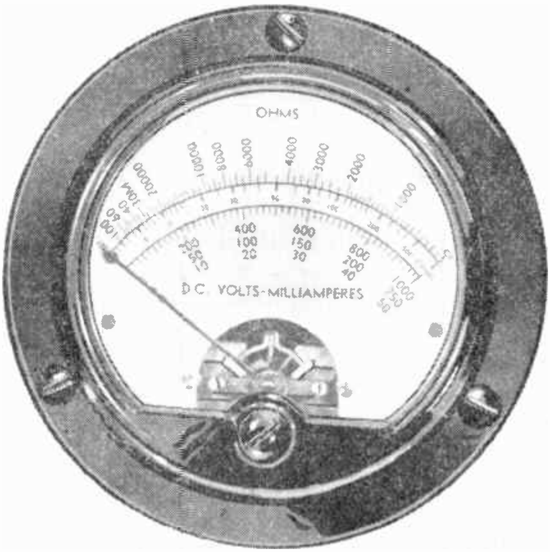


Fig. 2.—Meter scales for d-c volts and milliamperes, also for low and high resistances.

Although all analyzers are designed for similar purposes, they may have many different scale arrangements, different ranges, and different sensitivities of the meter movement. Fig. 2 shows the dial of a meter in an analyzer which is arranged to measure direct potentials and currents, and to measure resistances on one scale reading from zero at the left to 500 ohms toward the right, and on a second scale reading from zero at the right to 100,000 ohms at the left.

Still another scale arrangement is shown by Fig. 3. Note that on any scale showing both alternating and direct potentials, the direct potential values are evenly spaced, while those for alternating potentials are slightly crowded at the low end. This characteristic of rectifier voltmeters is explained in another chapter.

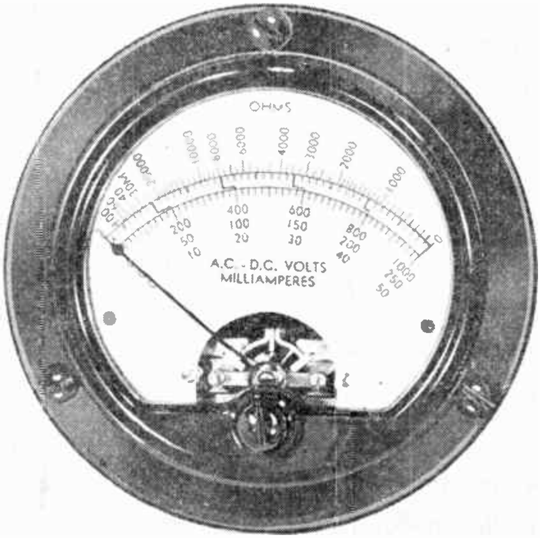


Fig. 3.—The a-c voltage scale always is slightly crowded near zero values.

Moving coil permanent magnet movements and their uses for measurement of direct currents and potentials, as well as their use in connection with instrument rectifiers for measurement of alternating potentials, have been explained in other chapters.

But the uses of such movements in a direct reading ohmmeter, and as a decibel meter, require some additional explanation before proceeding to examine the details of complete analyzers or multimeters.

Ohmmeters.—An ohmmeter is any instrument for the direct indication of resistances in ohms or megohms. Ohmmeters used in laboratories and in some kinds of industrial work may utilize the principle of the resistance bridge, or may have a moving element carrying two "differential" coils. But the type of ohmmeter nearly always used in radio service work, as well as in many other pursuits, consists essentially of a current meter in series with a battery and a resistor, so arranged that the unit whose resistance is to be measured may be connected in series with these other parts.

The elementary principle of the series resistance ohmmeter is shown by Fig. 4. The resistance of the meter movement is *Rm*. The series resistance is *Rc*. The battery potential difference is *E*. The resistance to be measured is connected at *Rx*. At the left there is nothing connected at *Rx*, or there is "infinite" resistance at this point in the circuit. No current flows, and the meter reads zero current.

In the center diagram of Fig. 4 there is direct conductive connection of negligible resistance at *Rx;* the *Rx* terminals are short circuited on each other. Resistance *Rc*, usually called the calibrating resistance, is of such value that the current now flowing causes full-scale deflection of the meter. The circuit

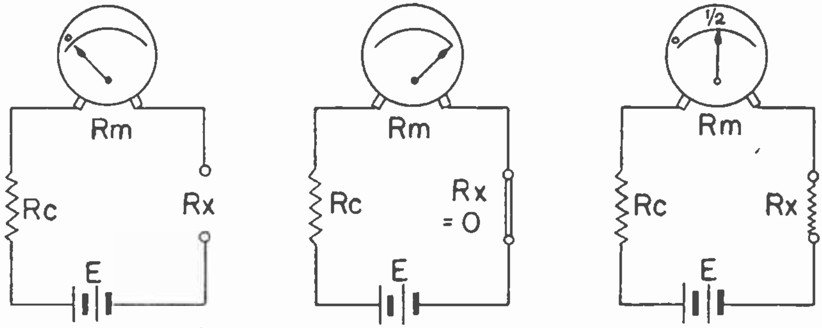


Fig. 4.—The principle of the series-resistance type of ohmmeter.

resistances are *Rc* and *Rm* in series. The current corresponds to Ohm's law, $I = E / Rc + Rm$.

At the right there is connected between the *Rx* terminals a resistance which is equal to the sum of *Rc* and *Rm*. Now the total resistance in the circuit is twice as much as with the center diagram, the current is decreased to half its former full-scale value, and the reading on the meter is at center scale. With any greater resistance at *Rx* there will be less current in the circuit, and the meter will read toward the left from center-scale. With any less resistance at *Rx* there will be more current and the meter will read toward the right from center-scale. The meter scale may be graduated to read directly the number of ohms connected at *Rx*, and we have an ohmmeter.

The deflection of the meter pointer, as a fraction of the deflection for full scale at the right hand end, is given by

$$\text{Deflection fraction} = \frac{Rc + Rm}{Rx}$$

This formula assumes that the battery has zero resistance, which is not strictly the case. For more precise determination the term above the line on the right-hand side of the formula should be $Rc + Rm + Rb$, where *Rb* is the resistance of the battery.

The ohms scale for the series resistance ohmmeter always is crowded at the high-resistance or low-current end, and is opened up at the other end. The uneven scale graduations are clearly shown in Figs. 1 to 3.

With the simple circuit of Fig. 4 it is apparent that, as the battery discharges and furnishes lower and lower voltages, the currents for any given measured increase in resistance will become smaller and the ohms readings will become higher. Therefore, it is necessary to provide means which compensate for drop of battery terminal voltage.

In some ohmmeters the moving coil movement is fitted with a magnetic shunt on the magnetic circuit, with provision for adjusting the position of the shunt from the outside of the case. Changing the magnetic shunt changes the sensitivity of the meter, and readings for a given measured resistance may be made to remain practically constant until battery voltage drops to an unusable value. The magnetic shunt is adjusted while the terminals for the measured resistance are short-circuited, as at the center of Fig. 4.

Fig. 5 shows a picture of an ohmmeter fitted with a magnetic shunt, also a diagram of the internal connections for the 5,000-ohm and 50,000-ohm ranges. On the 5000-ohm range resistors *R1* and *R2* are in series with the movement, with *R3* in parallel with the movement and the other two resistors mentioned. On the 50,000-ohm range *R1* and *R4* are in series between the movement and the external terminal, with *R2* and *R3* connected together in series and acting as a shunt across the movement and *R1*.

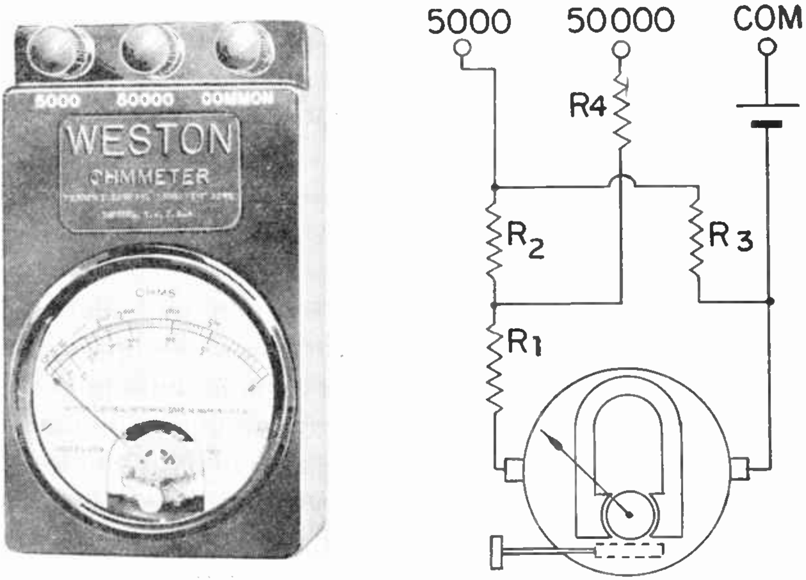


Fig. 5.—A Weston ohmmeter and its internal connections.

At the left in Fig. 6 is shown another method of compensating for drop in battery terminal voltage. Here there is an adjustable shunt resistance across the meter movement. The adjustable shunt consists of fixed resistor *Ra* and of variable rheostat *Rb*. With a new battery the slider on the variable resistor will be toward the left, reducing the shunt resistance and diverting more current from the meter. As the battery becomes weaker the slider is moved toward the right, increasing the shunt resistance and forcing more current through the meter movement. The shunt is adjusted while terminals *Rx* are short-circuited on each other, with the adjustment made to bring the meter pointer exactly to the right-hand end of its scale. This adjustment is made at the beginning of each measurement of resistance.

The sum of resistances *Ra* and *Rb* is made equal to five or more times the meter resistance, *Rm*, with most of the shunt resistance in the fixed unit, *Ra*.

The value required for the calibrating resistance *Rc* is found thus.

$$\begin{matrix}\text{Rc}\\ \text{ohms}\end{matrix} = \frac{\text{battery volts}}{\text{full-scale amps}} = \begin{matrix}\text{effective parallel resistance}\\ \text{of meter and shunt}\end{matrix}$$

Note that full-scale meter current for this formula is in amperes, not milliamperes, when the resistance of *Rc* is determined in ohms. If the meter movement resistance were 60 ohms, for an example, and the resistance of *Ra* plus *Rb* were 300 ohms with *Rb* at the center of its adjustment, the effective parallel resistance of meter and shunt would be 50 ohms. If the meter were 1-milliampere type the full scale amperes would be 0.001

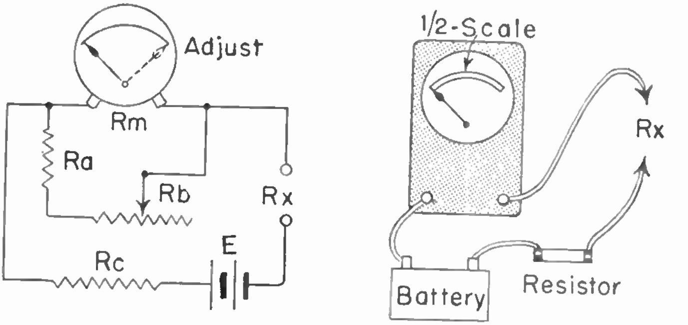


Fig. 6.—A resistance shunt for an ohmmeter (left) and a method of increasing the measurement range (right).

ampere. Assuming the use of a single dry cell delivering a nominal 1.5-volt potential difference, and placing the assumed values in the formula, we would have,

$$\underset{\text{ohms}}{\text{Rc}} = \frac{1.5}{0.001} - 50 = 1500 - 50 = 1450 \text{ ohms}$$

The resistance indicated at half-scale on the meter always will be equal to the sum of the resistances of the calibrating resistance, the meter as shunted, and the internal resistance of the battery. Neglecting the battery resistance, as is done in the preceding formula, the half-scale or center-scale reading for the ohmmeter having the 1450-ohm calibrating resistance would be 1,500 ohms.

In general, when the calibrating resistor is of correct value to allow full-scale deflection of the meter with the *Rx* terminals shorted, the half-scale resistance reading may be found from dividing the number of battery volts by the full-scale current in amperes. By figuring out a few combinations of volts and amperes you will discover that for measurement of higher resistances it is necessary either to decrease the full-scale current by using a more sensitive movement or to increase the battery voltage. Conversely, to measure lower resistances with this series resistance ohmmeter, it is necessary to use a movement having greater full-scale current or else to use less battery voltage. Since a single dry cell gives about 1.5 volts we are limited as to reduction of battery voltage, and, for low resistance measurements we must use less sensitive movements. For measurement of high resistances it is common practice to use dry cell batteries of 22½ volts or greater potential differences, and to use movements having sensitivities down to 100 microamperes or less. With 45 volts and a 50-microampere movement the half-scale reading would be for 900,000 ohms.

The range of an ohmmeter of the series resistance type may be increased as shown at the right in Fig. 6, placing in series with one of the leads an extra resistor and an extra battery whose voltage is enough to permit adjusting the meter pointer to zero ohms with the leads short-circuited at *Rx*. Using an extra resistance equal to the resistance reading at half-scale will double the range in ohms, and adding any greater number of times the center-scale resistance will increase the range by more than the same number of times, provided enough extra battery voltage is added to permit zero adjustment. For instance, if the center-scale reading is 4,500 ohms, adding 4,500 ohms will make the center-scale reading correspond to 9,000 ohms. Adding four times the original 4,500 ohms, or 18,000 ohms, will increase the range by four plus one times, or by five times, and the center-scale reading will correspond to 22,500 ohms.

An ohmmeter circuit arranged for measurement of small resistances is shown by Fig. 7. The battery *E*, calibrating resistance *Rc*, and meter are in series with one another, with the zero-adjusting shunt resistors *Ra* and *Rb* connected across the meter as in preceding diagrams. But instead of connecting the measured resistance in series with the ohmmeter circuit it is connected in parallel with the meter so that the measured resistance acts as a shunt on the meter. With this arrangement, the smaller the resistance at *Rx* the more of the meter current will flow

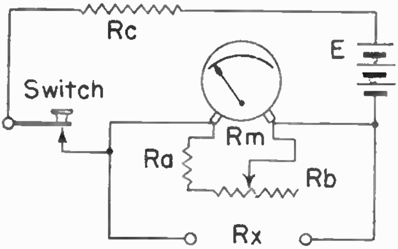


Fig. 7.—An ohmmeter with which the measured resistance is placed in parallel with the meter movement.

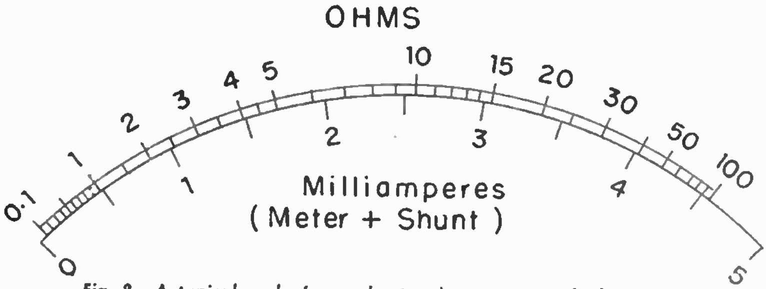


Fig. 8.—A typical scale for a shunt-resistance type of ohmmeter.

through Rx and the less through the meter movement. Then we have an ohms scale with low resistances toward the left or at the low current end, and with resistances increasing toward the right.

A scale for this shunt resistance type of ohmmeter is shown by Fig. 8. The resistance scale here is placed above a uniformly graduated scale showing current in the meter and its zero-adjusting shunt resistors. This particular scale would fit an ohmmeter of the following construction. Movement having full-scale deflection at 5 milliamperes and internal resistance of 12 ohms, with zero adjusting shunt of 48-ohm resistance. The battery would be assumed to deliver a 4.5-volt potential difference. The calibrating resistance would be 893.4 ohms.

The battery circuit in the shunt resistance ohmmeter must be kept open by a switch except during resistance tests. A press-button or key switch of the momentary contact type would be used. Fig. 9 shows a shunt resistance scale placed above a series resistance scale. Resistances from $\frac{1}{10}$ ohm to 10 ohms would be measured with the shunt arrangement, reading the upper scale; the resistances from 10 to 1,000 ohms would be measured with the series arrangement and read on the lower scale.

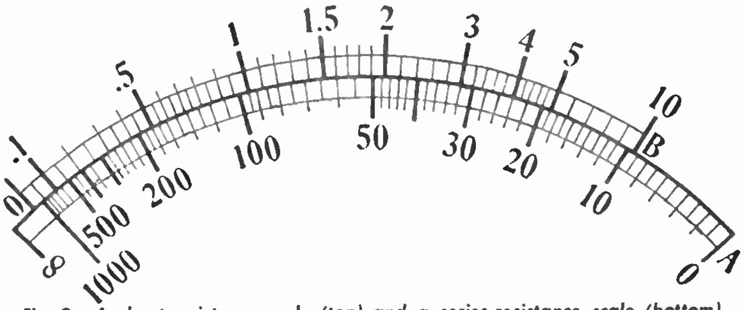


Fig. 9.—A shunt-resistance scale (top) and a series-resistance scale (bottom) for the same instrument.

When using an ohmmeter of the types which have been described, always short-circuit the external terminals and adjust the pointer for zero ohms before making measurements. Accurate readings depend on the precision with which this adjustment is made. When the ohmmeter cannot thus be adjusted to zero it is time to replace the battery or batteries with new ones.

To make accurate measurements of resistances it is advisable to work between one-quarter and three-quarters of the distance across the scale. Accuracy is best near the center of the scale, and when several ranges are provided it is well to use the one which permits most of the readings to be taken near center-scale. Measurements at the left-hand end of the scale, or at the low-current end, suffer from inherent inaccuracy of the meter which, as you will recall, usually increases in percentage of the actual reading when moving away from the full-deflection end of any scale. With a series-resistance ohmmeter, readings at the left-hand end of the scale are too crowded for accuracy, and with a shunt resistance type the readings are too crowded at the right-hand end.

Never let your fingers touch the metallic part of prods or clips while making measurements, this because the rather low resistance of your body then shunts the leads and makes readings of high resistances most inaccurate.

If the unit whose resistance is being measured is connected into a radio circuit be sure to shut off the power before making tests. If capacitors are to be checked for leakage resistance, make sure that they are discharged by short-circuiting their terminals before applying the ohmmeter. This applies especially to power supply filter capacitors.

When testing electrolytic capacitors for leakage connect the negative terminal of the capacitor to the ohmmeter terminal or lead which goes to the negative end of the ohmmeter battery. The voltage ratings of most electrolytics are higher than voltages of batteries used in ohmmeters, but the voltage relations are worth considering if there is any doubt.

Output Meters.—Output meters which are constructed as separate instruments ordinarily are rectifier type a-c voltmeters with their scales graduated in volts, in decibels, or in both units. The meter is arranged to have a resistance or impedance of at least four or five thousand ohms, so that when connected to a circuit whose output is to be measured the meter will not have too much short-circuiting effect and will not unduly affect the impedance of any line to which connected. Output meters are provided with selector switches that permit measurements in any of several ranges of voltages or decibels.

In order that the impedance of the output meter may remain practically constant when the various voltage or decibel ranges are used, many of these meters have in their range shifting circuits combinations of resistors such as shown by Fig. 10. At the left there is a voltage divider much like some radio volume controls, with the ends of the resistor connected to the input terminals, and the slider and one end of the resistor connected to the meter. The total resistance of the divider remains across the input while the portion of the voltage applied to the meter is varied.

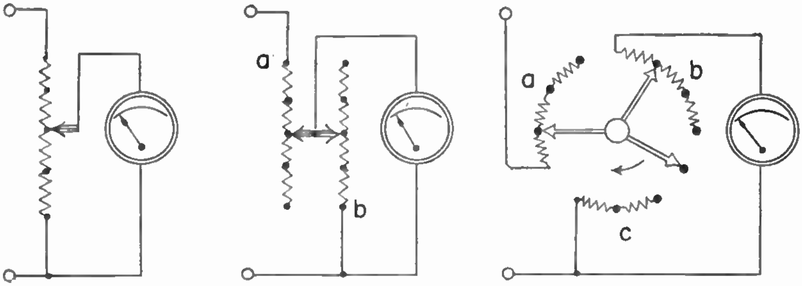


Fig. 10.—Constant impedance range-shifting circuits for output meters.

In the center diagram there are two resistance arms with a single slider. As the slider is moved the sum of the resistances across the input does not change, this sum being equal to the resistance from *a* to the slider plus the resistance from the slider to *b*. But the resistance shunted across the meter is only the portion between the slider and *b*, which increases with upward movement of the slider, and decreases with downward movement.

In the right-hand diagram there are three resistance sections and a three-armed contact member. When the three-armed rotor in the position shown there is in series with the meter one section of the resistances in arms *a* and *b*. As the rotor is turned in the direction of the arrows more of the series resistances *a* and *b* are cut in, while all of the resistance in arm *c* is placed in parallel with the meter. The final movement of the rotor cuts in all of the series resistances *a* and *b*, and cuts out part of the parallel resistance from arm *c*.

When there is direct current along with the alternating current in the circuit tested, as is the case with plate circuits and some others, and when it is desired to measure only the alternating voltage or output, a capacitor must be connected in series with the meter to block the direct current. The series capacitance should be at least one-tenth microfarad for audio-frequency measurements, and often is as much as two microfarads, with a rated voltage of 600 or more. In some output meters and in some analyzers there are two terminals or pin jacks for alternating potential measurements, one of these having in series a blocking capacitor used when direct current is to be kept out of the meter. As frequency in the measured circuit becomes lower, the reactance of the blocking capacitor increases, and at some of the lower frequencies this may cause serious errors.

Fig. 11 shows an output meter with a scale graduated in

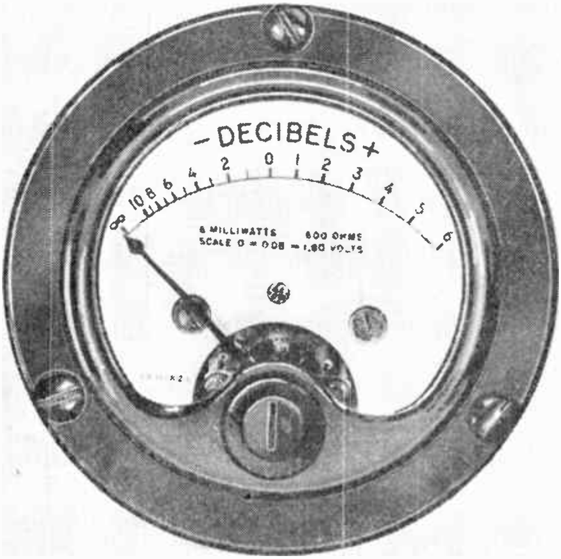


Fig. 11.—A decibel scale used on a rectifier type a-c voltmeter.

decibels. Generally similar scales appear on some of the preceding pictures. These scales read decibels "down" or minus, or read losses below zero, and read decibels "up" or plus, indicating gains, above zero. The zero point on the scale, or the zero voltage level, usually is based on a power of 6 milliwatts (0.006 watt) in either a 500-ohm line or else in a 600-ohm line. In any case the number of volts at zero decibels is equal to the square root of the product of line ohms and watts. For example, with a 500-ohm line and 6 milliwatts or 0.006 watt we have,

$$\text{Volts for zero db} = \sqrt{500 \times 0.006} = \sqrt{3} = 1.732 \text{ volts}$$

Making a similar computation for 600 ohms and 0.006 watt would show 1.987 volts as corresponding to zero decibels. The voltages for 500-ohm and 600-ohm lines usually are specified as 1.73 and 1.90 volts, the latter value appearing on the scale of Fig. 11.

When measurements are made on lines or loads having resistances or impedances other than the 500 ohms or 600 ohms for which decibel scales are graduated it is necessary to add to or subtract from the meter indication the numbers of decibels listed in the accompanying table.

CORRECTIONS FOR DECIBEL READINGS

Actual line	Calibration		Actual line	Calibration	
impedance	500 ohms	600 ohms	impedance	500 ohms	600 ohms
50 ohms	+ 10	+ 10.8	400 ohms	+ 0.97	+ 1.76
75 ohms	+ 8.14	+ 9	500 ohms		+ 0.79
150 ohms	+ 5.23	+ 6	600 ohms	— 0.79	
200 ohms	+ 4	+ 4.77	1000 ohms	— 3	— 2.22
300 ohms	+ 2.22	+ 3	2000 ohms	— 6	— 5.23

When several ranges may be used for a meter graduated in decibels, the basic range or the "one-to-one" range is read directly from the meter scale, but with other ranges in use it is necessary to add to or subtract from the scale readings certain numbers of decibels. These numbers of decibels to be added or subtracted usually are shown on the positions of the range selector switch or on the pin jacks used for the several ranges. On the analyzer pictured by Fig. 12 the pin jacks used for decibel measurements are in the upper horizontal row. Above each jack is shown the number of decibels to be added to the meter indication when that jack is used for a test lead. The addition is algebraic. That is, when the meter indication and correction are both positive the addition is made in the usual way, as + 4 on the meter and + 20 on the jack would mean + 24 decibels. But were the meter reading — 6, for example, and the jack number + 20, the number 6 would be taken away from 20 to give the output as + 14 decibels.

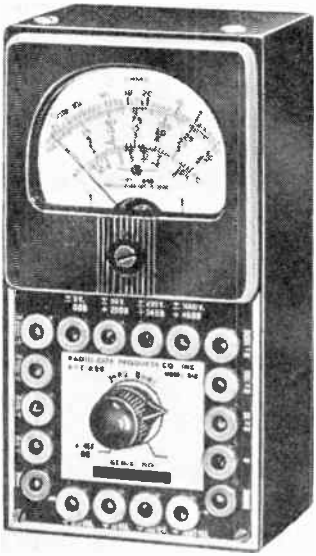


Fig. 12.—An RCP Multitester for measurement of a-c and d-c potentials, d-c currents, resistances, and output decibels. (Radio City Products Co.)

On the output meter of Fig. 13 the decibel additions and subtractions for the meter scale indications are shown at the various positions of the rotary range selector switch that is on the panel below the meter.

D-c Volt-ohmmeter.—Fig. 14 shows internal connections for one type of combination multi-range d-c voltmeter and ohmmeter. To the left of and below the meter is a two-position switch which is set at the "VM" position when the instrument is to be used as a voltmeter, and at "RES" when it is to be used as an ohmmeter. External test connections are made by inserting the tips of test leads in pin jacks arranged in two rows across top and bottom of the panel. For voltage tests one lead is placed in the negative jack, and the other in the jack marked with the maximum voltage of the range desired. Correct connection polarity should be observed, connecting the positive of the measured source to positive of the meter, and negative to negative.

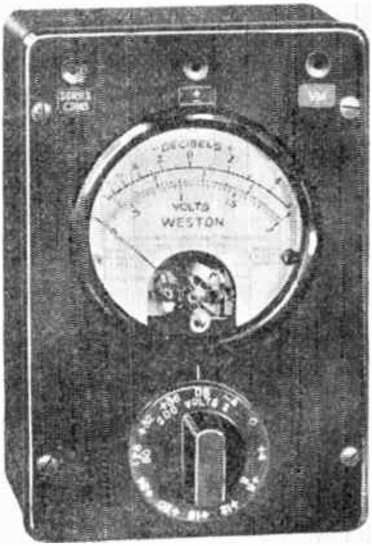


Fig. 13.—A Weston power level meter having 20,000 ohms constant impedance, and reading in volts and decibels.

When used as an ohmmeter the "Battery Adjustment" rheostat and series resistor are connected across the meter terminals to permit setting the meter pointer to zero ohms while short-circuiting the resistance pin jacks for any range. For resistance measurements one test lead is placed in the *X* jack and the other lead in the jack for the range to be used. The 4.5-volt dry cell battery is in series with the *X* jack. When the *R* jack is used the resistance is read directly from the meter scale. With the *R* × *10* jack the scale readings are to be multiplied by 10, and by 100 or 1000 when the other jacks are used.

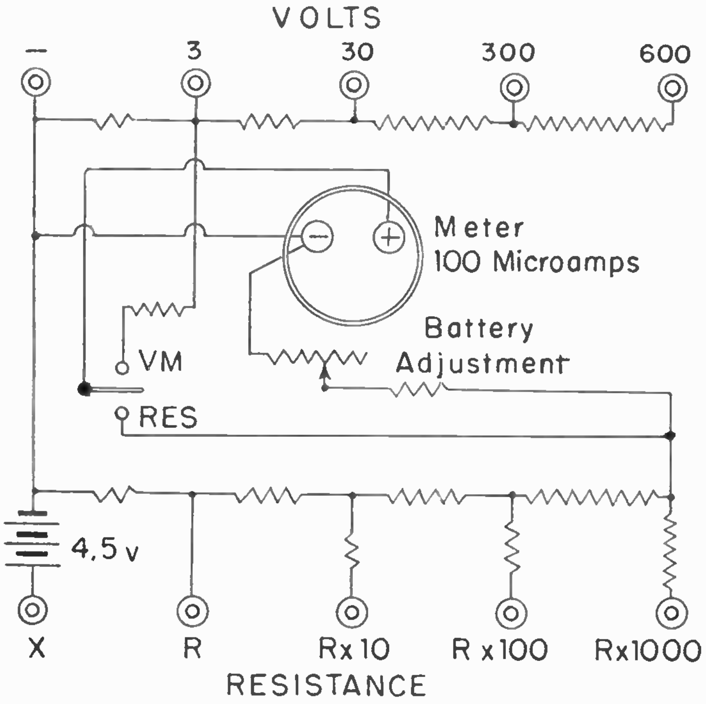


Fig. 14.—Internal connections for one type of multi-range Weston volt-ohmmeter.

AC-DC Volt-milliammeter.—Fig. 15 shows internal connections for one style of combination multi-range instrument for measurement of d-c volts, a-c volts, or d-c milliamperes. The full-wave bridge type instrument rectifier used for a-c voltage is shown below the meter. Below the rectifier is a three-pole double-throw switch that is placed in the *DC* position (all three contact arms upward) for d-c voltage measurements with the meter connected to multiplier resistors without the rectifier in circuit. Moving this switch to the *AC* position places the meter across the rectifier output, connects one rectifier input terminal to the negative pin jack at the lower right, and connects the other rectifier input terminal in series with multiplier resistors and the upper positive pin jack which is used for voltage measurements.

The range switch has eight positions for connection to meter shunts *Ra*, *Rb* and *Rc* for d-c milliampere measurements, and to multiplier resistors *Rd*, *Re* and *Rf* for both d-c and a-c voltage measurements. Current measurements are made by using the negative pin jack and the lower positive jack. With the range switch at *1* the meter is not shunted and would read smallest currents. At *2*, *3*, and *4*, shunts of successively lower and lower resistances are placed across the meter to permit reading greater and greater currents by multiplying the scale indications. With the range switch at *5* the meter, or meter and rectifier, are in series with all three multipliers, *Rd*, *Re* and *Rf*, to permit meas-

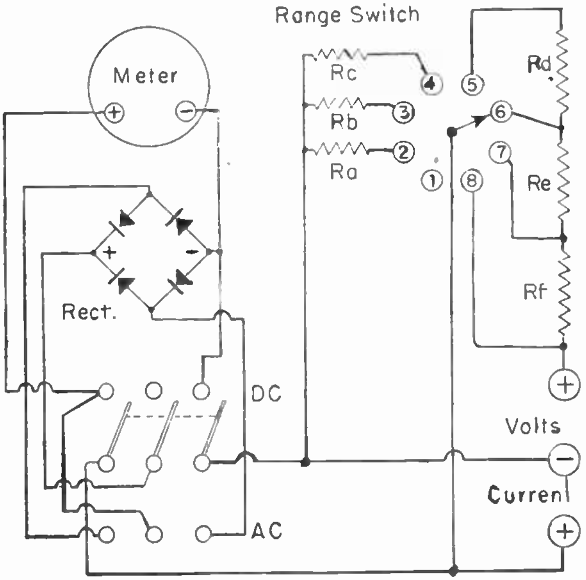


Fig. 15.—Connections for a multi-range volt-milliammeter.

urements in the highest voltage range. At position *6* only *Re* and *Rf* remain in series, at *7* only *Rf* remains in circuit, and at *8* there is no multiplying resistance and we would have a millivoltmeter. At position *1* the meter is not shunted, and will indicate its normal current. With the circuit of Fig. 15 we have four ranges for d-c volts, four for a-c volts, and four for current.

On all a-c voltage ranges found in analyzers the sensitivity usually is no greater than 1,000 ohms per volt, although the d-c voltage sensitivity may be greater. The limited a-c voltage sensitivity is selected because it permits enough current in the instrument rectifier to avoid the effects of the high and varying rectifier resistance which occur with small currents in the rectifier. The variation of rectifier resistance with rectifier current was explained in connection with the general characteristics of such rectifiers. When higher sensitivity is provided for d-c voltage measurements the d-c movement will have full-scale deflection with currents of 500 down to 50 or fewer microamperes, and will be used with suitable multipliers for d-c voltages. To reduce the sensitivity for a-c voltage measurements, and thus allow more current in the rectifier, the movement is shunted with a suitable value of resistance.

Analyzer Circuits.—Fig. 16 shows the internal connections of the analyzer pictured by Fig. 12. The meter movement is of 200 microampere sensitivity. At the left of the meter is shown the two-position switch which is moved to the upper point for resistance measurements, and to the lower point for all other measurements. The "Zero Ohms" adjusting resistor is in series with the "Ohms" position of the switch.

Pin jacks shown in the upper row on the diagram are used for current measurements. The "Common" jack at the right-hand end of this row is the common negative jack for all current ranges and for all d-c voltage ranges, and is the common jack for one test lead used for all a-c voltage ranges.

The common jack for all resistance ranges is the one marked "Ohms." Using this jack and the *R* jack at its left allows reading ohms directly on the meter scale. Using the *R* × *10* jack or others toward the left requires multiplying the scale readings by the factors shown under the other jacks. Note that there is a single 1.5 volt dry cell in series with the "Ohms" jack, and that in series with the "R × 1000" jack there is an additional 3-cell 4.5-volt dry battery which provides the necessary higher potential for measuring high resistances.

The rectifier used in this analyzer is a half-wave germanium crystal diode type which permits a-c and decibel measurements at frequencies up to 50 kilocycles with good accuracy.

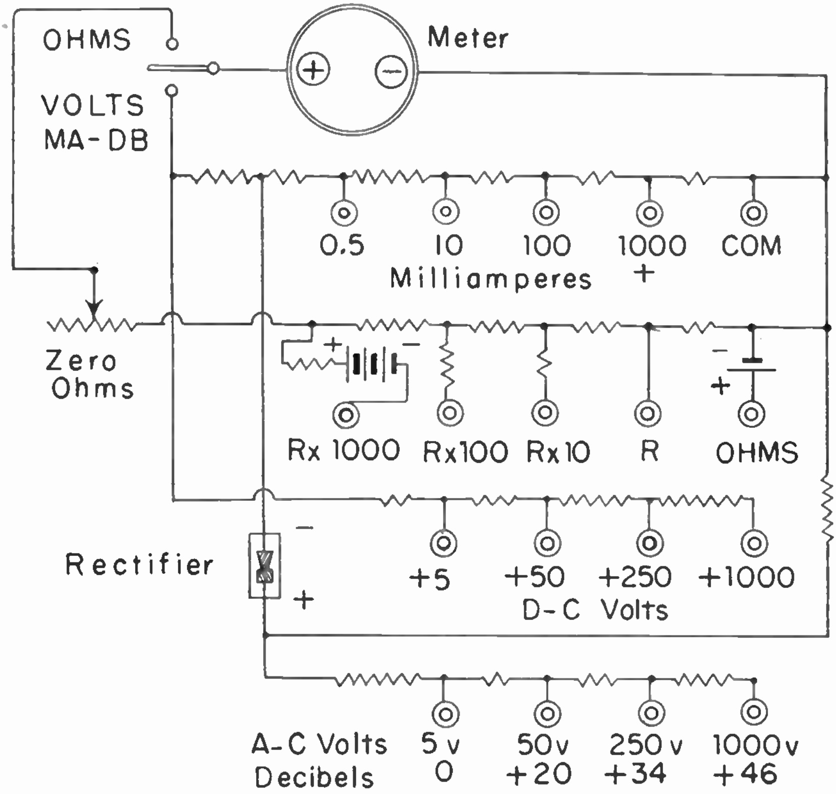


Fig. 16.—Internal connections of one type of RCP Multitester.

Fig. 17 shows the internal connections for an analyzer designed to measure direct and alternating currents and potentials, also resistance, and all of these in several ranges. On the panel of the instrument are eight plug jacks which, in the diagram,

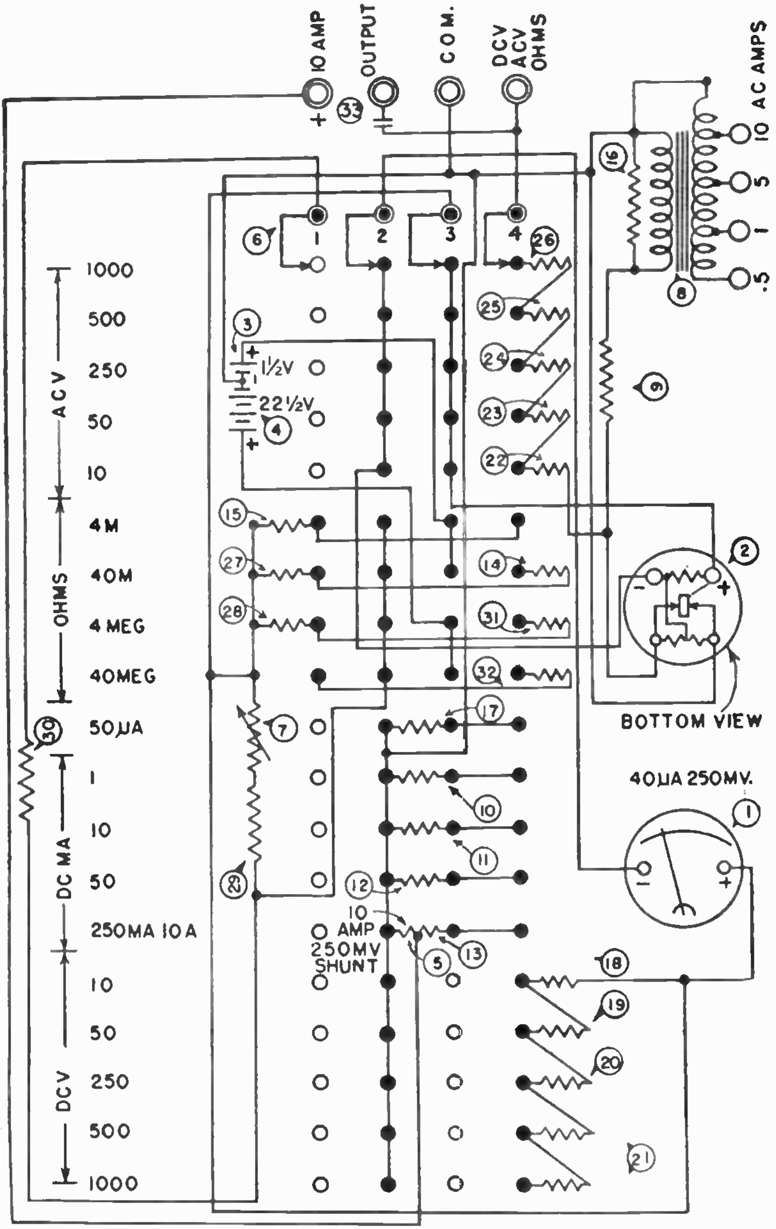


Fig. 17.—Internal connections and switching for a Triplett volt-ohm-milliammeter.

are shown across the top and at the upper right-hand side. The test leads are placed in various pairs of these jacks; which pair depending on the kind of value to be measured.

The ranges for the several kinds of measurements are controlled by a 20-position four-section rotary switch. The rotor and the contact positions for each of the four sections are represented by four vertical rows of circles extending downward from four top circles numbered *1*, *2*, *3* and *4* from left to right. It is to be assumed that, as the selector switch is rotated, contacts from these numbered circles pass downward successively over all of the circles below each of them. On the left-hand side of the diagram are shown the positions of the range selector switch. At the top is indicated the position (of the contacts *1*, *2*, *3* and *4*) for the 1000-volt a-c range. For this one range the numbered contacts are shown connected by arrowheads to the four points immediately below. On the next lower position of the selector switch, for the 500-volt a-c range, the arrowheads would be assumed to move downward to the four points next below, and with following movements of the selector switch the contacts would move downward onto the four points opposite each of the ranges shown at the left.

The meter movement is shown at *1* on the diagram. The rectifier unit, which is a replaceable plug-in assembly, is shown at *2*. At *3* is shown the 1.5-volt dry cell used when measuring resistances in the ranges having maximums of 4,000 and 40,000 ohms, while at *4* is shown the 22.5-volt dry battery used for the ranges of 4 and 40 megohms. At *7* is shown the adjustable resistor used for bringing the meter pointer to zero ohms at the beginning of resistance tests, this unit being in series with fixed resistor *29*. All of the remaining resistors are shunts, multipliers, and calibrating units.

Fig. 18 shows connections to the jacks for the various kinds of measurements. The common (COM) jack always is used for one of the test leads. As shown by the diagram at the upper left, most measurements are made by using the common jack and the one at its right, marked DCV-ACV-OHMS. The four jacks in a vertical row at the right are used for measurements of alternating current. These jacks connect to taps on the primary or input winding of the transformer shown at 8 in Fig. 17. The secondary of this transformer connects to the instrument rectifier.

Fig. 19 is a picture of another multi-range tester with which various combinations of jacks and selector switch positions are used for making a variety of measurements. The circuit diagram for this tester is shown by Fig. 20. On the panel are eight jacks, three on each side of the meter and two in each of the lower corners. All of these jacks are shown at the bottom of the diagram. There are three adjustment or selector knobs or pointers across the panel. The one at the left is for making the zero ohms setting at the beginning of resistance measurements. The adjustable resistor for this purpose is *R25* at the upper right in the diagram. The center pointer operates the range selector switch which is represented in the diagram by the four horizontal rows of 12 contacts each. The rotors which are moved over the contacts as the switch is moved from position to position are represented by the arrowheads touching the left-hand contacts in each row. The right-hand pointer on the panel controls the circuit selector switch that is shown on the diagram, enclosed by a

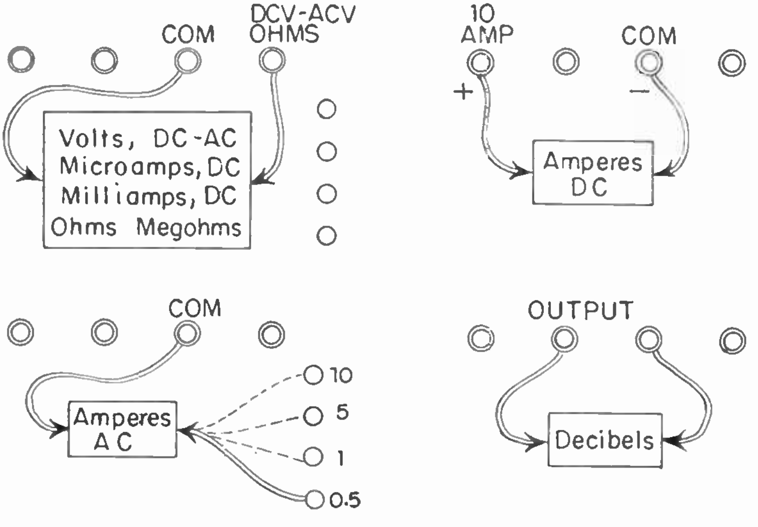


Fig. 18.—Connections to the jacks of the Triplett volt-ohm-milliammeter.

broken line, at the lower left. This is a three-position four-section switch for which the four rotors are represented by four arrowheads in the diagram.

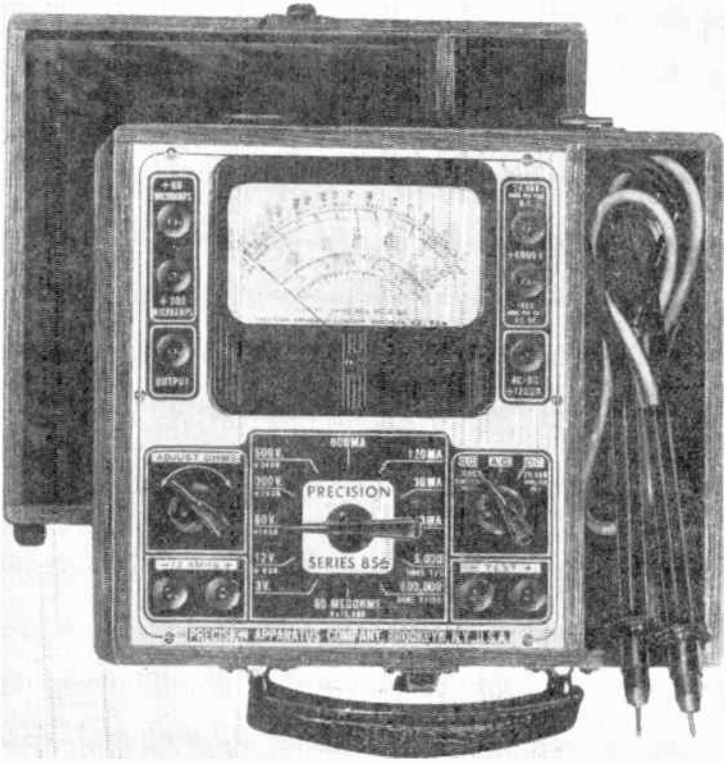


Fig. 19.—A multi-range tester with two selector switches and zero ohms adjuster on the panel. (Precision Apparatus Company)

The meter *M1* has a 50-microampere d-c movement. The rectifier *X1* for a-c measurements is shown below the meter. Resistors *R7*, *R13* and *R32* are calibration units which are sealed after the factory adjustment. The 1.5-volt dry cell used for low-resistance measurements is at *B1*, and the additional 22.5-volt battery for high-resistance measurements is at *B2*.

The accompanying table shows the pair of jacks that are used, and the settings of the two selector switches, for measurements of various kinds and ranges of potentials, currents and resistances. The left-hand column lists the kinds of measurements made. Voltmeter sensitivities are given in the second column for the jack combinations and selector switch settings listed on the same horizontal lines. The third column lists maximum values of potentials, currents, and decibels which may be measured with the given settings and jacks. The jacks to be used are given the same names as appear on the picture in Fig. 19.

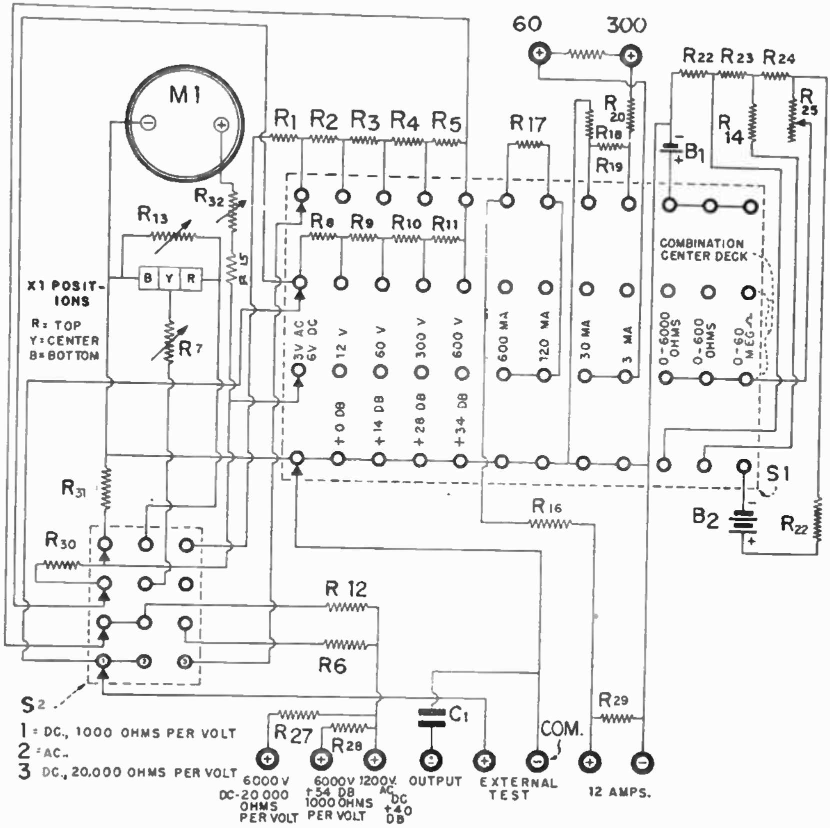


Fig. 20.—Internal connections of the Precision Apparatus multi-range tester.

"PRECISION APPARATUS" MULTI-RANGE TESTER

CHARACTERISTIC MEASURED	SENSITIVITY Ohms/Volt	HIGH LIMIT	JACKS TO BE USED		SET RANGE SELECTOR	SET CIRCUIT SELECTOR
Volts, d-c	1,000 or 20,000	600 v	— Test	Test +	For range	DC 1,000 or DC 20,000
		1200 v	— Test	AC-DC + 1200	At 600 v	As above
		6000 v	— Test	1000 AC-DC	At 600 v	As above
Volts, a-c, Output or Decibels, when DC is present	1,000	600 v or + 34 db	Test +	Output	For range	A.C.
Volts, a-c, Output or Decibels, when no DC present	1,000	600 v or + 34 db	— Test	Test +	For range	A.C.
Volts, a-c, Output or Decibels, when no DC present	1,000	1200 v or + 40 db	— Test	AC-DC + 1200	At 600 v	A.C.
		6000 v or + 54 db	— Test	1000 AC-DC	At 600 v	A.C.
Amperes, d-c		12 amp	— 12 Amps	Amps +	At 600 ma	DC 20,000
Milliamps, d-c		600 ma	— Test	Test +	For range	DC 20,000
Microamps, d-c		300 micro-A	— Test	+ 300 microA	At 30 ma	DC 20,000
		60 micro-A	— Test	+ 60 microA	At 30 ma	DC 20,000
Ohms, Megohms			— Test	Test +	For range	DC 20,000

The pictures and circuit diagrams shown in this chapter illustrate some of the general practices followed in the design and construction of analyzers and combination multimeters. It is possible to utilize the general principles with a great variety of tests made by any given instrument, and in the ranges of measurement which are made available.

Analyzer Operation.—When using an analyzer or multimeter for trouble shooting on radio apparatus it is usual practice to commence by measuring the voltages in heater or filament circuits, plate circuits, screen circuits, and control grid circuits. Service instruction diagrams furnished by manufacturers often show the voltage measurements which are normal at various points, otherwise it is possible to get fairly good ideas of normal voltages by noting the types of tubes and referring to tube specification or characteristic tables. If voltages are abnormal in only one or two stages, or only in certain sections of the apparatus, and are normal or close to normal elsewhere, only these sections need be checked. But if all voltages are high, or all are low, the power line, power transformer, or the d-c power supply should be checked. This means commencing with a measurement of line voltage, then following through the power supply system until reaching the voltage divider or the voltage dropping resistors connecting to the several tube circuits.

Voltage tests are made while the line or battery power is being applied to the receiver, amplifier, or other apparatus. Measurements of current in any of the tube circuits requires opening a connection for insertion of the current meter in series. The power always should be shut off while making the meter connections, then turned on while taking readings.

When measurements of voltages, and sometimes of currents, have shown the part of the apparatus in which trouble exists, it is usual practice to use the ohmmeter for checking resistance of resistors and windings, for checking capacitors for leakage, for locating short circuits and accidental grounds, and for locating abnormally high resistance at connections, or completely opened circuits. Ohmmeter tests are made while the power is shut off. Whether resistance can be measured in a certain unit without disconnecting one side or the other of that unit from its circuit depends entirely on whether there are in parallel with that unit any paths wherein testing current from the ohmmeter might flow to give erroneous indications. Often it is quicker to disconnect a suspected part than to figure out whether its resistance may be correctly measured without disconnection.

It is obvious that a circuit diagram or wiring diagram of the troublesome apparatus will be of great help in any case. With apparatus having complicated or unfamiliar circuit and wiring arrangements a diagram is a practical necessity.

With multi-range meters always commence testing with the highest range unless you are certain that voltage or current will not exceed some certain range. There seldom is any such certainty with a circuit which is giving trouble. Having determined the current or voltage maximum, turn off the power and shift to the range which will suit the conditions. It is best to select a range with which measurements may be made in the upper half of the meter scale, thus avoiding the increasing percentage error which occurs with lower readings.

When measuring currents try to make connections of correct polarity between circuit and test instrument. That is, connect positive to positive and negative to negative. Ordinarily a d-c meter will not be damaged by a reversed current which is no greater than the full-scale current in the correct direction unless the reversed current is applied so suddenly as to bend the pointer.

Always examine the meter pointer before the instrument is connected or turned on to note whether the pointer stands as zero current or voltage point, and make a zero adjustment if necessary. Always check the reading for zero ohms, usually by short-circuiting two resistance terminals, before making resistance measurements.

When using voltmeters of high sensitivity, such as 20,000 ohms per volt, make certain that insulation between terminal or jack connections is clean and dry. Otherwise the lowered surface resistance will shunt the meter and cause incorrect readings. Surface leakage should be prevented also between connections at the part tested. It must be kept in mind that the potential difference indicated by any voltmeter, no matter how sensitive, will be less than the potential difference existing without the meter connected. The greater the meter sensitivity or resistance the less will be this error. Most a-c voltmeters of the rectifier type read somewhat lower than true potential differences between the meter terminals at frequencies higher than eight to ten kilocycles.

When an analyzer provides a choice between two d-c voltage sensitivities, one of 1,000 ohms per volt and one higher than this, the 1,000 ohm per volt sensitivity is used in connection with service instructions or service diagrams which show point-to-point voltages determined with a meter of this sensitivity. So long as the test information is based on measurements with a given sensitivity, a meter of the same sensitivity must be used if actual measured voltages are to be compared with the service data. Using a meter of much greater sensitivity would give readings which actually would be more nearly in line with voltages existing in the tested circuit under normal operating conditions (with no meter connected), yet such readings might be misleading when compared with those listed for service work.

Many analyzers and multimeters have voltage ranges extending to several thousands of volts, such high ranges being needed when checking certain circuits in television receivers and in transmitting apparatus. Work with high voltages is dangerous unless certain precautions are taken. As previously mentioned, test connections should be made only while power is turned off, and only after all high-voltage capacitors have had both terminals short-circuited to ground to make certain that these units are discharged. Even when these precautions are taken, connections should be made by using only one hand at a time. Hands and shoes must be dry. If a floor is damp it should be covered with a clean, dry board or other good insulation.

High-voltage circuits should not be worked upon unless there is at hand an accurate wiring diagram plainly indicating the locations of all high-voltage terminals and other units. It is advisable to make a good conductive connection from the metal panel of any service instrument to an effective ground, such as a cold water pipe. This will prevent accumulation of dangerous static charges on the panel. When working with television apparatus or other cathode-ray devices having the positive of the power supply grounded to the chassis, external ground connections which are made either directly or through capacitors should be disconnected before proceeding with tests. All bypass and other capacitors should be assumed to retain high-potential charges, and should be discharged as mentioned above.

REVIEW QUESTIONS

1. What properties usually are measured by an analyzer; volts, henrys, milliamperes, microfarads, ohms, or what others?
2. In an ordinary multi-range ohmmeter will measurement of higher resistances require more or less battery voltage, more or less series resistance, assuming that the meter and its shunting remain unchanged?
3. Which is more suitable for measuring small resistances, a series-resistance or a shunt-resistance type of ohmmeter?
4. Is an output meter or decibel meter a d-c type or an a-c type?
5. Which voltage ranges of an analyzer usually have greater sensitivity in ohms per volt, the d-c ranges or the a-c ranges?
6. When making service tests with an analyzer in what order are the following measurements usually made; currents, voltages, resistances?
7. Should tests be commenced by using the high ranges or low ranges of the analyzer?
8. Describe precautions to be taken during high-voltage measurements. Mention such items as power switches, dampness, capacitor terminals, grounds, etc.

Chapter 7

ELECTRONIC VOLTMETERS

It is difficult to measure potentials in grid circuits and plate circuits with any of the generally used types of voltmeters, especially when the circuits are carrying signal currents as in normal operation. The principal reason for the difficulty is insufficient resistance in the usual voltmeters for use on grid and plate circuits whose own resistances are high and in which the currents are small. In the chapters dealing with voltmeters in general it was explained why the connection of a voltmeter to a high-resistance low-current circuit changes the currents and potential drops in the measured circuit, and at the same time causes the meter indications to be quite different from the voltages existing without the meter.

Further difficulties arise when attempting to make measurements at radio frequencies and at intermediate frequencies. Then

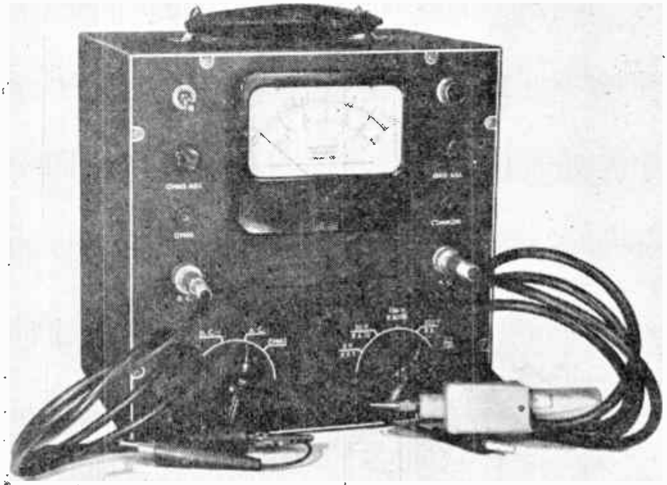


Fig. 1.—An electronic voltmeter with shielded probes for measurement of direct and alternating potentials.

the capacitances and inductances of any of the usual types of voltmeter are connected to the measured circuit. The result is detuning of the circuit. Even more troublesome is the fact that none of the commonly used voltmeters which will give reliable indications at these frequencies can be made with high resistance. They all take too much current.

Electronic voltmeters are designed to overcome most of the difficulties encountered with other types. These instruments are of very high input resistance for both direct and alternating potential measurements, and they may be made to operate at frequencies all the way from power frequencies to many megacycles of radio frequency.

All electronic voltmeters employ amplifying tubes to whose control grid circuits there is applied the potential to be measured, either directly or indirectly. The measured potential causes the control grids to vary the plate current in the meter tubes, and variations of plate current are indicated by a meter in the plate circuit. This meter is graduated or calibrated to show the values of potential being applied to the control grid circuits. This is the basic principle of all electronic voltmeters, but there are many modifications in actual designs.

The input resistance of electronic voltmeters for measurement of direct potentials usually is ten megohms or more, even when the range of the meter is only a few volts. Then, for example, on a five-volt range the sensitivity of the electronic voltmeter will be something like two millions ohms per volt.

For measurement of alternating potentials the advantages of the electronic voltmeter are even greater. Input resistances of these meters for a-c measurements are as high or almost as high as for d-c measurements, whereas the sensitivity of rectifier type a-c voltmeters often is only 1,000 ohms per volt. Then too, while some rectifier voltmeters will retain fair accuracy only to frequencies somewhat above the high audio limits, electronic voltmeters may be designed to have fair accuracy at frequencies up to many megacycles.

For the measurement of potentials in high-resistance low-current circuits, and for measurements at frequencies above the audio range, the electronic voltmeter is the most practical instrument. Compared with other types of voltmeters, however, the electronic unit has the disadvantages of much higher first cost, greater weight and size, and any of the common troubles which always beset fairly complicated electronic equipment.

There have been so many different designs of electronic voltmeters, or, as they often are called, vacuum tube voltmeters, that it would be almost impossible even to mention all of them. Consequently, we shall concern ourselves chiefly with types which are at present in most general use. Most of these types operate with power from the lighting lines, although several are designed to use battery power.

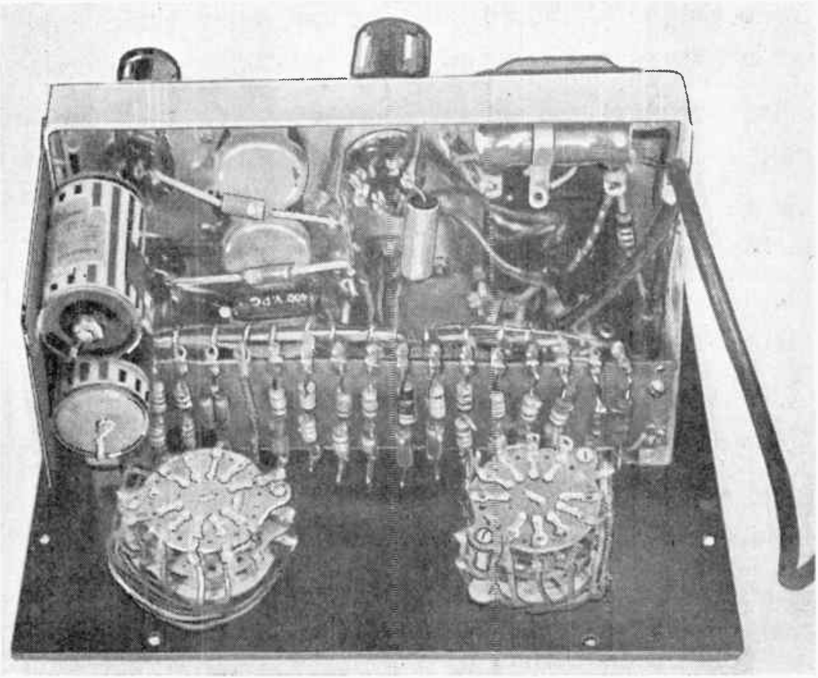


Fig. 2.—The parts inside of an electronic voltmeter.

Practically all radio service instruments which contain electronic voltmeters are constructed as multi-purpose instruments, in that they comprise a voltmeter for both direct and alternating potentials, and also an ohmmeter for resistances. In addition, many of these instruments include switching arrangements permitting the measurement of direct currents, and some provide for measurement of capacitances and even of inductances. For volts, ohms, and any other values measured, there will be four to eight ranges for each function, so that all values from very small to very great may be indicated with good accuracy.

Grid Rectifier Meters.—A principle which has been employed in many electronic voltmeters is identical with that of the grid rectification detector or the grid leak detector so familiar in many early radio receivers. The elementary circuit is shown by Fig. 3. The grid resistor *Rg* may be connected in parallel with the grid capacitor *Cg* for measuring direct potentials, and may be connected from tube grid to cathode for measuring alternating potentials. In the latter position or connection the capacitor *Cg* acts as a blocking or coupling capacitor to prevent direct potentials from reaching the tube grid. In the d-c position the capacitor is bypassed by the resistor to permit direct potentials to act between grid and cathode.

For a-c measurements, grid rectification occurs between the control grid and cathode of the tube. The grid capacitor is charged by positive alternations of the applied potential, and discharged slowly through the grid resistor. With suitable values of capacitance and resistance the capacitor voltage becomes nearly equal to the peak values of the applied potential, and the tube grid is made negative by this voltage. The greater the

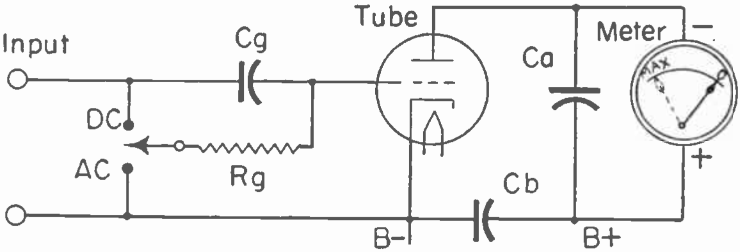


Fig. 3.—The grid rectification or grid leak electronic voltmeter.

amplitude or voltage of the applied alternating potential the more negative the grid becomes, and the less is the plate current.

With no potential across the input terminals the grid has zero bias, and the plate current has a value corresponding to this bias for the type of tube and the plate potential being used. This zero-bias current will be the maximum indicated by the meter in the plate circuit. The greater the alternating potential applied at the input terminals, the more negative becomes the grid and the less becomes the plate current. Obviously, the meter cannot be damaged by excessive applied potentials, because at some certain applied potential and at all greater ones there is plate current cutoff. Note that the grid and cathode of the tube are acting as a diode rectifier to charge the grid capacitor, while the plate, grid and cathode are acting as an amplifier or as a detector.

The capacitive reactance of the grid capacitor should be small in comparison with the resistance of the grid resistor for the lowest frequencies to be measured. Grid resistor values usually are between one and ten megohms, which calls for a large capacitance for low-frequency measurements. The bypass capacitors *Ca* across the meter and *Cb* across the battery or other power supply, should likewise have low reactance at the lowest measured frequencies. Tubes of high amplification factors are desirable because they take small plate currents and allow using a more sensitive meter. The current that flows in the grid resistor to maintain the grid bias must come from the measured

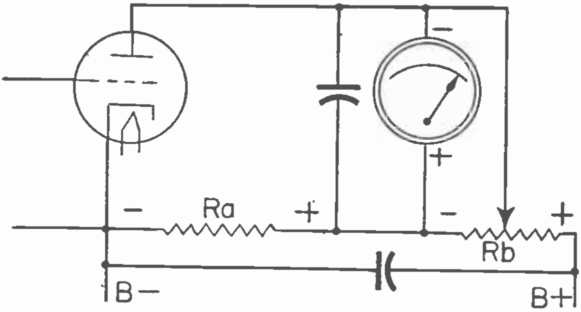


Fig. 4.—One method of bucking the plate current.

circuit, which means that the circuit is "loaded" to some extent, and this additional current in the measured circuit will upset normal potentials to a greater or less extent.

With the grid rectification voltmeter, and with any other types having maximum plate current with minimum applied potential, a more sensitive meter may be used and small changes of measured potential more easily read if part of the plate current is "bucked" out of the meter to begin with. One method is shown by Fig. 4 where the B-supply voltage is applied across resistors *Ra* and *Rb* in series, with a slider on *Rb* connected to the negative side of the plate current meter.

Electron flow in the tube plate circuit passes downward (negative to positive) through the meter. But the polarity of the potential applied from the portion of *Rb* which is across the meter tends to cause electron flow upward through the meter. Adjustment of the slider on *Rb* is made to reduce meter current to full-scale value, which then corresponds to the indication for zero measured voltage on the grid circuit of the tube.

Slide-back Voltmeter.—The principle of an electronic voltmeter called a slide-back type is shown by Fig. 5. In the tube plate circuit there is a bypassed current meter which indicates values of plate current. Plate potential is furnished from a portion, *Ra*, of the voltage divider between B + and B —. Grid bias potential is furnished by the part of resistor *Rb* which is between the slider and the cathode. The bias is indicated by a voltmeter.

To use this instrument the grid bias is adjusted by the slider on *Rb* to give a plate current reading of 1/20 to 1/10 of full-scale on the plate current meter, and the bias voltage is read from the voltmeter. If an alternating potential now is applied across the input terminals this potential will act between control grid and cathode of the tube. Because the tube has a negative grid bias sufficient to bring the plate current to a low value the tube acts as a biased rectifier or detector in exactly the same manner that a tube would act when thus operated as a biased detector, power detector, or plate rectification detector in a receiver. That is to say, the plate current will increase due to the applied alternating potential in the grid circuit.

Now the bias is readjusted to bring the plate current back down to its original value of 1/20 to 1/10 of full-scale. The difference between the new bias voltage and the original voltage, as read from the voltmeter, is approximately equal to the peak value of the alternating potential applied to the grid circuit. The purpose of resistor *Rg* Fig. 5 is only to provide a grid return. If there is a conductive connection through the measured circuit this resistor is not needed, and then the initial adjustment of the meters is made by short-circuiting the input terminals.

Because the tube of the slide-back meter always operates with a high negative bias the resistance across the measured circuit is that of resistor *Rg*, or, when *Rg* is not used, is equal to the leakage resistance between the instrument terminals. The calibration is that of the voltmeter in the grid circuit. Variations of operating potentials and of tube characteristics have practically no effect on calibration. The voltage range is limited only by the grid bias which may be applied. Some slide-back meters switch the one meter to read both plate current and grid bias. Others use an electron-ray tube as a plate current indicator, with the initial setting made for a thin line on the target, and with bias readjusted to obtain the same thin line.

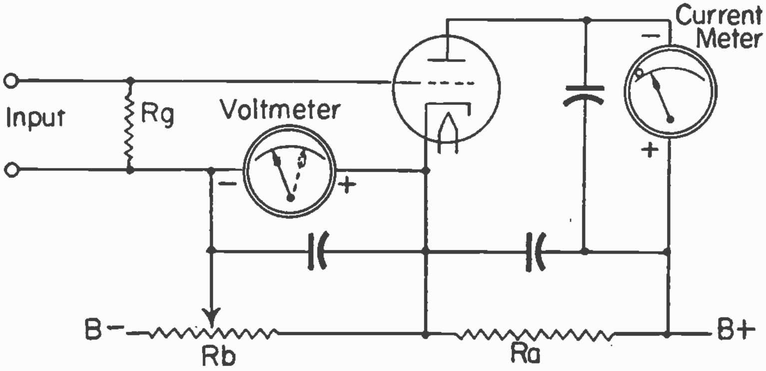


Fig. 5.—The circuit for one type of slide-back voltmeter.

Cathode-bias Meters.—Fig. 6 shows the elementary circuit for an electronic voltmeter in which cathode-bias is provided for a tube acting as a plate rectification detector. The bias resistor *Rb* is connected between the tube cathode and ground (which is B-minus), with the indicating meter in the cathode circuit. The initial bias is such that plate current is held almost at the cutoff point. Application of a measured alternating potential, or the positive side of a measured direct potential, at the input terminal connected to the grid, with the other side of this potential connected to ground, causes an increase of average plate current.

The increased plate current is indicated by the meter. At the same time, the increased plate current flowing in the bias resistor increases the bias voltage and makes the grid more negative than before. Consequently, the plate current is maintained at small values, and it is possible to use a sensitive indicating meter.

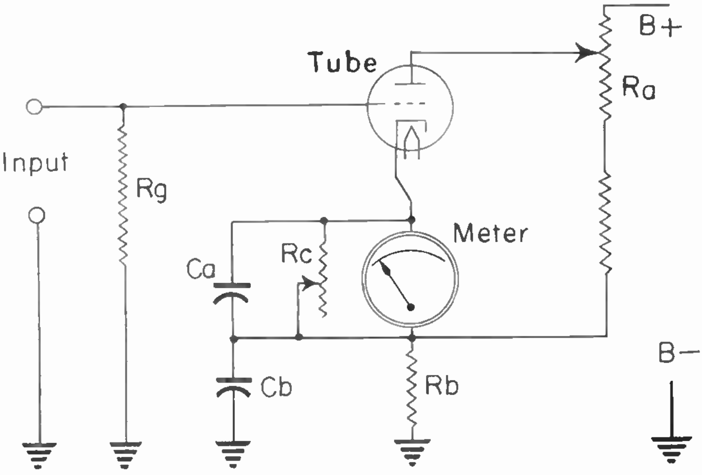


Fig. 6.—The principle of the cathode-bias electronic voltmeter.

Grid resistor *Rg* provides a grid return when no such return might exist through the measured circuit. The resistance of *Rg* may be ten or more megohms. Since the tube always has a highly negative bias, the only current taken from the measured circuit is that through *Rg* except for small amounts which may go through the capacitance of the tube elements. Resistor *Rc* is a calibrating shunt resistance across the meter. This resistance, and the meter, are bypassed by capacitor *Ca*. Capacitor *Cb* bypasses the bias resistor. The slider on *Ra* in the voltage divider allows initial adjustment of the meter for zero indication when no potential is applied to the input.

In meters having cathode bias, and in other types wherein the bias does not depend on the input, the tube may be operated on the lower bend of its grid-voltage plate-current characteristic curve and then will act so that meter indications are proportional to the effective or r-m-s values of input alternating potentials rather than to peak values. Operation higher on the curve gives indications more nearly proportional to average values.

Fig. 7 shows the complete circuits for an electronic voltmeter operating on this general principle. Input to the tube grid is taken through the range selector switches shown under *R*. The three contacts, shown by arrows, are moved over the eleven points indicated by circles in the three vertical rows. These ranges cover various values of a-c volts, d-c volts, resistances, and capacitances.

Near the top center of the diagram is shown the meter *M*. Below it is the pentode tube *T* connected to operate as a triode. Next below is a voltage regulator tube *V* which maintains nearly constant supply potentials in the instrument when there are considerable variations in the line voltage. Down below is the full-wave rectifier tube which feeds the instrument circuits with direct current through a filter.

Above the letters *A* to *G* on the diagram is shown the circuit selector switch consisting of 12 sections shown by 12 horizontal rows with seven circles in each row to indicate the seven positions. The movable contacts are indicated by arrows, with the arrows shown on the second contact point from the left in each row. From left to right the circuit positions are as follows; the letters being across the bottom of the diagram.

A, battery check, for measuring voltage of the ohmmeter battery. *B*, d-c volts when negative of measured voltage to input jack. *C*, d-c volts when positive of measured voltage to input jack. *D*, resistance measurements. *E*, a-c volts. *F*, capacitance measurements. *G*, line check, for checking zero setting.

In some electronic voltmeters employing cathode-bias the voltage ranges are provided by changing the value of the bias resistor. In meters having ranges running from maximum readings

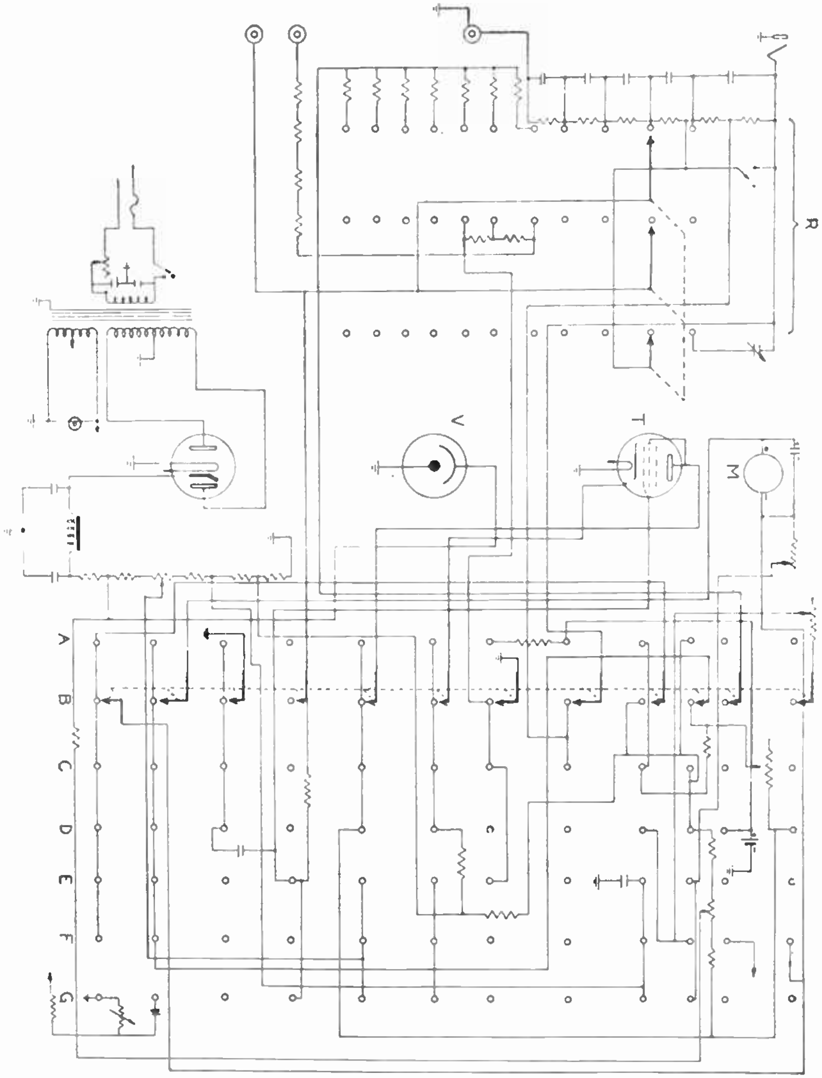


Fig. 7.—Schematic circuit diagram for a Radio City Products electronic voltmeter.

of one to 150 volts the bias resistor may be varied between such limits as 2,500 ohms on the one-volt range to about two megohms on the 150-volt range. Degeneration may be provided by omitting or reducing the capacitance of the bypass for the bias resistor. This allows more uniform scales for the several ranges, and also increases the voltage range for a given bias resistance. Instruments employing cathode-bias sometimes are called reflex types, because plate current changes react on the control grid bias.

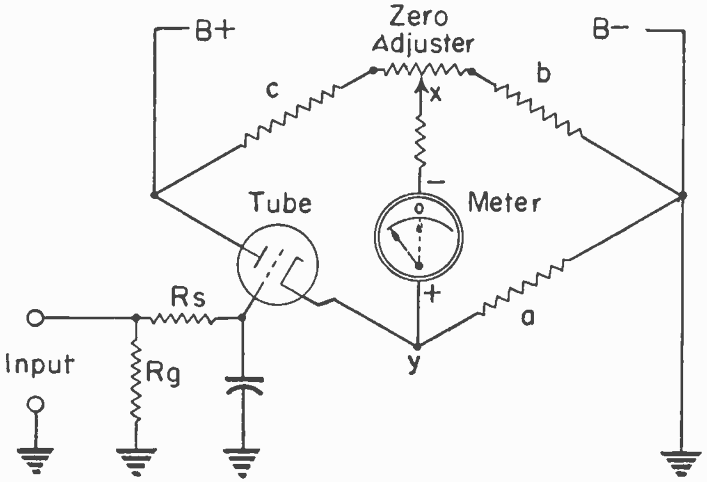


Fig. 8.—A voltmeter circuit in which the meter tube forms one arm of a bridge.

Bridge Circuit for Meter.—Fig. 8 shows the principle of an electronic voltmeter circuit in which the tube forms one arm of a bridge circuit, with the indicating meter connected between opposite points of the bridge and the B-supply potential connected between the intervening opposite points.

Electron flow takes one path from B — through resistor *a*, through the tube from cathode to plate, and to B +. There is electron flow also through the parallel path formed by resistor *b*, the zero adjuster resistor, and resistor *c*, to B +. The values of the bridge arm resistors, and the setting of the zero adjuster, are such that there is a potential difference across the bridge and meter, from *x* to *y*, such that a certain definite electron flow goes through the meter. This flow is just enough to bring the meter pointer to center scale, which becomes the zero point of the scale for electronic voltmeter measurements. This position of the meter pointer will be maintained as long as the grid voltage does not change from the value fixed by potential drop across resistor *a*, which is the bias. The grid is connected through resistors *Rs* and *Rg*, and ground, to the B — end of resistor *a*.

When a direct potential is applied between the input terminals, this potential alters the grid potential. If the applied potential

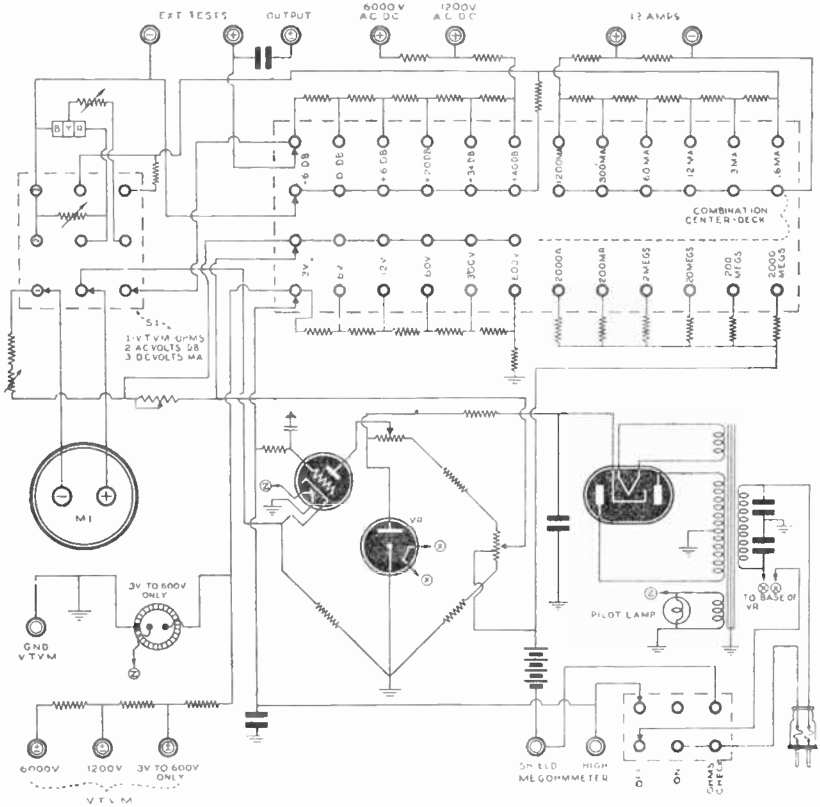


Fig. 9.—Schematic circuit diagram for a Precision Apparatus electronic voltmeter having the meter tube in a bridge circuit.

is in one polarity the grid is made less negative, and if it is in the opposite polarity the grid is made more negative. This change of grid potential changes the effective plate-cathode resistance of the tube, which is the resistance in one arm of the bridge. The resulting change in rate of electron flow through the tube and resistor *a*, with no change in resistors *c* and *b*, alters the potential difference between points *x* and *y*. Then the meter pointer moves toward the right or left, depending on the polarity of the input potential which is being measured. The meter is graduated and calibrated to read values of input potential.

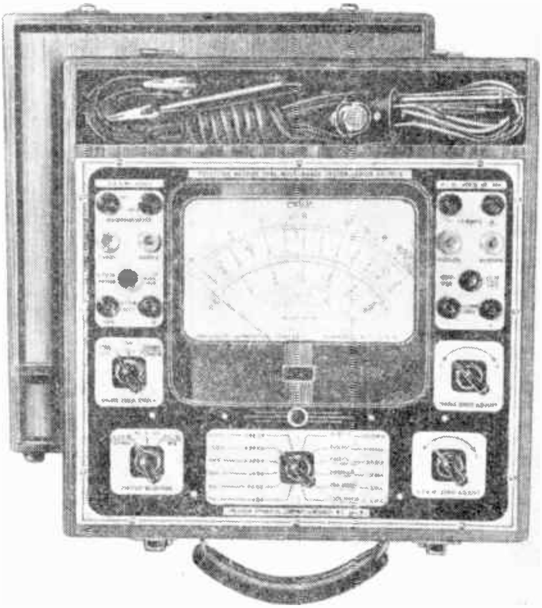


Fig. 10.—Panel arrangement of the Precision Apparatus electronic voltmeter.

The circuits of an electronic voltmeter employing this bridge principle are shown by Fig. 9. The tube is shown in one arm of the bridge. Between the B + and B — points of the bridge is shown a voltage regulator tube which maintains practically constant bridge voltage with line voltage fluctuations. Tracing the connections will show that the meter is connected between the tube cathode and the opposite point of the bridge.

The jacks shown along the bottom of the diagram are for connection of the electronic voltmeter to external circuits for measurement of direct potentials and of resistances. The jacks along the top of the diagram are used when the meter is employed as a regular moving coil unit for direct potentials and currents, and as a rectifier type meter for alternating potentials. At the upper left is a three-section selector switch for (1) the electronic voltmeter, (2) alternating potentials and decibels, and (3) direct potentials and currents. The range selector consists of four sections shown toward the upper right, with the movable contacts

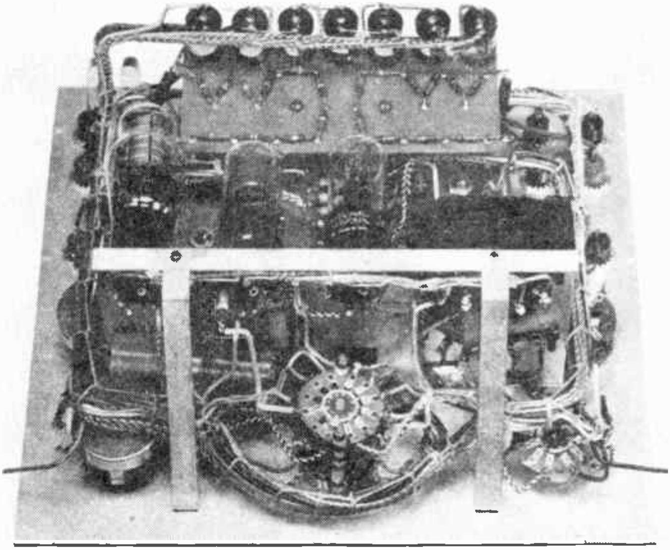


Fig. 11.—Internal construction of the Precision Apparatus electronic voltmeter.

indicated by arrows traveling over the twelve contact points indicated by circles in each of the four horizontal rows.

Fig. 10 shows the panel arrangement for the meter of Fig. 9, with the twelve-position selector switch directly below the meter. The electronic voltmeter jacks are at the left of the meter. One of these jacks, shown just above the three at the lower left in Fig. 9, is for connection of a "probe" by means of which the electronic voltmeter is used for measurement of high-frequency alternating potentials. This probe is one of the units shown in the upper compartment of the instrument case. The internal construction of the same instrument is illustrated by Fig. 11.

Diode Rectifier.—The basic features of an input circuit used in various forms with many electronic voltmeters for measurement of alternating potentials are shown by Fig. 12. The input terminals, which are connected to the measured potential, are connected to the plate of a diode rectifier through a coupling capacitor, and to the cathode of the diode through a direct connection. Across the diode is a leak resistor. The elements in this much of the circuit are practically the same as those which include the grid and cathode of a grid rectification detector; with the coupling capacitor taking the place of the grid capacitor, the leak resistor taking the place of the grid resistor or leak, and the plate of the diode taking the place of the grid in the grid rectification detector tube.

When an alternating potential is applied to the input terminals the rectification in the diode causes charging of the coupling capacitor in the polarity marked. The charge tends to leak off through the leak resistor, and continually is renewed by the positive peaks of the applied potential. There is developed across the leak resistor, and also across the coupling capacitor, a potential difference which is nearly equal to the peak value of the applied potential when the capacitance and resistance are of values suited to the frequency of the applied potential.

The potential difference which is across the leak resistor is applied between the control grid and cathode of the meter tube, acting through the filter resistor on the control grid side, and directly through the cathode side of the circuit. The filter capacitor acts to bypass any alternating currents which go through the filter resistor, and to leave a nearly smooth direct potential for the grid-cathode circuit of the meter tube.

As may be seen from the polarities marked on the coupling capacitor and leak resistor, the output potential from the diode circuit makes the grid of the meter tube negative with reference to its cathode. The higher the alternating potential applied to the input terminals the higher becomes the potential across the leak resistor, and coupling capacitor, the more negative becomes the control grid of the meter tube. The whole action is quite like that of a grid rectification detector or a grid rectification electronic voltmeter, with the difference that here the rectification is performed in the diode tube and the amplification in the separate meter tube.

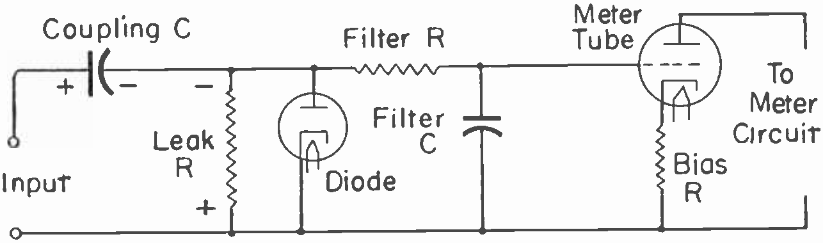


Fig. 12.—A diode rectifier for a voltmeter circuit.

The coupling capacitor is charged only by the positive peaks of the applied potential, and so is charged only once per cycle. If there is time between cycles for much of the charge to leak away through the leak resistor, the average voltage of the coupling capacitor will fall considerably below the peak voltage of the measured potential. On the other hand, if there is but little loss of charge between successive cycles, the capacitor voltage will remain nearly as high as the peak of applied potential.

How rapidly the coupling capacitor loses its charge and voltage depends on the relation between its capacitance and the resistance of the leak resistor, or on the time constant of the combination. The greater the capacitance and the greater the resistance the more nearly the average capacitor voltage will come to the peak of applied potential regardless of the frequency.

At high frequencies it would be sufficient to have small capacitance and resistance, because the recharging alternations occur so often that but little of the charge has time to leak away. But then the capacitor voltage will drop off at low frequencies, because there are longer intervals between recharges, and the indications of the meter will undergo wide variations with changes of frequency. Furthermore, when using a small coupling capacitance, the capacitive reactance at low frequencies becomes so much higher than at high frequencies that the higher reactance limits the charging pulses enough to cause a reduction of meter indications at the low frequencies.

For reasonably uniform indications from about 60 cycles up through audio and radio frequencies the capacitance of the coupling capacitor usually is made 0.02 mfd or greater, and the resistance of the leak resistor is made 10 megohms or more. The resistance of the filter resistor, which is in series with the diode output, most often is between one and five megohms. The capacitance of the filter capacitor usually is fairly small; often being something between 0.002 and 0.005 mfd. The chief usefulness of the filter capacitor is in keeping high-frequency currents out of the leads which run to the meter tube, and in confining them to the parts between the input and the diode rectifier.

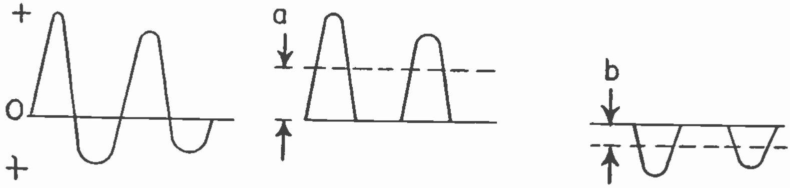


Fig. 13.—An unsymmetrical potential gives potentials depending on which side is rectified.

The current which flows to recharge the coupling capacitor once during each cycle has to come from the measured circuit; consequently has to flow in the resistance or impedance of that circuit. This extra current in the measured circuit affects the potentials in that circuit, while the resistance or impedance of the measured circuit tends to limit the flow of charging current into the diode circuit. These undesirable effects are lessened by longer time constants for the coupling capacitor and leak resistor, since this lessens the charging current per cycle or pulse.

Examination of Fig. 12 shows that the plate-cathode capacitance of the diode rectifier is in parallel with the input terminals. There is current flow into and out of this tube capacitance, with the flow supplied from the measured circuit. The less the tube capacitance the smaller will be this current.

When the diode circuit is used for measuring a sine-wave potential, with which there are equal positive and negative alternations, the meter indication will be the same no matter which of the input terminals is connected to which side of the measured circuit. But if the measured potential has greater amplitudes in one polarity than in the other, the meter indications will depend on which way the input terminals are connected to the measured circuit. This is shown by Fig. 13. At the left is an unsymmetrical wave form. If the diode rectifier is connected to cut off the negative and pass the positive alternations the average rectified output will have the value at *a*, but if the positive alternations are cut off and the negative passed, the average output will be the much smaller value *b*.

For measured potentials greater than two to five volts the output of the diode rectifier system is almost exactly proportional to the input potential, and the same graduations of meter scales may be used for various voltage ranges. But for lower input potentials there usually is a separate scale on which the graduations are not uniformly spaced.

Bridge Amplifiers.—Fig. 14 shows the elementary form of a bridge amplifier circuit which is used in various modifications in connection with diode rectifiers for measurement of alternating potentials. Two of the arms of the bridge contain triodes *A* and *B* with their cathode bias resistors. Arms *C* and *D* contain resistors of equal resistance. Between these latter arms is a potentiometer used for adjusting the meter to zero. The slider of this zero adjuster connects to B+. The two cathode bias resistors connect to B—. The control grid of triode *A* is connected to ground through resistor *Rr*, while the grid of triode *B* is connected directly to ground.

Since the two triodes are alike, and since both are subjected to equal plate potentials and grid biases, their currents and the currents through arms *C* and *D* are equal. Then there is no potential difference across the upper and lower junction points of the bridge, between which is connected the meter. Thus the meter current is zero.

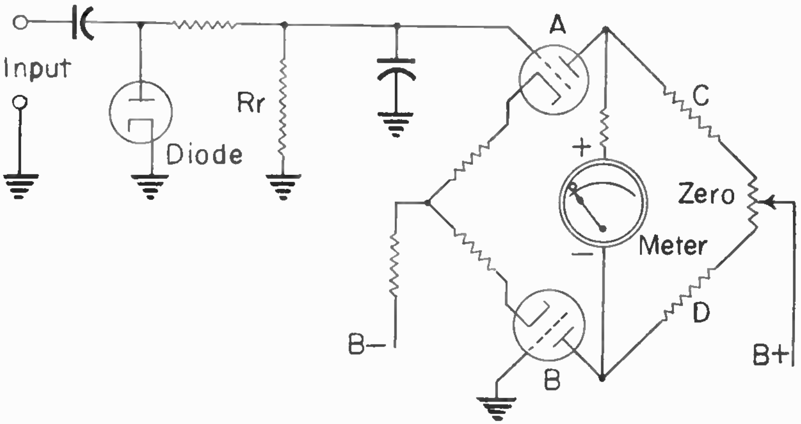


Fig. 14.—Bridge amplifier circuit used with a diode rectifier.

When an alternating potential is applied to the input of the diode circuit, the rectified direct potential in the diode output makes the grid of triode *A* become more negative. This increases the effective resistance of *A* and decreases its current. There no longer are equal potentials at the upper and lower junctions of the bridge, and through the meter there is a current which is proportional to the value of alternating potential applied to the diode input. Triode *B* is unaffected, and continues to carry the same current as before.

The greater the alternating potential applied to the diode circuit the more negative becomes the grid of triode *A*, and no matter how great the measured potential the plate current of *A* can drop only to zero. Potentials, tube currents, and resistances in the circuits are so chosen that with plate current cutoff in tube *A* the meter current due to current in tube *B* will be only

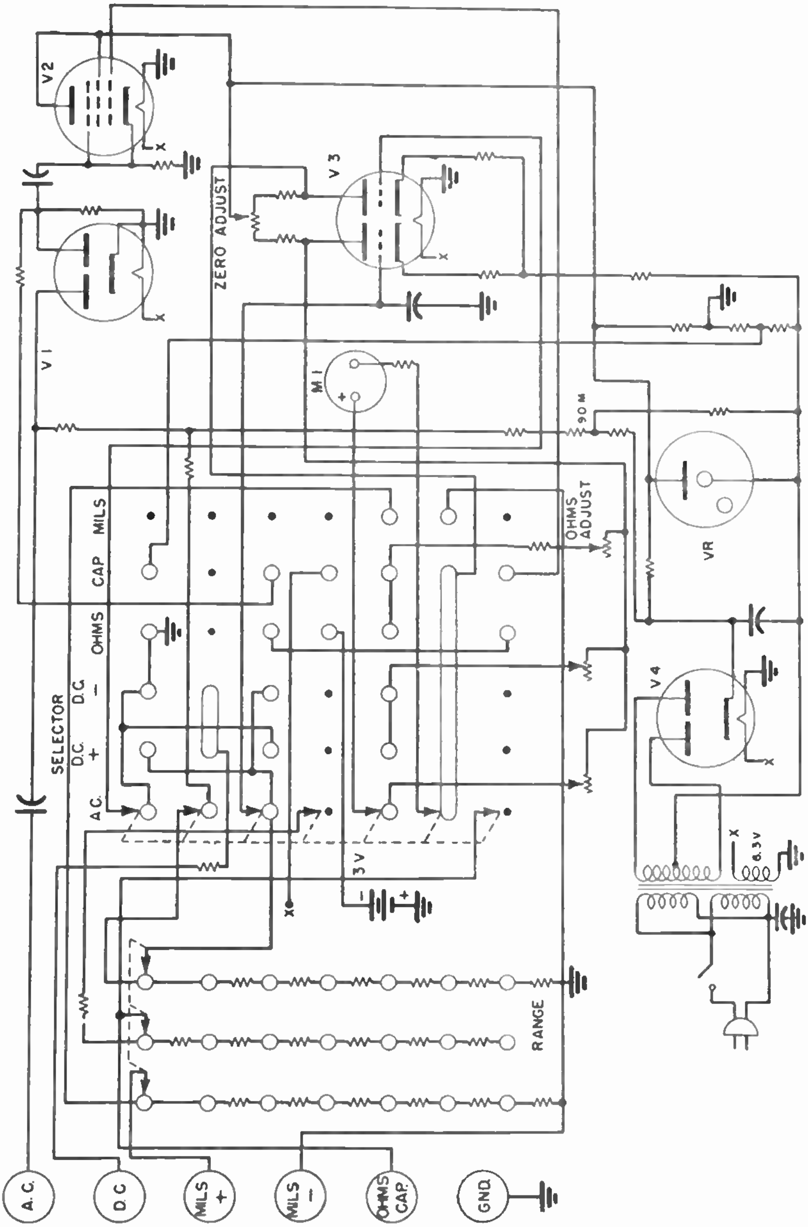


Fig. 15.—The schematic circuit diagram for a Hickok electronic voltmeter.

a little more than full-scale value. Consequently the meter cannot be damaged by any potential applied to the diode input terminals.

Fig. 15 shows the circuits of an electronic voltmeter which employs the bridge amplifier principle just explained. The rectifier diode for a-c measurements is the left-hand section of double diode *V1*, whose plate connects through a capacitor to the *A.C.* jack at the upper left-hand side of the diagram. The two bridge triodes are the two sections of the double triode tube *V3*, to whose plates connect the two bridge resistors and the zero adjusting potentiometer. The meter is shown at *M1*. The meter is connected to the bridge circuit through the selector switch shown in the upper center. This switch has seven sections with six positions on each. From left to right, as marked above the positions, the functions are (1) a-c volts, (2) d-c volts with positive to the *D.C.* jack at the left, (3) d-c volts with negative to the jack, (4) ohms, (5) capacitances, and (6) d-c milliamperes. The resistors used in the range switch are shown toward the left. The 3-volt dry

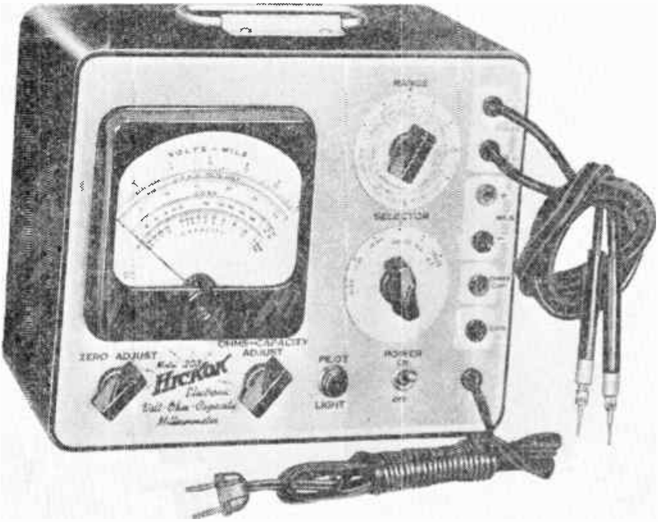


Fig. 16.—The panel arrangement of the Hickok electronic voltmeter.

battery for resistance measurements is shown at *3V*. In the power supply system there is a voltage regulator tube *VR*.

The instrument for which Fig. 15 is a schematic circuit diagram is pictured by Fig. 16. The jacks for test cords are at the right, with the range and selector switches between the jacks and the meter.

The indicating meter is not always connected between or across the plates of the bridge tubes, as it is in Fig. 14, but may be connected between the cathode leads of these tubes, as in Fig. 17. Here the meter, *M*, is connected between resistors which are in the cathode-bias leads. The meter is shunted with an adjustable resistor used for calibration. The zero adjusting potentiometer is in the cathode circuit rather than in the plate circuit. The plates of the two bridge tubes, *VT2* and *VT3*, are connected together and to B+, which is the lead from the cathode of the

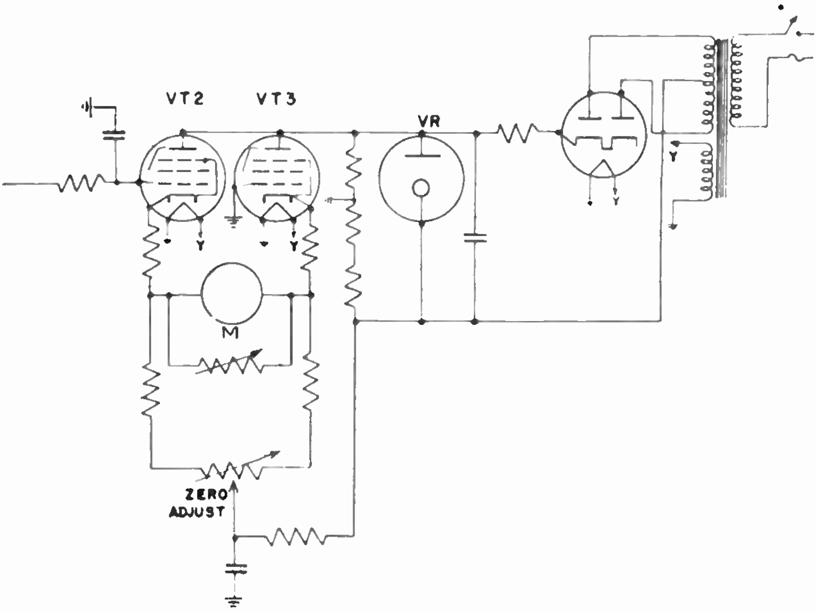


Fig. 17.—The bridge amplifier circuit used in a Reiner electronic voltmeter.

full-wave rectifier at the right. The slider of the zero adjusting potentiometer is connected through a resistor to B—. Between B+ and B— is a voltage regulating tube, *VR*. The input from the measured circuit comes to the control grid of bridge tube *VT2*. In the connections to the measured circuit (not shown) is a resistance connection to ground. The control grid of bridge tube *VT3* is here shown connected directly to ground.

Contact Potential.—Even when no electrons are being caused to flow through a tube there is emission of electrons from the cathode when it is heated, and these emitted electrons form a space charge within the tube before they fall back into the cathode. The effect of this space charge and of ions within the tube is to make whatever other element is near the cathode become slightly negative with reference to the cathode. In a triode the control grid is made slightly negative, and in a diode the plate is made slightly negative with reference to the cathode so long as the cathode is heated. The difference of potential between the nearby element and the cathode is called *contact potential.*

When using a diode in the input for an electronic voltmeter the contact potential makes the plate somewhat negative even when no external potential is being measured. With the diode plate connected to the control grid of one of the two tubes in a bridge amplifier, and with the other bridge tube having only its normal negative bias, the grid of the first tube becomes somewhat more negative than the grid of the second bridge tube. In some tubes the contact potential may be as great as one volt. There are various ways of compensating for the negative contact potential.

In the instrument shown by Fig. 15 the contact potential in the left-hand diode of tube *V1* is neutralized by a small positive potential applied to the diode plate through a 90-megohm resistor in the lead running downward from the plate line to the positive side of the B-supply shown at the bottom of the diagram. This positive potential is approximately equal to the negative contact potential developed in the diode.

Fig. 18 shows another method of compensating for contact potential. The upper part of the diagram shows the diode input section, which connects to the bridge amplifier shown down below. Instead of employing only a single diode tube in the rectifying circuit there is a double diode *VT1* shown within the broken line enclosure. The lower section of the diode tube, or the lower diode, is connected through the range selector to the control grid of bridge tube *VT2*. The circuit for this diode, including the coupling capacitor and the filter resistor and capacitor, is like the diode circuits previously explained. The upper diode is con-

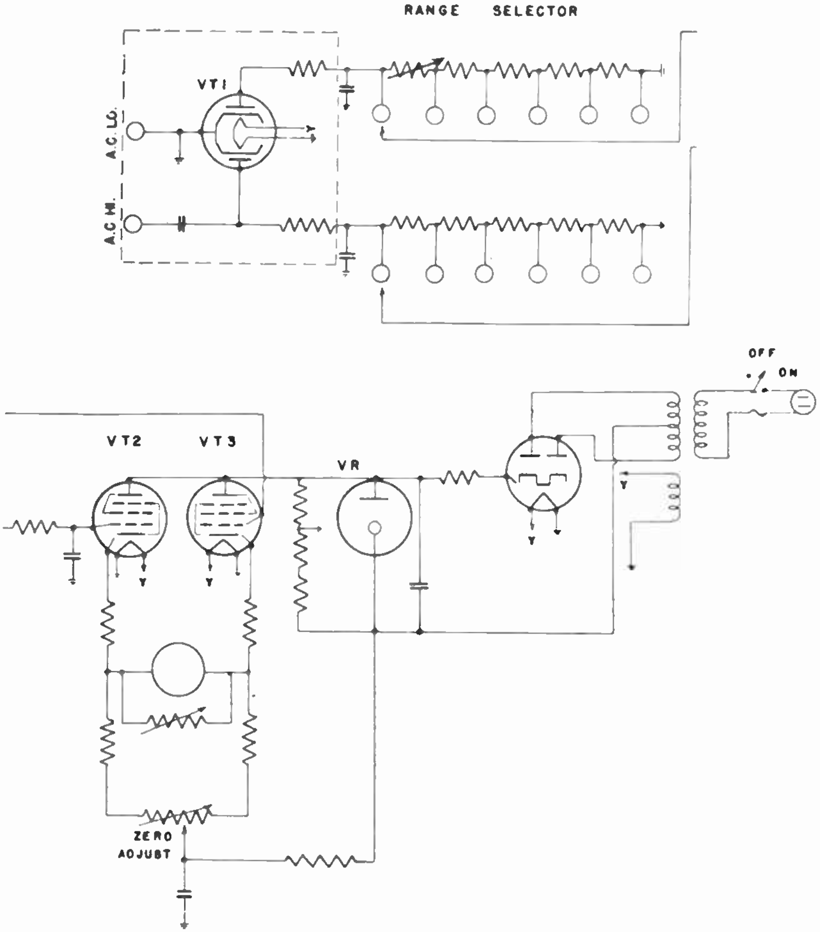


Fig. 18.—One section of the double diode is used to compensate for contact potential in the other section. Reiner electronic voltmeter circuit.

nected through a similar filter system and through the upper portion of the range selector to the control grid of the other bridge tube, *VT3*. There is no connection for applying a measured potential to the plate of this upper diode. However, the contact potential developed in this upper diode is applied to the grid of tube *VT3* while the contact potential developed in the lower diode is applied to the grid of tube *VT2*.

Since the two sections of any double-diode tube normally are alike in performance, the two contact potentials should be alike and should balance each other. In case there is a small difference, however, the right-hand resistor in the upper range selector section is made adjustable to equalize the effects on the two bridge tubes.

In some instruments there are two separate diode tubes, which are selected to have, as nearly as possible, equal contact potentials. Because contact potential results from cathode heating

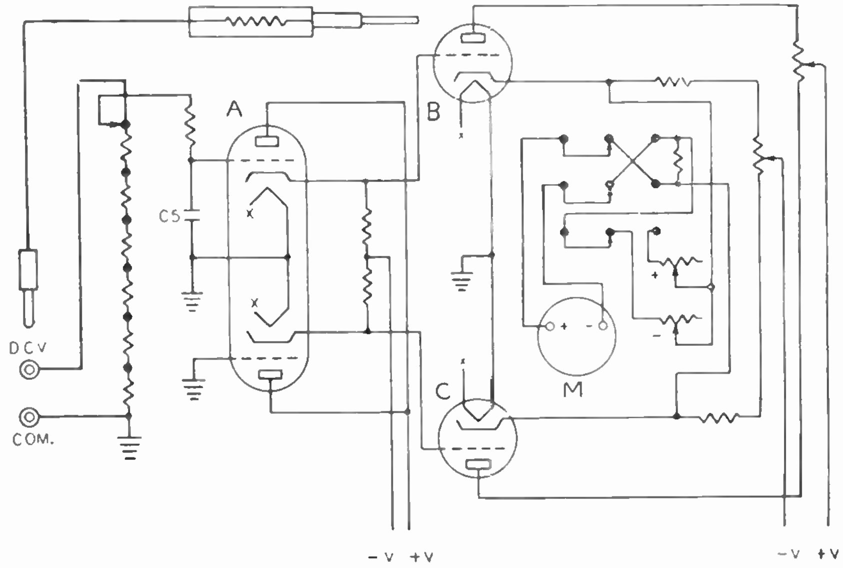


Fig. 19.—Cathode follower bridge circuit as arranged for direct potential measurements in a Triplett electronic voltmeter.

and electron emission, the heater currents or potentials may be varied in separate diodes to equalize the contact potentials or the effects of these potentials at the grids of the bridge tubes.

Cathode Follower.—In the circuit of Fig. 19 connection to the measured potential is made through the jacks and the test probe shown with its cord at the left. The measured potential is applied to the control grid of the upper section of the twin triode *A*. The cathode of this section is directly connected to the control grid of amplifier tube *B*. The upper section of tube *A* and tube *B* form one arm of a bridge amplifier circuit. The contact potential developed in the upper section of tube *A* is matched by the similar contact potential in the lower section of this tube, whose control grid is connected to ground rather than to the input jacks. The cathode of the lower section of *A* is directly connected to the control grid of amplifier tube *C*. The lower section of *A* and tube *C* form a second arm of the bridge amplifier.

The remaining two arms of the bridge are formed by resistors

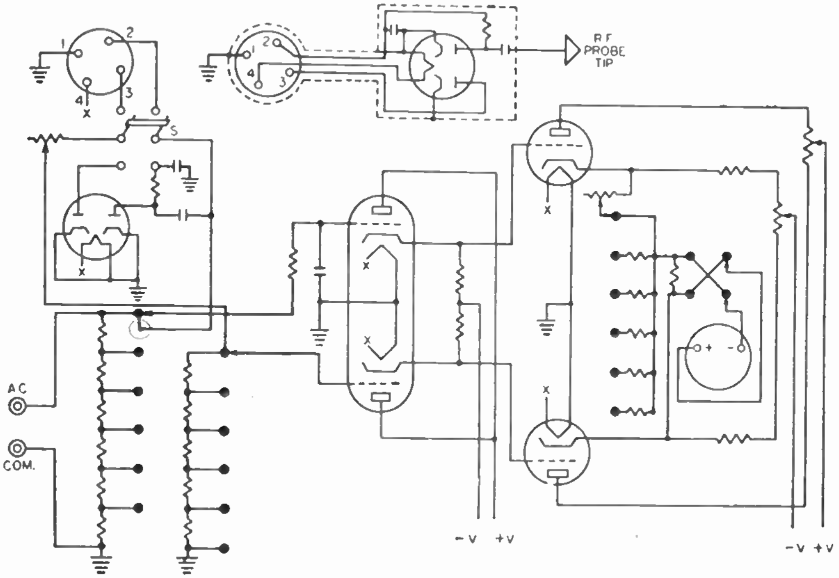


Fig. 20.—The Triplett bridge circuit as arranged for use with diode input during measurement of alternating potentials.

in the cathode leads of tubes *B* and *C*, with the meter *M* connected between these two cathodes. The switch which is above the meter is a reversing switch for allowing readings when the positive side of the measured direct potential is applied to either of the input jacks. Placing the principal bridge tubes in the cathode circuits of the input tubes makes this circuit of the cathode follower type, the purpose being to provide or permit high resistance at the input terminals and across the measured circuit.

The same bridge amplifier circuit which is shown by Fig. 19 for direct potential measurement is shown by Fig. 20 with rectifying diode input for measurement of alternating potentials. There are two separate and distinct diode circuits. The double-diode and its connections shown immediately above the range selector and input jacks at the left are used for measurements

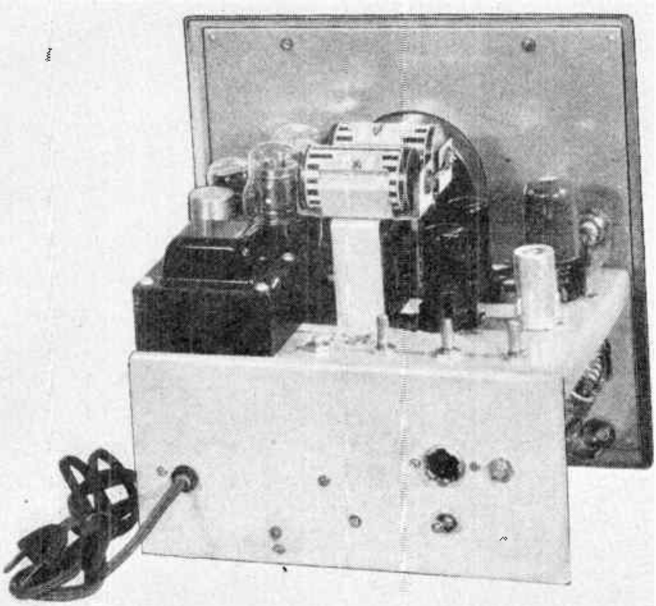


Fig. 21.—The interior of the Triplett electronic voltmeter.

at frequencies from the lowest in the audio range up to about 50 kilocycles. For measurements from 50 kilocycles to above 100 megacycles there is used the double-diode with its filter circuit shown within the broken-lines at the top of the diagram. This double-diode is inside of a shielded "probe" which is connected to the main instrument case through a flexible shielded cable and the plug connector whose pin contacts are numbered from *1* to *4*. The double-pole double-throw switch *S* is used to connect either of the diode systems to the input of the bridge amplifier.

Fig. 22.—The Reiner electronic voltmeter with its high-frequency probe.

In each of the double-diodes shown by Fig. 20 one of the diode sections is used only to balance the contact potential developed in the other diode section. That other diode section is the one used for coupling to the alternating potential which is to be measured. Fig. 21 is a picture of the upper part of the interior of the electronic voltmeter for which circuit diagrams are shown in Figs. 19 and 21.

High-frequency Probes.—When the electronic voltmeter is to be used at frequencies higher than four or five megacycles it is usual practice to place the diode rectifier and filter system in a probe having a metallic enclosure fitted with exposed input terminals, and connected to the amplifier and selector unit through a shielded cable. Such a design is shown by the diagram of Fig. 20. Another probe circuit is shown by Fig. 18, where the probe contains all of the parts which are enclosed within the broken-line rectangle at the upper left. The probe for this latter instrument may be seen in Fig. 22, where it is lying in front of the main housing. The shielded cable goes to a jack connection on the back of the main housing.

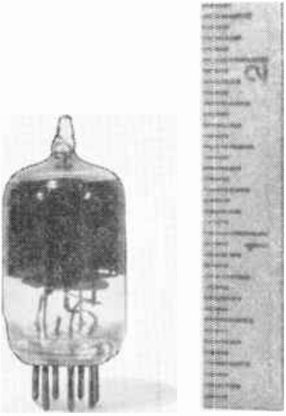


Fig. 23.—A midget tube such as may be used in a high-frequency probe.

The tubes used as diode rectifiers inside of the probes usually are of the acorn type, the miniature type, or else the midget type. A midget tube is pictured in Fig. 23. Miniature tubes are of the same diameter, but a little longer. The acorn envelope is about the same size as the midget.

When the probe tube is a double-diode one of the diode sections usually is used to balance the contact potential of the other section, with that other section used as the rectifier for measured potentials. When the probe tube is a single diode type a second similar diode may be placed within the main body of the instrument and used for balancing the contact potential of the probe tube.

The probe is designed to receive the high-frequency potentials which are to be measured, to rectify these potentials, and to deliver through the connecting cable a direct potential which is proportional to the received high-frequency potential. It is important that high frequencies be kept out of the connecting cable, in which there is considerable capacitance and inductance and in which there might be serious losses at high frequencies. To accomplish this purpose the high-frequency circuit must be confined to the probe. The probe tip or terminal which goes to the coupling capacitor for the diode plate is applied to one end of the measured potential. To the other end of the measured potential is connected a short extension which connects to the shielding metal enclosure of the probe or to the cathode side of the diode circuit within the probe. It is desirable also that the probe be completely shielded except for the small central tip or terminal in order that there may be no pickup of energy from strong high-frequency fields existing in the region where the probe is applied.

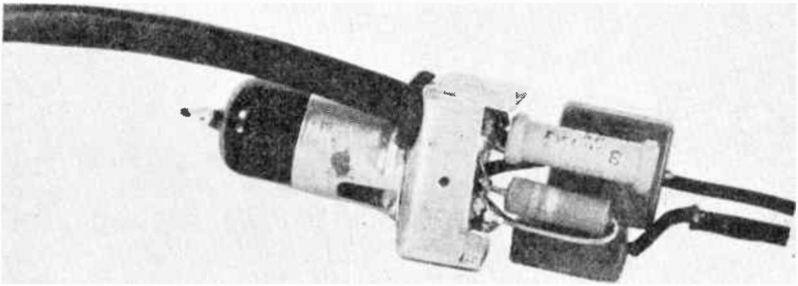


Fig. 24.—Internal construction of a high-frequency probe.

For use in high-frequency probes the capacitors should be non-inductive and made with low-loss dielectric and insulation. Resistors should have minimum self-capacitance, should be non-inductive, and of low-loss construction in general. The probe tube should have small capacitance between plate and cathode. In many of the probes used with service instruments there is no leak resistor within the probe; sufficient capacitor discharge being allowed through leakage resistances of the measured circuit and of other circuit elements within the probe.

The internal construction of one type of probe is shown by Fig. 24. The shielded cable extends from the left, where may be seen also the probe tube with part of its shield in place. The resistors and capacitors are toward the right. The leads for the insulated center terminal and for the ground or cathode connection are at the right. The same probe is shown by Fig. 25 with the main body of the shield in place, from which extend the central insulated tip and a flexible lead with alligator clip for the external ground connection to the measured circuit. Only part of the tube shield is in place. Probes usually are arranged to make various kinds of terminal connections for the insulated tip and for the ground connection.

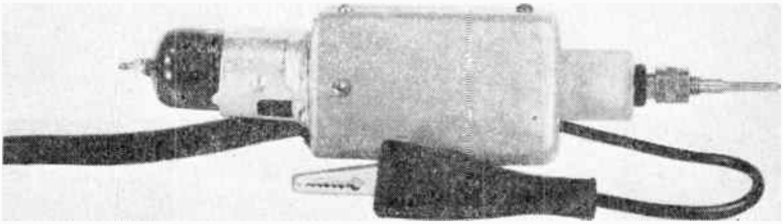


Fig. 25.—The probe with the main shield in place.

Direct Potential Measurements.—As is evident from many of the circuit diagrams in this chapter, the same amplifier and meter are used for measuring either alternating or direct potentials. The amplifiers are designed to be actuated by direct potentials applied to their grid-cathode circuits, and when alternating potentials are to be measured these potentials are rectified before application to the amplifier. Any electronic voltmeter arranged for measurement of direct potentials might be adapted for measuring alternating potentials by placing ahead of it an effective rectifier system, although the calibration and meter readings would not be the same for both alternating and direct measured potentials without special compensating arrangements in the range selector circuits. If an instrument designed for measurement of alternating potentials is to be used for direct potentials it would be necessary to remove or short circuit the coupling or blocking capacitor to permit the direct potential to act on the tube grid. Again the calibrations would be different for the two kinds of potential. In the amplifier circuits which have been shown it may be seen that there is a bypass capacitor, or sometimes a low-pass filter system, from the grid of the amplifier tube to ground so that alternating potentials will not affect the grid.

The prod which is applied to the high side of the measured circuit for direct potentials usually has within it a resistor of about one megohm so that operation of the measured circuit will not be affected to any great extent. This resistance is in addition to resistances in the range selector system.

Most instruments are arranged so that the connections to the meter may be reversed by a switch on the direct-potential positions, thus allowing the meter always to read in a forward direction by operating the switch to suit the polarity of the measured potential. With the instrument of Fig. 10 the meter is made of the zero-center type for all of the electronic voltmeter functions, thus avoiding the need for a polarity reversing switch. The meters used in electronic voltmeters have full-scale ranges of from 100 to 500 microamperes. All are of the moving coil permanent magnet type. The meter is used with a dry-cell battery, and sometimes with direct potential from the power supply system, for operation as an ohmmeter. Most of the power supply systems include voltage regulator tubes.

The input resistance of an electronic voltmeter being used for measurement of direct potentials is equal to the resistance of whatever portion of the range selector voltage divider system is connected between the high input terminal and the ground or common terminal. To this resistance is added whatever resistance may be used in the d-c prod or probe. As shown by diagrams in this chapter, the voltage divider in the range selector usually is arranged so that the total resistance remains across the input terminals for all ranges, with the voltage applied to the amplifier being taken off at the various range taps.

High-frequency Performance.—The input characteristics for measurements of alternating potential usually are specified as a certain number of ohms of resistance, shunted by a certain capacitance. From these two values it is possible to determine the effective input impedance at any frequency. The capacitive reactance decreases with an increase in frequency, as would be expected, but through the very high frequency ranges there is also a decrease of effective resistance to only a fraction of the low-frequency value. This decreasing resistance places an increasing load on the measured circuit as the frequency goes up. There are losses of energy in the rectifier socket, in the insulation of resistors, capacitors, and conductors, in the shields, and in all other parts of the input circuit. These losses cause absorption of power from the measured circuit.

The input capacitance is the total of the capacitances between tube elements, and between socket connections and other conductors in the rectifier circuit. This capacitance is added to that in any tuned resonant circuit being measured, and there will be more or less detuning. Sometimes it is worth while to retune the measured circuit to resonance by adjusting the trimmers to compensate for the added capacitance. The trimmers then have to be readjusted after measurements are completed.

Unless the coupling capacitor in the diode circuit is of large capacitance, its reactance will become so high at some rather low frequency as to make a decided reduction in rectifier output, with consequent low readings at the meter. At very high frequencies there may be resonance of the inductances and capacitances of the diode circuit, which would cause readings to be too high. This effect is opposed by the increasing energy loss at the very high frequencies.

Operating the Electric Voltmeter. — After the voltmeter is turned on by the line power switch it should be allowed to warm up for several minutes before making any measurements. The warm-up is completed when there is no longer any shift of the meter pointer away from the zero point to which it is adjusted. When the meter is to be used frequently during service work it is well to leave it turned on all the time.

When using the high-frequency probe keep the metal housing of the probe, and also the shielded cable, as far as possible from circuit parts in which there are alternating currents and potentials with their radiated fields. The ground connection from the probe should be made to a point as close as possible to the point at which the test tip is used.

If readings differ when the test leads or prods are reversed during alternating potentials it probably means that the measured potential is not of sine wave form. One reading is correct for the positive side of the wave; the other reading is correct for the negative side.

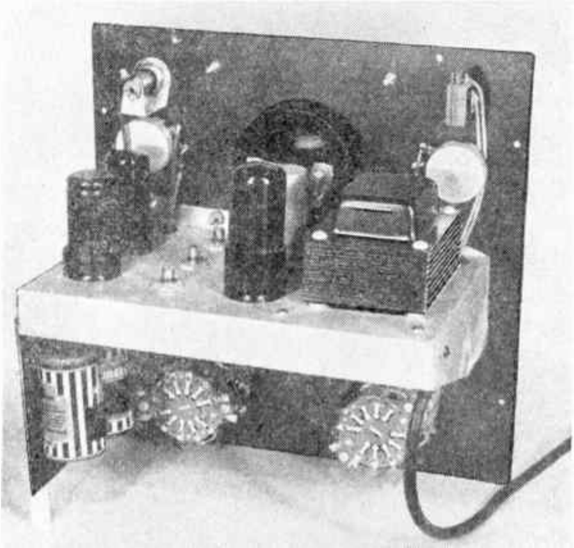


Fig. 26.—Calibration adjusters are on the shelf panel between the tubes.

With reference to the measurement of high voltages the same precautions should be observed as when using any other type of voltmeter; all of which are explained in chapters dealing with voltmeters in general. A measured circuit may carry alternating potential well within the safe measurement range of the electronic voltmeter, yet in the same circuit there may be direct potentials higher than the working limit of the coupling capacitor or other elements. In such cases there should be connected between the meter prod and the measured circuit a large capacitance capacitor of amply high working voltage rating.

For resistance measurements the same precautions should be observed as explained in the chapter on ohmmeters of other types. This applies also to the measurement of currents, where it is easily possible to burn out the meter.

Calibration of electronic voltmeters is not a difficult operation; requiring only that there be available direct and alternating test potentials whose values are known with accuracy. Directions for calibration differ with each make and type of electronic voltmeter. Such directions are included in the instructions furnished with the instruments. In Fig. 26, on the horizontal shelf panel and in between the tubes, may be seen the three potentiometer shafts which are used in the calibration of this particular instrument.

Uses for the Electronic Voltmeter. — Because the electronic voltmeter is an instrument of great sensitivity for measurement of direct potentials and also for alternating potentials from power frequencies well up into the megacycles, the tests which may be made are limited in practice only by your familiarity with the normal and abnormal behavior of the circuits to be worked upon. A few of these tests will be described, as they are made in the standard broadcast frequency range.

Gain of Antenna Coupler.—With a signal generator set at 600 kc, with unmodulated output, connect the generator to the antenna and ground posts of the receiver. Set the electronic voltmeter for a-c volts, and connect it to the receiver antenna and ground posts while noting the volts input. Turn the receiver tuning control to get the minimum voltage reading, indicating resonance and energy absorption from the generator. Now reconnect the voltmeter between the stator of the receiver antenna tuning capacitor and ground. Retune the receiver for maximum voltage reading. This second reading divided by the first (input) reading is the gain of the antenna coupler. The receiver need not be turned on during this test. Similar gain measurements may be made at any other frequency.

Align Antenna Trimmer.—With the signal generator set at 1,500 kc and connected between receiver antenna and ground posts, and with the electronic voltmeter connected between the stator of the antenna tuning capacitor and ground as in the preceding test for gain, tune the receiver to obtain maximum voltage. The tuning dial is now set for 1,500 kc. If the dial does not indicate this frequency, set it at 1,500 kc and adjust the antenna trimmer to obtain maximum voltage. Similar checks may be made at other frequencies, but the trimmer will make a correction at only one frequency at the high-frequency end of the dial. The generator output need not be modulated provided the voltmeter will measure the potentials at the input frequency being used.

Wave Trap Alignment.—The signal generator is set at the intermediate frequency of the receiver being worked upon, and is connected to the antenna and ground posts. The electronic voltmeter, set for a-c measurement, may be connected between control grid and either cathode or ground of the tube which follows the wave trap, or else the voltmeter may be connected from plate to ground on the same tube provided the voltmeter will not be damaged by the high direct potential on the plate. The receiver dial is set at its low-frequency end and the receiver is turned on. Then the wave trap is tuned for minimum voltage reading on the voltmeter. The generator output may or may not be modulated.

Measure Oscillator Output.—The signal generator is not used during this test, but the receiver is turned on. The electronic voltmeter, set for a-c measurement, is connected between ground and the stator plates of the oscillator tuning capacitor, or else between ground and the oscillator grid of the converter tube. The stator plates usually are easier to reach with the prod.

Now the voltage is observed while the tuning capacitor is turned slowly throughout its entire range, from lowest to highest frequency, and this is repeated in each of the bands to which the receiver tunes.

Normally there are some variations of oscillator voltage throughout each of the frequency bands, and there will be differences between the voltages developed in the different bands. The voltage usually will be somewhere between 3 and 30 a-c volts. If the voltage drops very low or disappears at some points, there are faults in the tuning system or in the coils; such as undesirable couplings, excessive dust or dampness, shorted turns in coils, and other troubles which prevent oscillation.

With another method the electronic voltmeter is used to measure the direct potential between the oscillator grid and ground, making the meter prod connection directly to the oscillator grid socket terminal rather than to the tuning capacitor for the reason that there often is a capacitor between the grid and the tuning capacitor. The grid is negative with reference to ground, so the meter is set for negative d-c potentials. The test is carried through the entire frequency range of each band, just as when measuring the a-c output. The d-c voltage will vary in about the same manner as the a-c voltage, and excessive drops indicate the same troubles as mentioned in the preceding paragraph.

Stage Gains.—For describing a typical procedure for measuring the gains in the various amplifier stages it is assumed that the receiver is a superheterodyne with one r-f tube, untuned coupling to the converter signal grid, one i-f stage, a combined diode detector, avc and first a-f tube, and a single output tube.

The first step is measurement of gain in the tuned r-f stage, from antenna to converter signal grid. The signal generator is set at 600 kc, unmodulated, and is connected between the antenna and ground posts. The electronic voltmeter, set for a-c measurements, is likewise connected between the antenna and ground posts, the receiver is tuned for minimum voltage reading, and this voltage noted. Then the voltmeter is connected between the converter signal grid and ground, the receiver is retuned to give maximum voltage, and the voltage is noted. Dividing this second voltage by the first one gives the gain in this portion of the receiver.

Separate measurement of antenna coupler gain has been described previously. If the generator is connected between r-f grid and ground, and the voltmeter used to measure the voltage across these two points, then is used between the converter grid and ground (retuning at each operation as explained above), dividing the second by the first voltage will give the gain from r-f grid to converter signal grid. If the work is being correctly performed, this gain multiplied by the antenna coupler gain will give the same gain figure as determined by measurement from antenna to converter grid within a very few per cent.

Now the generator is connected between the converter signal grid and ground, is tuned to the intermediate frequency for the receiver, and is left unmodulated. The electronic voltmeter is used to measure this input voltage, between converter signal grid and ground, then is connected from the control grid of the i-f tube to ground for a second reading. Dividing the second by the first voltage gives the gain of the converter, from its grid to the grid of the following tube. There is no object in retuning the receiver during these tests. However, the grid side of the first i-f transformer may be temporarily re-aligned in order to obtain maximum voltage reading with the voltmeter connected from the i-f grid to ground. The generator setting should not be changed.

The next step is to measure the gain of the i-f stage, from the control grid of the i-f tube to the detector diode plate or plates. The signal generator is left at the intermediate frequency and is connected from the i-f control grid to ground, the voltmeter is connected across the same two points, grid to ground, and the voltage noted. Then the voltmeter is connected between the detector diode plate or plates and ground, and this voltage is noted. Temporarily re-align the grid side of the second i-f transformer to obtain maximum voltage readings. Dividing the second by the first voltage gives the gain of the i-f stage.

Now the a-f amplifier is tested. The signal generator is set to deliver an a-f voltage, usually 400 cycles, of only moderate strength in order not to overload the audio stage. The generator is connected between ground and the input from the detector stage to the a-f grid. This latter connection usually may be made at the slider on the volume control, although the receiver diagram should be referred to. The electronic voltmeter is connected across the same points as the generator, and the a-f voltage noted. Then the voltmeter is connected between ground and the control grid of the output tube and the voltage noted. The volume control may be adjusted for maximum voltage. Dividing the second by the first voltage gives the gain of the a-f stage.

The final test is for gain in the output tube. With the generator still set for delivering the a-f voltage, it is connected between the control grid of the output tube and ground. The voltmeter is connected across the same points and the voltage noted. Then the voltmeter is moved to between ground and the plate of the output tube and this voltage is noted. The voltmeter must surely be set for a-c measurements, and its input rectifying circuit must be capable of withstanding the direct plate potential of the output tube. Dividing the second by the first voltage gives the gain of the output tube.

The tests as described are made with all of the tubes in place and operating normally. With another method, which may be more accurate, the second readings of each measurement are made with the electronic voltmeter connected just as described, but with the tube across which the meter is connected removed from its socket. That is, the voltmeter is connected in place of the tube rather than in parallel with the tube. The tube removed is the one to whose control grid connection the voltmeter is attached for the second reading in each test. If the receiver has series heaters, a resistor must be connected between the heater terminals of the socket from which the tube is removed. This is easily done by using pig-tail resistors and sticking the pig-tails into the correct socket holes from the top of the chassis. The correct resistance is determined by dividing the normal heater volts by the heater current in amperes. For example, a 12.6-volt 0.15 ampere heater would be replaced by an 84-ohm resistor. Anything from 60 to 100 ohms would serve during service tests.

Push-pull Performance.—In a push-pull stage the a-f voltages should be alike, or should differ by not more than 10 per cent, from both control grids to ground and also from both plates to ground. If there is a preceding driver or phase inverter stage, the same rule applies to this stage. The test is made by applying to the receiver antenna and ground posts a modulated r-f signal with the receiver tuned to the generator frequency. Usually it is sufficient to measure only the control grid signal voltages, thus avoiding the danger to the voltmeter from the high direct potentials in the plate circuits.

Discriminator Alignment.—For aligning the discriminator of f-m receivers the electronic voltmeter, set for a-c measurements, may be connected across the entire load resistance, or across both sections of this resistance. The zero adjuster of the voltmeter, when the meter is not of the zero center type, is operated to bring the meter pointer up to some one of the principal voltage divisions on the dial. This position then serves as a temporary zero. Alignment is made for zero voltage, with the meter pointer brought to the point selected as the temporary zero. The details of alignment are described in the chapters dealing with f-m receivers.

F-m Transformer Alignment.—As explained in chapters on f-m receivers, the electronic voltmeter is one of the few instruments suited for measuring voltages in the limiter grid circuit during alignment of the i-f stages.

Avc and Grid Bias Voltages.—Avc voltages are measured with the electronic voltmeter set for measurement of negative d-c voltages and connected between ground and any point along the avc bus in the receiver. The voltage may be measured also between ground and the input from the diode detector circuit to the avc filter system, or between ground and the control grids of any of the tubes whose gain is controlled by the avc system.

The generator, set for a modulated r-f signal, is connected to the receiver antenna and ground posts, and the receiver is tuned to the generator frequency. The avc voltage should be maximum when the receiver is tuned to resonance, and should fall off either side of resonance. The generator output should be raised and lowered. The avc voltage should be small with small generator outputs, and should increase as the generator signal strength is increased.

The control grid bias of any tube may be measured with the connections described, whether or not the bias is automatically controlled. In some amplifier circuits it may be necessary to measure the potential difference between the tube control grid and cathode to determine the working bias. The electronic voltmeter may be used for measuring the direct potential of bias cells, which cannot deliver enough current to actuate any other type of voltmeter.

Coupling Capacitors. — Coupling capacitors in resistance-capacitance coupled stages are checked for leakage by removing from its socket the tube preceding the capacitor, thus leaving one side of the capacitor connected only to the B+ lead, then setting the voltmeter for positive d-c measurements and connecting it between the control grid of the following tube and ground. Any indicated voltage is due to leakage through the coupling capacitor. This voltage will make the bias less negative on the following tube.

Bypass Capacitors.—The generator should be used to apply a rather strong signal to the grid of the tube in whose plate, screen, or cathode circuits is the bypass capacitor to be tested. The signal should be at radio, intermediate, or audio frequency, depending on the frequency at which the tube normally operates. The electronic voltmeter is set for a-c measurements, and is connected across the capacitor. Any indicated voltage is due to alternating potentials that are not being bypassed, showing that the reactance of the capacitor is so high, and its capacitance so small, that there are alternating potentials built up on the tube side.

If the bypass is for a cathode-bias resistor in an amplifier where degeneration is desired, the capacitance may be intentionally small enough to develop some alternating potential across it. That is, it may not be desired to have complete bypassing, and a voltmeter reading does not indicate faulty performance.

Other Uses.—The electronic voltmeter, set for a-c measurements, may be used as an output meter during alignment adjustments on any receiver. The voltmeter may be connected either from plate to ground on the output tube, or to the secondary of the output transformer, or to the voice coil of the loud speaker. This type of voltmeter may be used as an output meter during alignment of r-f and i-f stages by measuring the avc voltage as previously described. This avc voltage will increase as the alignment adjustments approach and reach their correct positions.

The electronic voltmeter makes an efficient resonance indicator for practically all of the high-frequency tests described in the chapter dealing with such tests and measurements.

High-frequency currents may be measured approximately by placing in series with the current path a capacitor whose capacitance is known, and whose capacitive reactance may be computed for the existing frequency. The electronic voltmeter then is used to measure the potential drop across the capacitor. Current in amperes is computed by dividing the volts reading by the capacitive reactance in ohms. Similar measurements may be made with a low-loss non-inductive resistor in series with the measured current.

REVIEW QUESTIONS

1. What advantages are gained by balancing or bucking the plate current in an electronic voltmeter?
2. Does accuracy of a slide-back voltmeter depend chiefly on the meter for plate current or the one for grid voltage?
3. In a cathode-bias electronic voltmeter does plate current in the meter tube increase or decrease when the measured alternating potential increases?
4. When a diode is used in a voltmeter probe for measurement of alternating potentials, does the diode circuit deliver alternating or direct potentials to the tube in the bridge circuit?
5. Explain the meaning of contact potential in electronic voltmeters, and describe methods for counteracting the effects of this potential.
6. How can you determine when an electronic voltmeter has a warm-up period sufficient to stabilize the indications?
7. Describe the use of an electronic voltmeter for measuring output voltage of a superheterodyne oscillator.
8. Explain the steps in measurement of amplifier stage gains by use of an electronic voltmeter.

Chapter 8

SIGNAL TRACING

Signal tracing is the name of a method of trouble shooting in which you literally follow a radio signal from its first appearance in the receiver, at the antenna terminal, all the way through to the loud speaker—provided the signal ever gets to the speaker. Otherwise you trace the signal to a point where you no longer can find it, and know that trouble lies between that point and the last one at which the signal was detected.

Signal tracers may be simple instruments which tell only that

Fig. 1.—The Supreme Audolyzer, showing meter of electronic voltmeter, frequency measuring dial, speaker grille, test probe, and controls.

some kind of fault lies somewhere between two points along the path from antenna to speaker. Or the instrument may be so complete that it not only traces all kinds of signals, but accurately measures all voltages and all frequencies, and almost lays a finger on the one particular resistor, capacitor, inductor or conductor which is causing the difficulty. All except a few of these instruments give also a measurement of either relative or precise values of signal potentials on suitably calibrated indicating meters. Some types have electron ray tubes as indicators of signal strength.

Headphones or speaker on a signal tracer will make audible any signal which is modulated at audio frequency. But the oscillator output is not so modulated, and some type of visual indicator, a meter or electron ray tube, is needed to check oscillator performance. By listening to audible signals it is possible to get some idea of the relative gains from stage to stage, but for any precise measurements a meter is required.

Any electronic voltmeter may be used as a signal tracer, giving accurate indications of signal levels and oscillator outputs, provided the instrument is capable of responding to all frequencies

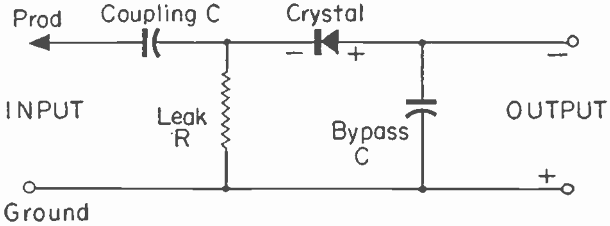


Fig. 2.—A crystal probe using a conventional diode detector circuit.

from radio down to audio ranges, and does not cause too much loading or detuning of resonant circuits in the receiver being tested.

Some of the smaller and simpler types of signal tracing instruments may be operated from either line power or battery power, but the larger and most complete types always are operated by line power.

Crystal Rectifier Tracer.—The simplest signal tracer consists of a crystal detector and headphones. A detector is necessary because in r-f and i-f circuits the frequency is far above audibility and must be detected or rectified to obtain the modulation which is at audio frequency and which may be heard in the phones.

The circuits for one type of crystal probe are shown by Fig. 2. The arrangement is exactly the same as used for a crystal detector in a receiver. The crystal itself may be of any type, adjustable or fixed, but by far the best results are had when using a germanium crystal diode.

Another crystal probe circuit is shown by Fig. 3. Here the arrangement is like that used with a diode tube in probes for electronic voltmeters, with the crystal replacing the tube. Satisfactory operation is had with either of the crystal probe circuits by using a mica coupling capacitor of about 0.002 mfd capacitance, a leak resistance of 20 or more megohms, a bypass of 0.001 to 0.005 mfd capacitance, and, in the circuit of Fig. 3, a load resistance of 20,000 to 100,000 ohms.

Probes of the types shown will pick up and change into audible frequencies any signals which are in radio-, intermediate-, or audio-frequency circuits of a receiver, on either the grid sides or the plate sides of the tubes. They are of no use for the unmodulated potentials from the oscillator.

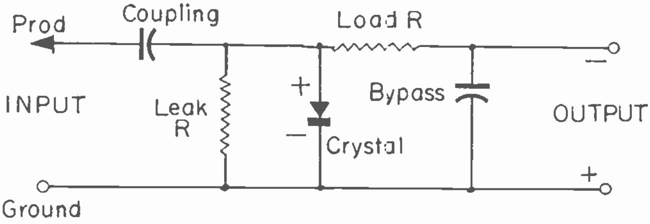


Fig. 3.—A crystal probe circuit with the crystal as a rectifier.

The input to the antenna-ground terminals of the receiver being tested may be from a strong local broadcasting station or, preferably, from a signal generator or test oscillator operating at some radio frequency in the standard broadcast or shortwave bands, and modulated with audio frequency.

The output current from the crystal probes is only a few microamperes, and would require a delicate current meter for indications. However, the output is ample to operate high-impedance headphones used with ear muffs, it may be fed to an electronic voltmeter arranged for measurement of negative direct potentials, or it may be fed to the input circuit of a one- or two-stage audio amplifier whose output goes to a loud speaker or to headphones.

If the probe circuit and the headphones used with it have good fidelity for all audio frequencies it is possible to note whether or not the audible signal is distorted, and to note the point in the receiver amplification system at which distortion first appears. Fidelity is improved by using leak resistances of fairly low values with large coupling capacitances, but the output power is reduced by lessening the leak resistance. Crystal type headphones are better than other types for checking fidelity, especially in the lower audio frequencies, and have greater sensitivity than other types.

Greater sensitivity may be had by using in the probe a miniature or midget tube connected to operate as a grid-rectification or grid-leak detector with its output going to headphones, an audio amplifier, a current meter, or an electronic voltmeter. An arrangement of this type is shown by Fig. 4. The grid capacitor or coupling capacitor is *Cg* and the grid leak resistor is *Rg*. The tube may be a triode, or a pentode connected as a triode. A fila-

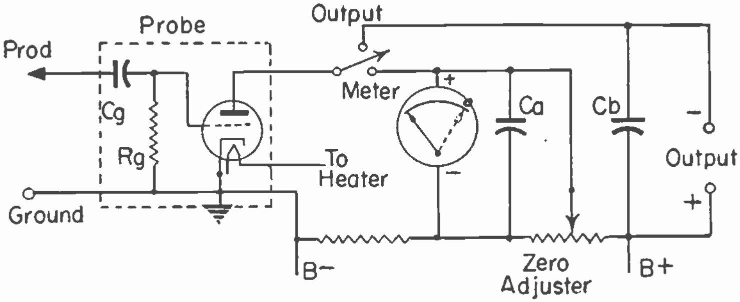


Fig. 4.—A meter-equipped tracer having a grid-rectification detector in the shielded probe.

ment-cathode tube may be used when operation is from battery power. These parts are contained within the shielded probe, from which extends an insulated prod coupled to the tube grid, and also a ground clip.

The detector output may be switched to either the meter which is shown or else to the output terminals for headphones or an electronic voltmeter connection. In the meter circuit is a zero adjuster potentiometer which is set to buck the normal plate current, which tends to make the meter read down-scale, by furnishing an opposing potential which tends to make the meter read up-scale. Capacitor *Ca* is a bypass for the meter, which is of the d-c moving coil type, and *Cb* is a bypass for the phones or other indicator connected to the output terminals. The greater the output from the detector in the probe, or the greater the measured potential between the prod and ground, the farther down-scale the meter will read.

With an instrument of the general type shown by Fig. 4 it is possible to use headphones for tracing r-f, i-f and a-f signal circuits, and to use the meter for checking the operation of the oscillator.

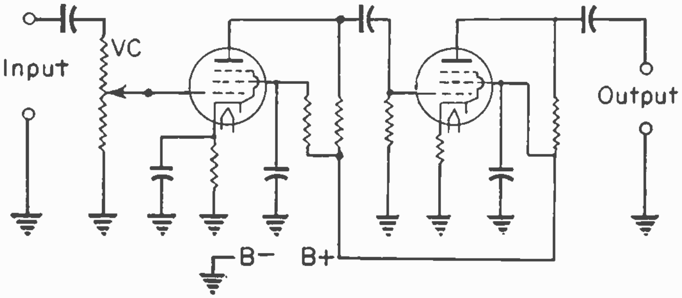


Fig. 5.—An untuned amplifier such as used with crystal or detector types of probes.

The output of the rectifier or detector type of probe may go to the input of a simple two-stage resistance-capacitance coupled audio frequency amplifier such as shown by Fig. 5. In the input control grid circuit is an attenuator (volume control) *VC* used to suit the output of the amplifier for the reproducer used, speaker or headphones, or for an indicating output meter. The values of coupling capacitors and resistors, and of cathode-bias resistors and their bypasses, would depend on the types of tubes used. There are a number of suitable voltage amplifying and power amplifying pentodes of the miniature type, both in heater-cathode and filament-cathode types. The latter would be required for a battery-powered amplifier. Degeneration may be used in the second stage or power stage to provide good response over a wide range of audio frequencies, although the response or fidelity will depend also on the characteristics of the circuit and parts used in the probe.

All of the circuit arrangements shown so far respond quite well to all radio, intermediate, and audio frequencies, but they cannot distinguish between different frequencies. The outputs correspond to the total potential of all the frequencies which are present at the point tested. In the r-f circuits of a receiver there may be potentials due to interfering signals as well as to the desired or tuned signal. At the plate of the converter tube there will be at least four frequencies; the radio frequency, the oscillator frequency, the difference frequency which usually is the intermediate frequency, and also the sum frequency. To determine which frequencies are present and not present, and to measure the potentials at the several frequencies it is necessary to employ tuned amplifying systems in the signal tracing equipment, which then becomes much more than a simple signal tracer.

In the more elaborate instruments there are several sections, more or less independent of one another, adapted especially for indicating and measuring signal potentials at the various existing frequencies as well as direct potentials. The sections may be connected at the same time to several points in the receiver on test so that the effects of adjustments and other changes may be observed simultaneously in the radio-, intermediate-, and audio-frequency amplifying systems, or in whatever portions of these systems it is desired to make simultaneous checks.

Audolyzer.—In the Audolyzer, made by Supreme, there are three principal sections; a high-frequency amplifier used for radio, intermediate, and oscillator frequencies, also an audio-frequency amplifier system which includes a loud speaker, and finally an electronic voltmeter for measurement of potentials at any of the signal frequencies as well as direct potentials. In addition there are panel switching arrangements for the input probe, the meter functions and ranges, and other changes which are conveniently made by switching.

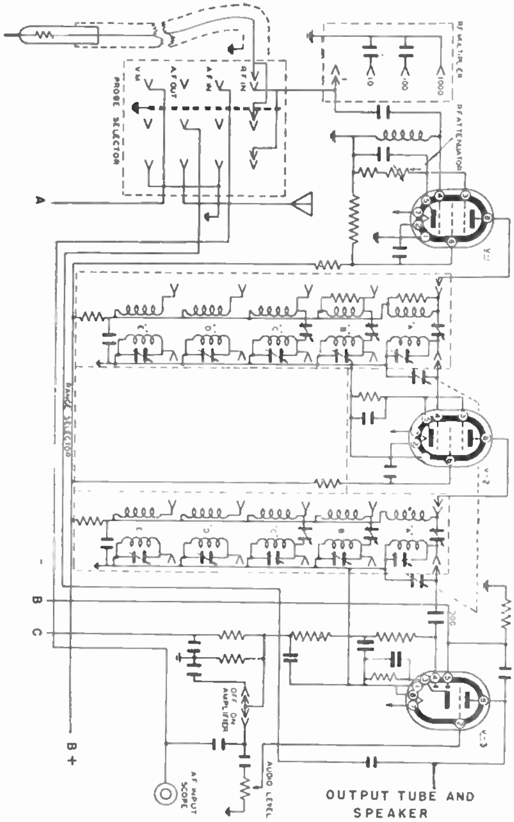


Fig. 6.—The tuned high-frequency amplifier, detector, first audio tube, and probe selector of the Audolyzer.

Fig. 6 shows the schematic circuit diagram for the high-frequency amplifier, the diode detector and first a-f tube, the input attenuator, and the switch for making suitable connections from the probe to the instrument circuits. The output tube or power tube and the loud speaker circuits are not shown here. The amplifier consists of two stages of tuned radio-frequency amplification covering the range from 95 kc to 15 mc in five bands which are switched by the range selector as required for the portion of a receiver being checked.

The probe selector switch, shown at the lower left with the attached cable and probe, has four positions. One is for pickup of signals anywhere between 95 kc and 15 mc, another is for pickup of audio-frequency signals, a third allows supplying audio-frequency potentials from the instrument to loud speakers being tested or for other purposes, and the fourth allows using the probe for input to the electronic voltmeter. The audio-frequency amplifier section of the instrument consists of the detector-amplifier tube shown at the upper right, of a following beam power output tube and a loud speaker not included in the diagram.

The electronic voltmeter contained in the Audolyzer is shown in schematic form by Fig. 7. The probe selector connects with

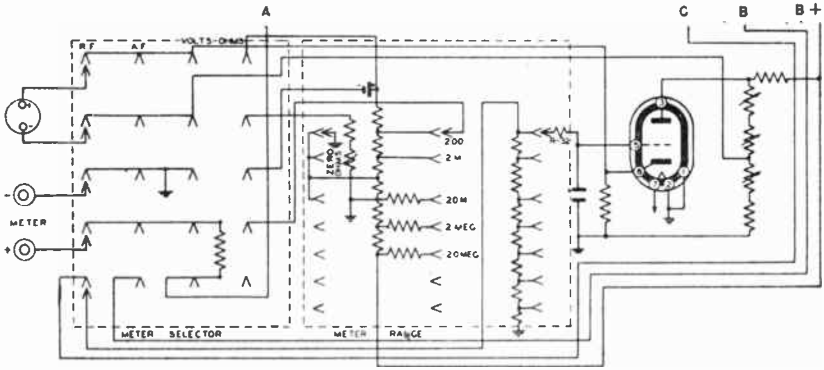


Fig. 7.—The electronic voltmeter used in the Audolyzer.

this voltmeter through connection *A* coming from Fig. 6. Connections *B* and *C* bring audio-frequency and radio-frequency potentials from the amplifier system to the voltmeter input through the meter selector switch.

The electronic voltmeter uses a triode tube in a bridge circuit. The meter is shown at the upper left, connected to the meter selector switch. The electronic voltmeter itself is arranged to measure direct potentials, which may come through the probe and probe selector switch of Fig. 6, or which may be rectified alternating potentials coming from the diode rectifier system of the right-hand tube in Fig. 6.

The front panel of the Audolyzer is pictured by Fig. 1 of this chapter. At the top center is the meter for the electronic voltmeter. Below and to the left is the tuning dial for the t-r-f amplifier of Fig. 6. This dial carries graduations, in frequencies, for the five bands. A frequency is measured or determined by tuning to obtain a maximum reading on the meter, whereupon the dial graduations show the frequency.

When the probe is touched to a point carrying radio, intermediate, or oscillator frequencies, with the selector switches set for *R.F.*, the frequency is tuned in by the dial and the potential is indicated by the meter. Modulated radio or intermediate frequencies may be demodulated by the detector, put through the audio amplifier, and monitored by the loud speaker or other connected audio reproducer.

With the selector switches set at *A.F.* audio-frequency potentials picked up by the probe may be measured by the electronic voltmeter, or they may be put through the audio amplifier and loud speaker. In one of the positions of the probe selector the instrument becomes a radio receiver whose audio-frequency output may be used for testing other devices requiring a-f potentials. The two meter jacks shown at the left in Fig. 7 may be used with external test leads for measuring any direct potential by means of the electronic voltmeter while the regular probe is employed otherwise.

Pickup Probes. — Some instruments are designed to be used with detachable probes and probe cables of several types, each especially suited to a particular kind of signal or potential. For pickup of radio-frequency and oscillator potentials these probes may have capacitors of from a little less to a little more than one micro-microfarad capacitance. For audio frequencies there usually is neither capacitance nor resistance in the probe tip or handle. For pickup of direct potentials for measurement by means of electronic voltmeters the probe may contain a resistance of one or more megohms. The high-frequency and direct potential probes reduce the sensitivity of the instrument, but they also reduce the loading and detuning effects in the circuits being traced or measured for potentials.

Traceometer. — In the Traceometer, made by Hickok, there are four separate electronic voltmeters, also a wattmeter, a loud speaker, and the amplifier and control circuits necessary for the operation of these indicator elements. A picture of the front panel is shown by Fig. 8. The meters for the electronic voltmeters are across the top. The meter at the left measures direct potentials, the one next toward the right measures radio- and intermediate-frequency potentials at from 100 to 1,800 kc, the next meter measures potentials in oscillator and other circuits at

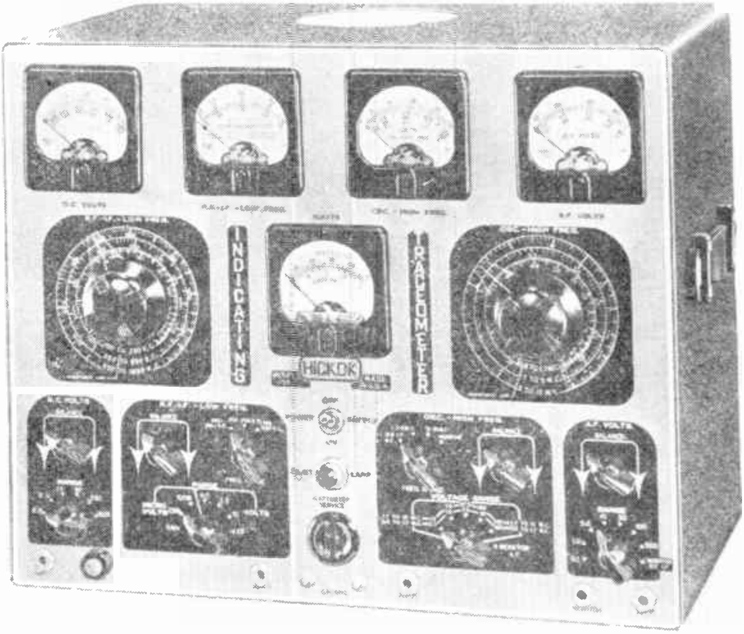


Fig. 8.—The panel of the Traceometer, showing the four meters for four electronic voltmeters, one for a wattmeter, also the frequency measuring dials and the controls.

frequencies from 600 kc to 15 mc, and the one at the right measures audio-frequency potentials. The wattmeter, for indicating power taken by the receiver or other apparatus tested, is in the center of the panel. At the left of the wattmeter is a frequency-calibrated tuning dial for the frequencies between 100 and 1,800 kc, while at the right is a second frequency-calibrated dial for the frequencies between 600 kc and 15 mc. Control selector switches and jacks are at the bottom of the panel.

The audio-frequency electronic voltmeter circuit is shown by Fig. 9. The a-f signal pickup from the probe and cable shown at the top comes through the input jack, with the cable phone plug inserted, and through the range control or attenuator to the control grid of the left-hand double-diode triode tube in which the diode plates are shown grounded. Output from the plate of this amplifier tube goes through the monitor jack and the diode plates of the right-hand double-diode triode tube which is the voltmeter tube. The diode output, rectified, is fed to the control grid of the same tube. The a-f voltmeter *M3* is in the cathode circuit of the tube. Zero adjustment of the meter is made by means of the balance potentiometer which furnishes the neces-

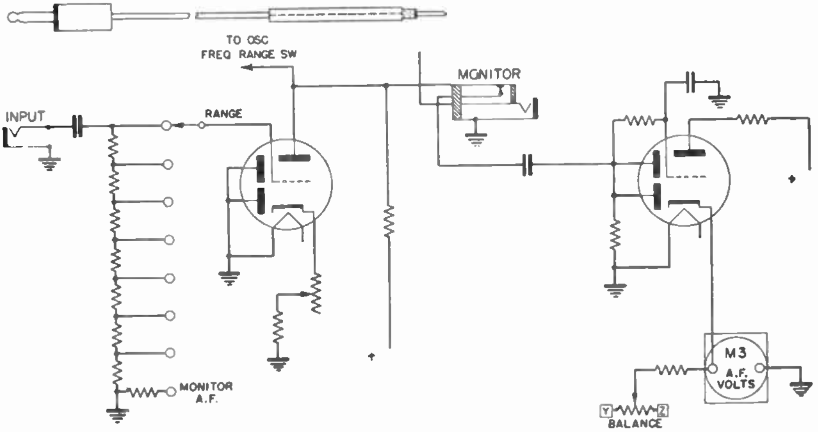


Fig. 9.—A simplified circuit diagram for the audio-frequency electronic voltmeter in the Traceometer.

sary potential from a battery circuit placed in operation when the instrument is turned on. The output may be taken also through the monitor jack to the control grid circuit of another tube acting as an a-f output tube, thence to the built-in loud speaker. With the plug inserted in the monitor jack, the voltmeter tube of Fig. 9 is disconnected from the plate of the amplifier at the left.

The rf-if amplifier used between 100 and 1,800 kc is a three-stage tuned radio-frequency type with switching for tuned coupling transformers for any of three frequency bands in this range. The pickup input is taken through a series capacitance type prod and a capacitance type voltage divider attenuator to the control grid of the first amplifier tube. On the output end of this amplifier is an electronic voltmeter tube and meter arranged similarly to those shown by Fig. 9, but with switching arrangements which allow using the diode plates of the voltmeter tube as a diode detector whose output may be fed to the audio amplifying system when desired.

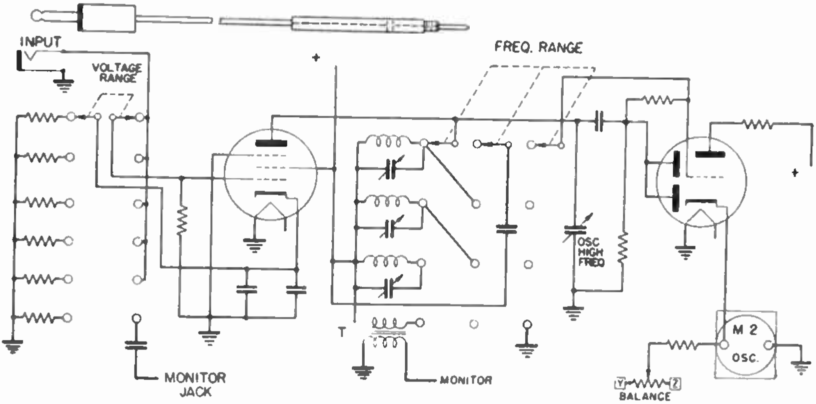


Fig. 10.—Simplified diagram of the amplifier and electronic voltmeter for frequencies between 0.6 and 15 mc in the Traceometer.

The amplifier for the oscillator electronic voltmeter, operating between 600 kc and 15 mc, is a tuned plate impedance type whose schematic diagram is shown by Fig. 10. The left-hand tube is the high-frequency amplifier whose control grid receives the measured potentials through a series capacitance probe and resistance type range attenuator. The amplifier output goes to the rectifying diode plates of the voltmeter double-diode triode tube at the right. The indicating meter is in the plate circuit of this second tube. The separate voltmeter tubes and meter circuits are essentially alike in all of the amplifying systems.

The fact that there are so many separate amplifiers and meters incorporated in the Traceometer makes it possible to observe conditions simultaneously at a number of points in a receiver being checked. Fig. 11 shows one way in which seven readings may be observed without changing any of the connections to the receiver, once they are made.

The readings are as follows: *1*, the rf-if voltmeter probe is on the plate of the first detector or converter tube. Tuning the dial for this voltmeter to obtain a peak reading of the meter allows observing the potential and also the frequency indicated by the dial, which might be the r-f or i-f frequency, depending on the tuning. *2*, the oscillator voltmeter, connected to the receiver oscillator, indicates the oscillator potential when the dial is tuned to the oscillator frequency, and the frequency itself is shown by the

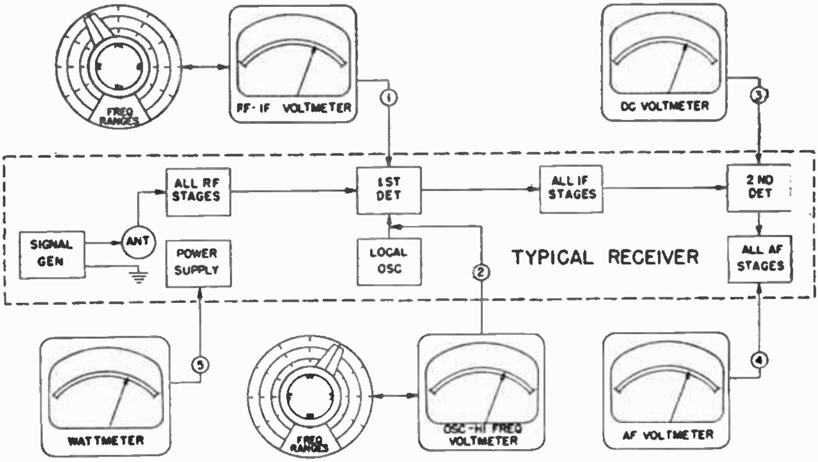


Fig. 11.—Connections for making seven simultaneous readings with a Traceometer.

dial setting. *3*, the d-c electronic voltmeter is connected to the output of the second detector in the receiver, and is indicating the avc potential. *4*, the a-f electronic voltmeter is being used as an output meter connected to the plate side of the output tube or to the loud speaker input. *5*, the wattmeter is indicating the power taken by the receiver.

Many other arrangements are possible. The rf-if input *(1)* might come from anywhere between the antenna and converter tube, with the oscillator voltmeter *(2)* being used at the converter, or the oscillator voltmeter *(2)* might be used between antenna and converter while the rf-if voltmeter *(1)* is used anywhere in the i-f system between the converter and the diode detector.

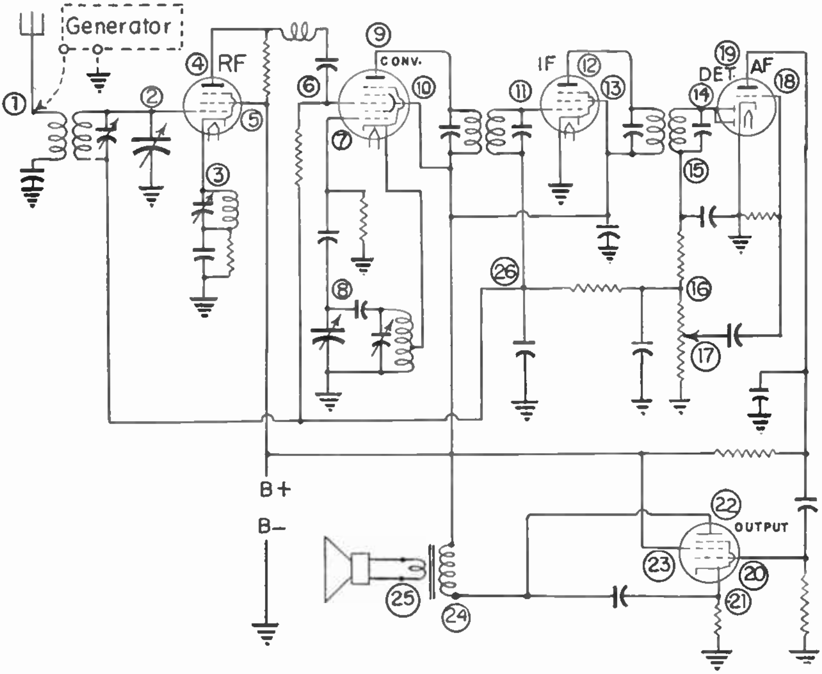


Fig. 12.—Some of the points at which tracer tests and potential measurements may be made in a simple type of superheterodyne receiver.

Tracer Test Points. — Some of the points at which potentials may be picked up in a typical superheterodyne receiver during the process of signal tracing are indicated by numbers on the diagram of Fig. 12. Some of the points may be checked when the input to the receiver is a broadcast signal coming from a local station, but for the measurements and indications to have much real meaning in relation to one another it is necessary that the input be from a signal generator or test oscillator coupled to the receiver antenna terminal and ground post (or chassis) and tuned to some frequency within the range of the receiver. The input signal should be modulated with audio frequency. The generator and receiver should be tuned to the same radio frequency.

1. Receiver antenna post. Tracer tuned to frequency of r-f input signal.

2. Control grid of r-f tube, or stator plates of r-f section of tuning capacitor. Tracer tuned to frequency of r-f input signal. Checks gain, if any, in antenna tuned coupler, also continuity of signal to this point.

3. Wave trap. Tracer tuned first to r-f frequency, then to intermediate frequency. There should be little or no alternating potential.

4. Plate of r-f tube. Tracer tuned to r-f input frequency. Checks gain of the r-f tube.

5. Screen of r-f tube. Should be little or no alternating potential.

6. Signal grid or r-f grid of converter tube. Tracer tuned to r-f input frequency. With most types of interstage coupling the signal potential here will be less than at point 4, or will be about the same.

7. Oscillator grid of converter tube. Tracer tuned to oscillator frequency, which, in standard broadcast range, will be equal to the sum of the r-f input frequency being applied and the intermediate frequency used in the receiver. In some short-wave receivers the oscillator frequency may be the difference between the

r-f input frequency and the intermediate frequency on some or all bands. The potential must be indicated by the meter of the tracer, since there should be no effect in headphones or speaker.

8. Stator plates of oscillator tuning capacitor. Tracer tuned to oscillator frequency. Indication should be practically the same as at point *7*.

9. Plate of converter tube. Here there are potentials at four frequencies; the r-f input frequency, the oscillator frequency, the difference between the first two, and the sum of the first two. If the tracer is untuned, or cannot be tuned to the several frequencies, the indication will be due to all of the potentials together, and should be much greater than at point 6. If the oscillator can be tuned to the radio frequency, intermediate frequency, and oscillator frequency the separate potentials may be measured.

10. Screen of converter tube. Should be little or no alternating potential.

11. Control grid of i-f tube. Tracer tuned to intermediate frequency. If the intermediate frequency was measured separately at point *9*, its potential here will be about the same. If the effect of all frequencies together was measured at point *9*, the potential here will be considerably less, because at the i-f grid we should have only the intermediate frequency.

12. Plate of i-f tube. Tracer tuned to intermediate frequency. The potential should be much greater than at point *11*, because of the amplification or gain in the i-f tube.

13. Screen of i-f tube. Should be little or no alternating potential.

14. Diode plates of detector. Tracer tuned to intermediate frequency. The potential here will be less than at point *12*, the value being almost anything down to one-fourth of the value at *12*.

15. Return end of transformer diode winding. With tracer tuned to intermediate frequency there should be only a small potential here. If the tracer is not of the tunable type the generator a-f modulation may be turned off, whereupon there should be but a small a-c potential at this point. With the modulation turned on there should be an indication, which is due to the audio-frequency signal or to the modulation of the i-f signal. The audio-frequency section of the tracer may be used for making a measurement at this point.

16. Detector filter output. The indications should be practically the same as at point *15.*

17. Slider of volume control. Using a-f section of tracer. With the slider at the high end, toward point *16*, the a-f potential should be the same as at *16.* Rotating the control away from this position should cause the potential to drop gradually, becoming zero at the grounded end of the control resistance.

18. Grid of a-f amplifier. Using a-f section of tracer. The a-f potential here should be only slightly less than at point *17.*

19. Plate of a-f amplifier. Using a-f section of tracer. The potential should be several times higher than at point *18*, depending on the type of tube, because now we have the amplification or gain of the a-f amplifier.

20. Control grid of output tube. Using a-f section of tracer. The potential here should be almost as high as at point *19.*

21. Cathode of output tube. Using a-f section of tracer. If, as shown in the diagram of Fig. 12, the cathode-bias resistor is not bypassed by a capacitor, there will be considerable a-f potential at this point. If there is a bypass the a-f potential will decrease with increase of capacitance in the bypass.

22. Plate of output tube. Using a-f section of tracer. The potential should be several times higher than at point *20*, depending on the type of tube. The increase is due to the gain or amplification in the tube.

23. Screen of output tube. Using a-f section of tracer. There should be little or no a-f potential at this point.

24. Plate end of primary winding in speaker coupling transformer. Using a-f section of tracer. The potential should be the same as at point *22*.

25. Secondary of speaker coupling transformer, or voice coil leads. Since this circuit is not grounded it will be necessary to connect the tracer input across the winding or coil rather than having one side of the tracer input to ground or chassis. Use the a-f section of the tracer. The a-f potential will be much lower than at points *22* and *24*, due to the voltage step-down (and current step-up) of the coupling transformer. Used at points *22*, *24* or *25* the tracer may be employed as an output meter or indicator during alignment of the receiver.

At all of the numbered points mentioned so far the measurements have been of alternating potentials at various frequencies. Alternating potentials may be checked also in the power supply system, usually with the a-f section of the tracer because of the fact that power frequencies are at the lower end of the audio-frequency range.

If the tracer has facilities for measuring direct potentials, such measurements may be made at the following numbered points of Fig. 12. These direct potential measurements ordinarily would be made at the same time as the a-c readings. Sometimes it is more convenient to proceed with the a-c readings at the several frequencies until trouble is indicated, then to check the direct potentials up to the same point.

2. R-f tube grid bias, which here is the avc voltage. Negative potential.

4. R-f tube plate voltage. Positive potential.

5. R-f tube screen voltage. Positive potential.

6. Converter signal grid bias, which here is the avc voltage. Negative.

7. Oscillator grid bias. Negative.

9. Converter plate voltage. Positive.

10. Converter screen voltage. Positive.

11. I-f amplifier grid bias, which here is the avc voltage. Negative.

12. I-f amplifier plate voltage. Positive.

13. I-f amplifier screen voltage. Positive.

14. Diode plate bias. Negative.

15 and **16.** Same as at *14*, or practically so.

17. Volume control slider. Negative. Will vary with position of control.

18. A-f amplifier grid bias. Negative. Should vary with operation of volume control when bias by grid rectification as shown.

19. A-f amplifier plate voltage. Positive.

20. Output tube grid voltage to ground. Would be practically zero with the circuit shown in Fig. 12, the bias being secured from the voltage drop in the cathode-bias resistor.

21. Output tube cathode. Positive to ground. This is the output tube grid bias voltage, the negative side of the resistor going to ground and thence to the control grid.

22. Output tube plate voltage. Positive.

23. Output tube screen voltage. Positive.

26. Avc bus leading to grid returns of tubes whose control grid bias is regulated by the automatic volume control. Negative potential. In the diagram of Fig. 12 the avc voltage is measured also at points *2*, *6* and *11*, and nearly the same value will be read at points *14*, *15* and *16*. Normal grid bias, usually no more than two or three volts, is read with the receiver volume control turned to minimum volume and with the signal generator input at a value below which there is no further drop of the measured avc voltage. The avc voltage should become more and more negative as the input from the signal generator is increased. With the circuits of Fig. 12 the avc voltage is not affected at all by the position of the receiver volume control.

In preceding paragraphs have been outlined briefly a total of forty-six tests and measurements which may be made on the simple receiver circuit of Fig. 12, not counting additional tests and measurements in the power supply system. All of these tests, and others not mentioned, may be made with the more elaborate types of signal tracing and measuring instruments. At least twenty of the points may be traced through with even the simpler types of signal tracers. All of the tracings, tests, and measurements, except those requiring separation of frequencies as at the converter plate, may be made with an electronic voltmeter which will respond to all frequencies as well as to direct potentials.

REVIEW QUESTIONS

1. In addition to a loud speaker or headphones, what other indicators may be used for output with a signal tracer?
2. Describe or mention the parts used in a type of signal tracer which has no electronic tubes.
3. What type or types of output indicator must be used when checking performance of the oscillator in a receiver?
4. What type of circuits must be included in a signal tracer which is to distinguish between different frequencies in parts being tested?
5. Will readings at the converter tube plate be higher with a tracer tuned to the individual frequencies or with the one responsive to all frequencies?
6. Should the signal at the diode plates of a detector be stronger or weaker than at the output from the last i-f tube?
7. Should the signal be stronger at the control grid of the first a-f tube or at the ungrounded end of the volume control?
8. What other test instrument may be used in a manner generally similar to that employed with a signal tracer?

Chapter 9

SIGNAL GENERATORS AND TEST OSCILLATORS

A signal generator is an instrument capable of furnishing radio-frequency signals at any and all of the frequencies which come from broadcasters or other transmitters. The signal from the generator differs from the broadcast signal in not furnishing music and speech for entertainment, but in every other way it is better than broadcast signals.

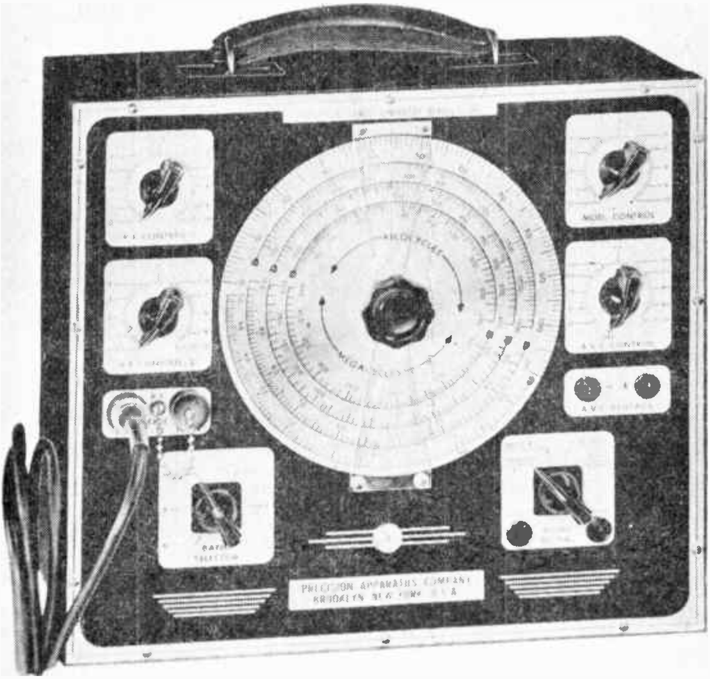


Fig. 1.—A signal generator providing modulated or unmodulated r-f potential, also a-f potential and adjustable direct potential. Precision Apparatus Company.

The signal generator will furnish radio frequencies which are continuously variable from somewhere around 100 kilocycles all the way up to many megacycles. The r-f potential is adjustable from a few microvolts up to a large fraction of a volt, and sometimes more. The generator will furnish also an audio frequency, usually at something near 400 cycles, but sometimes variable throughout the audio range, and sometimes variable also in amplitude or voltage. This audio frequency may be used to modulate the r-f output of the generator, or the r-f output may be modulated with some other frequency from an external source, or the r-f output may be had with no modulation at all—at constant frequency and amplitude.

The signal generator is one of the two instruments which are essential for rapid and efficient radio servicing. The other is a multimeter. With the controllable output of the signal generator available at radio frequencies, oscillator frequencies, intermediate frequencies, and audio frequencies, and with a meter which will show changes in alternating potentials or powers at the outputs of various amplifier stages, a well-informed technician can determine both the kind and approximate location of almost any kind of trouble which may occur in radio and sound apparatus.

The alternating potentials available from signal generators are produced within the instruments by one or more tubes, or sections of tubes, acting as oscillators. In principle these oscillators need not differ greatly from the ones used in superheterodyne receivers. Because all signal generators employ oscillator tubes these instruments, in types designed for radio servicing, often are called *test oscillators*. When designed for use in research and production laboratories the instruments are, and always have been, called *signal generators*. But present practice is to avoid confusion by applying the name signal generator to all commercially manufactured instruments which deliver controlled radio and audio signals, and this is the name which we shall use.

Oscillator Action.—An oscillator tube may be of almost any of the types usually employed as voltage amplifiers, either triodes or pentodes. The circuit connections are such that some small portion of the energy in the plate circuit may be applied to the control grid circuit. The plate, in addition to being coupled to circuits for which the oscillator supplies alternating power, is coupled also to the control grid circuit of the same tube. The input energy for the grid circuit comes from the plate circuit, and the oscillator tubes actually amplifies some of its own output. The return of plate-circuit energy to the grid circuit is called feedback. The feedback coupling may be by mutual induction, it may be capacitive, or it may be combinations of the two.

In the simplified circuit of Fig. 2 the feedback is by mutual induction between a coil *Lp* in the plate circuit coupled to a coil *Lg* in the control grid circuit. When the circuit is turned on, applying the B-voltage in the plate circuit, there will be current, increasing from zero, in coil *Lp*. The changing current in *Lp* induces a changing potential in *Lg*. The windings of the two coils are in such relative directions that this change of plate current induces a grid potential in such polarity as to make the grid more positive. The increasingly positive grid makes the plate current increase to the maximum value determined by the type of tube and the applied plate voltage. Then plate current stops changing. With no change of current in coil *Lp* no potential is induced in *Lg*, and the grid potential drops back to its original zero value.

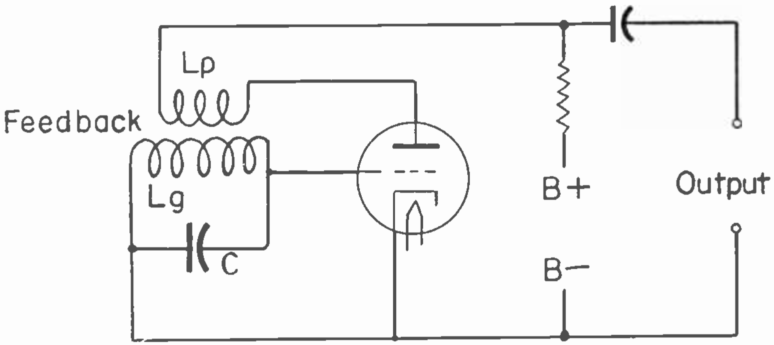


Fig. 2.—The elementary oscillator circuit.

As the grid becomes less positive the plate current is forced to decrease in value. This change of plate current in *Lp* induces a potential in *Lg*, but with plate current decreasing instead of increasing, the polarity of the new potential in *Lg* is opposite to that for the earlier condition, and the grid is made increasingly negative. As the grid becomes more and more negative the plate current becomes less and less, until it reaches cutoff. Then there is no change of plate current, there is no potential induced in *Lg*, and the grid returns to zero voltage. With the grid thus becoming less negative the plate current is caused to increase from the zero or cutoff value, and we are right back where we started. The increases and decreases of plate current constitute an alternating current, and corresponding alternating potential is delivered from the output of the oscillator system.

The frequency of alternating current and potential is determined by the resonant frequency of inductances and capacitances in the circuits, chiefly by the inductance of coil *Lg* and the capacitance of capacitor *C* which is across *Lg*.

Oscillator Grid Bias.—Oscillators are automatically biased by grid rectification, or grid leak bias, as shown by Fig. 3. The action is exactly the same as with this method of bias when used for any other purpose. Positive alternations charge grid capacitor *Cg*, which discharges through grid resistor or leak resistor *Rg*.

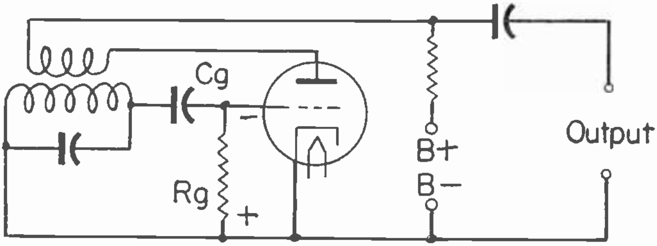


Fig. 3.—A tuned grid oscillator with inductive feedback.

Resistor *Rg* becomes negative at the grid end and positive at the cathode end, and the voltage drop across *Rg* becomes the negative grid bias.

This bias limits the maximum value to which plate current may rise during its alternations. This type of bias tends to maintain fairly constant amplitude of the alternating current and potential in the plate circuit, because stronger alternations make the grid more negative, while weaker alternations make the grid less negative. In radio-frequency oscillators the grid resistors often are somewhere between 20,000 and 60,000 ohms, with grid capacitors from something less than 50 to something more than 200 mmfd. The combinations have to suit the particular circuits and tubes with which they are used.

Tuned Grid Oscillator.—The general type of circuit shown by Fig. 3, wherein the control grid circuit is tuned to determine the frequency of oscillation, may be called a *tuned grid* oscillator circuit. It is used for both radio-frequency and audio-frequency oscillators in signal generators.

Fig. 4 shows a simplified schematic diagram of a tuned grid oscillator used for audio-frequency modulation of the r-f output

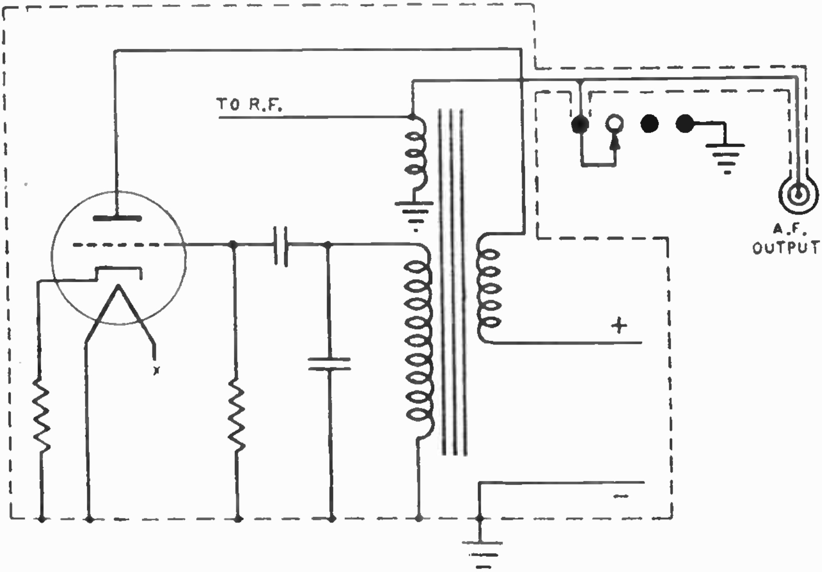


Fig. 4.—A simplified circuit diagram of the a-f oscillator in one type of Triplett signal generator.

in a signal generator. To the grid of the tube is connected the grid resistor going to ground, and the grid capacitor going to the transformer winding which is tuned by another capacitor across this winding. The plate circuit goes through the transformer winding shown on the right-hand side of the transformer core in the diagram, thus allowing energy feedback. The output from this oscillator system is taken from a third winding on the transformer, shown above the tuned grid winding. The output, from the top of the winding goes to the audio-frequency output jack, shown at the extreme right, and also through a lead toward the left to the r-f oscillator system where this a-f potential is used for modulating the r-f output of the generator.

Tuned Plate Oscillator.—Instead of tuning the control grid circuit of the oscillator to determine the oscillation frequency, it is possible to tune the plate circuit for this purpose. The tuned plate system, like the tuned grid, may be used for either radio-frequency or audio-frequency oscillators.

The circuit used for one style of tuned plate r-f oscillator is shown by Fig. 5. At *Cg* and *Rg* are shown the biasing grid capacitor and grid resistor. The main tuning capacitor, for frequency adjustment, is *C*. The trimmer capacitor *Ct* is in the coil unit which includes winding *Lp* in the plate circuit, tuned by *C* and *Ct*, and feedback winding *Lg* in the grid circuit. Several different coil units may be switched into and out of the oscillator circuit for coverage of the several frequency bands in the r-f range. For this particular circuit, which may use a 6J5 or similar tube, *Rg* is 60,000 ohms, *Cg* is 0.0015 mfd, *C* is variable

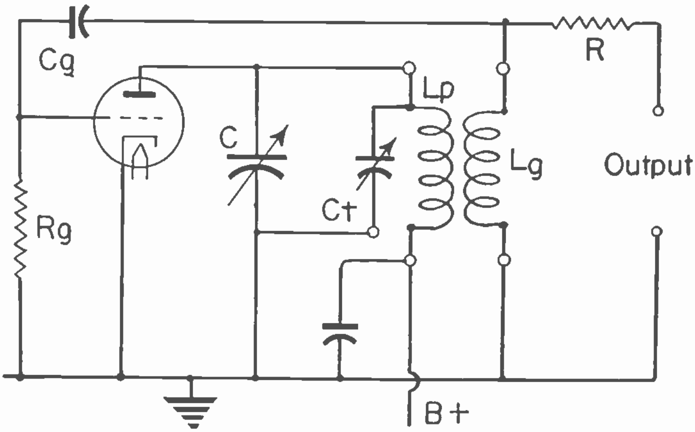


Fig. 5.—A tuned plate oscillator with inductive feedback.

from 10 to 275 mmfd, *Ct* is variable up to 30 mmfd, and *R* is 2,000 ohms. Coil windings have to be suited to the frequency ranges which, in five steps, may run from 100 kc to 30 mc or thereabouts. Plate potential is 80 to 90 volts and grid bias, when not oscillating, is 4 to 5 volts negative.

Hartley Oscillator Circuit.—An arrangement quite often used for production of either radio- or audio-frequency potentials in signal generators is the Hartley oscillator circuit shown in principle by Fig. 6. Coil *Lg* in the grid circuit and coil *Lp* in the plate circuit are connected together at one end of each, and to the cathode from this point. The main tuning capacitor *C* is connected across both coils, so that the oscillation frequency is dependent chiefly on the capacitance of *C* and the combined inductance of *Lg* and *Lp*.

Electron flow in the plate circuit is from plate through resistor *R*, the B-supply, and to the cathode. Alternating potentials and currents in the plate circuit go from the plate through coupling capacitor *Cp*, through ground to the lower end of coil *Lp*, and through *Lp* to the cathode. There is mutual induction between the two coils, which usually are wound on a single form, and potentials are induced in grid coil *Lg* as a result of the feedback. The greater the ratio of inductance in *Lp* to inductance in *Lg* the greater will be the feedback energy.

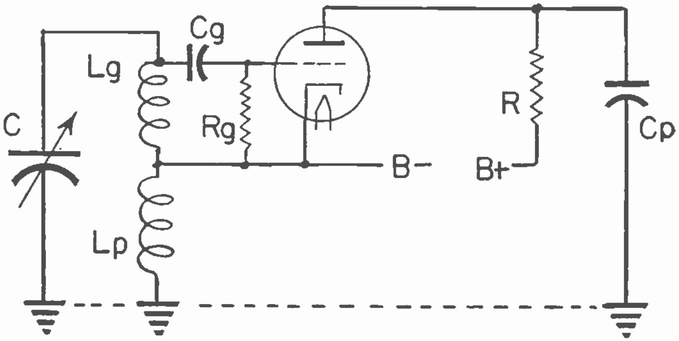


Fig. 6.—One arrangement of the Hartley oscillator circuit.

We may note that the oscillatory circuit which includes tuning capacitor *C* includes both of the windings or coils *Lg* and *Lp*. Consequently, the oscillating currents in this entire circuit must flow in both windings at the same time. As a result it is not absolutely necessary, although it is usual practice, to provide mutual inductive coupling between the windings, since there will be a certain transfer of energy in any case.

Colpitts Oscillator Circuit.—A circuit arrangement used for some r-f oscillators in signal generators, especially when they are to reach the very high frequencies, is called the Colpitts oscillator. The principle is shown by the diagram in Fig. 7. Here there is but a single coil, *L*. There are two tuning capacitors, *Ca* and *Cb*, which are operated together. The tuning capacitor unit is made with two sets of stator plates, one set being connected to each end of the tuning coil, and with the rotors connected together or constructed together, and connected to ground.

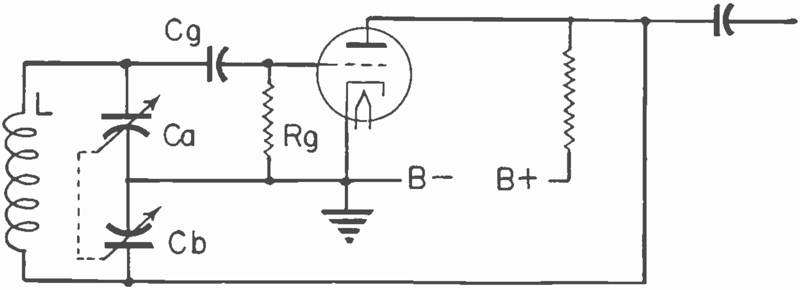


Fig. 7.—An elementary circuit diagram for a Colpitts type of oscillator.

In the Colpitts circuit we have capacitance coupling for the feedback, because alternating potentials between plate and cathode act in capacitor *Cb*, and this capacitance is part of the oscillatory circuit consisting of *Cb* and *Ca* together with coil *L*. The relative values of capacitive reactances in *Cb* and *Ca* determine the relative values of alternating potentials in the plate circuit (containing *Cb*) and the grid circuit (containing *Ca*).

A Colpitts oscillator circuit as used in a signal generator is shown by Fig. 8. The grid capacitor and resistor are *C21* and *R12*. The double tuning capacitor is *C6*. Capacitor *C7* is a trimmer across the tuning coil. Output to the amplifying and modulating system of the generator is taken through capacitor *C17*.

Crystal Controlled Oscillator.—One certain frequency of oscillation may be maintained with great precision by using in the oscillator circuit a small slab or plate of quartz cut in a particular manner from a crystal of quartz. The slabs or plates usually are called *quartz crystals* or *piezo-electric crystals.* They are mounted between pieces of flat metal in insulating holders from which extend pins or other terminals allowing the pieces of metal to be connected betwen points of an oscillator circuit.

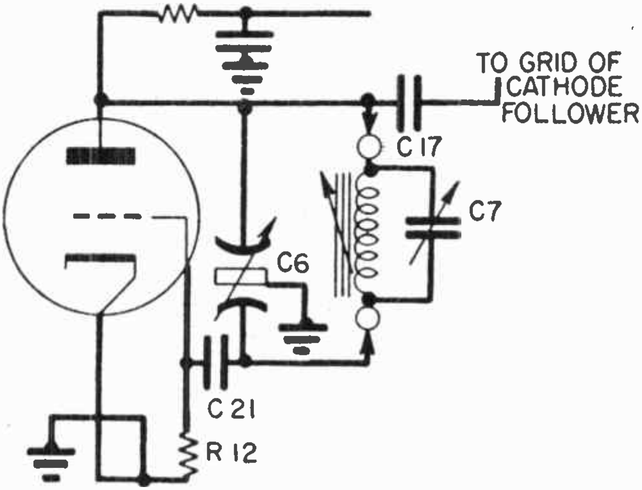


Fig. 8.—The radio-frequency oscillator circuit of a Hickok signal generator which will tune to as high as 160 megacycles.

When an alternating potential is applied across the metal pieces between which is the quartz, and the frequency of the potential is varied, there may be found one frequency at which the quartz vibrates. At this frequency the piece of quartz produces on its opposite sides or faces an alternating potential nearly the same as the applied frequency. Thereafter the applied frequency may be varied to some extent in either way, but the quartz will continue to vibrate and produce an alternating potential at its own natural frequency. This frequency of the crystal depends on its dimensions, especially on its thickness, and on the manner in which it has been cut from the original large crystal.

The quartz crystal may be connected between the control grid and cathode of an oscillator tube, with a resistor paralleling the crystal to provide a conductive grid return, as shown by Fig. 9. When the crystal is supplied with enough power to keep it vibrating, the frequency in the control grid circuit will be that of the crystal itself, and we have a precisely "tuned" grid circuit. The power needed by the crystal is furnished from a tuned plate circuit by means of capacitive feedback, through the plate-to-grid capacitance inside of the tube. In the diagram the crystal is marked "Xtal," a common abbreviation for "crystal," and the paralleled resistor is *R15*.

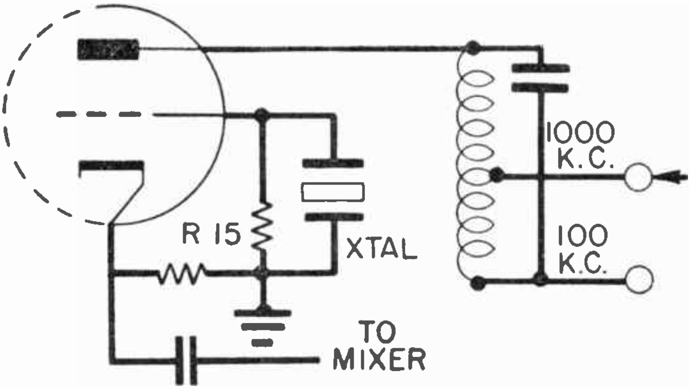


Fig. 9.—The crystal oscillator circuit in a Hickok signal generator.

In order to maintain oscillations, the plate circuit is tuned to a frequency slightly higher than the natural frequency of the crystal. This makes the plate circuit act inductively, or like an inductive reactance, at the crystal frequency. Otherwise there would not be the required energy feedback, and oscillations could not be maintained. The oscillator output frequency will be the natural frequency of the crystal, or, with suitable circuits and crystals, will be some harmonic of that natural frequency.

The circuit of Fig. 9 may be used to produce frequencies of either 100 kc or 1,000 kc. The final output, after going through other tubes in the generator, may be used at the 100-kc fundamental and at harmonics up to the 30th to 40th to provide accurately known frequencies at each 100-kc. For higher frequencies the harmonics of the 1000-kc frequency are used to give known frequencies at each 1000-kc or at each megacycle.

Electron Coupled Oscillators.—One of the major problems in the design of signal generators is to prevent the oscillation frequency from being altered when the oscillator is connected or coupled to some external circuit in which the alternating potentials are to be used. The circuit connected to the output of the oscillator or generator is a load which may have various combinations of resistances, capacitances and inductances. An effective and economical way of isolating the external load from the oscillator while furnishing alternating potentials to the load is to employ what is called *electron coupling* to the output circuit, or to use what is called an electron coupled oscillator.

One method of electron coupling is shown by Fig. 10, where the tube is a pentode. Compare this circuit with that shown in Fig. 8, where the tube is a triode and the circuit is a Hartley type. The two control grid circuits are exactly the same. In the electron coupled arrangement the screen is connected just as is the plate in the earlier arrangement, both connect to a B+ line and, through a capacitor and ground, both connect to the lower end of the tuned oscillatory circuit. Then, considering only the cathode, control grid, and screen of Fig. 10, we again have a

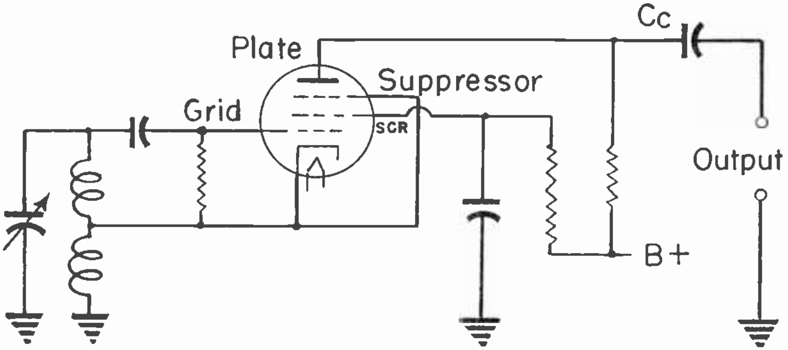


Fig. 10.—One type of electron coupled oscillator.

Hartley oscillator but have the screen acting as the oscillator plate. Instead of the Hartley oscillator, which has been shown merely as an example, we might have any other type which has been shown with a triode tube, and might use the pentode screen for the oscillator plate or anode.

Returning to Fig. 10, note that the suppressor of the pentode is connected to the cathode, consequently, it is at cathode potential and acts an electrostatic shield between the screen, which is acting as the oscillator plate, and the actual plate, which is a collector of electrons that come through the screen. Due to the oscillator action in the tube the potential of the screen varies at the oscillation frequency, which makes the electron stream from the cathode through the screen vary at the same frequency. But this is the electron stream going to the plate, and so electron flow in the plate circuit varies at the oscillation frequency while the plate is electrostatically shielded from the oscillator section of the tube.

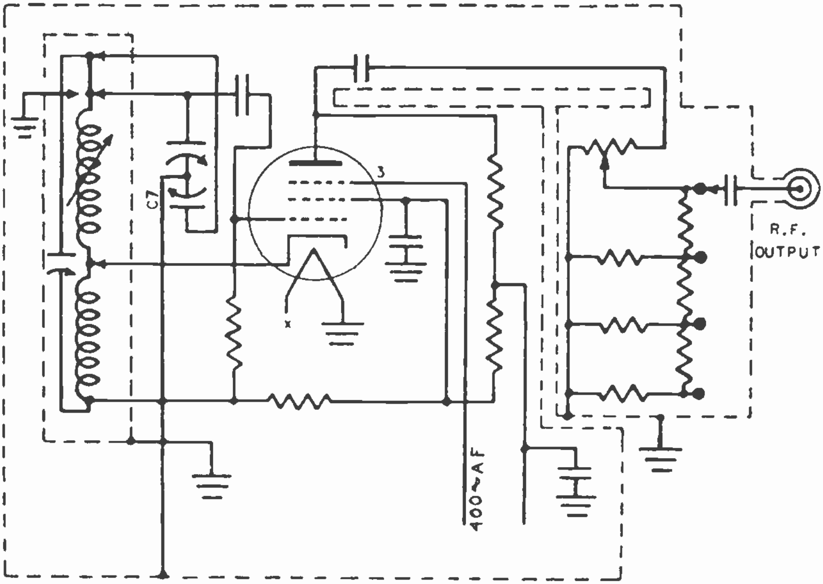


Fig. 11.—An electron coupled r-f oscillator used in a Triplett signal generator.

The plate is coupled through capacitor *Cc* to the generator output and the connected external load. The external load circuit, coupled to the plate, is shielded from the oscillator section of the tube, and conditions in the load circuit can have but little effect on the frequency of the oscillator. The coupling between oscillator and load circuit is by means of the electron stream in the tube, and so we have electron coupling to the output or load. Just as in any pentode, the variations of plate current are controlled by variations of control grid potential, and the average plate current is controlled almost wholly by the screen potential and can be changed but little by variations of plate potential.

A practical electron coupled oscillator circuit is shown by the simplified diagram of Fig. 11. The capacitor at the left of the two-section tuning coil is the trimmer for this coil. The main tuning capacitor is variable unit C7, both of whose sections are connected in parallel for frequencies up to eight megacycles, with one section used alone for higher frequencies. The suppressor grid, *3*, is here used for introducing the 400-cycle a-f modulating potential into the electron stream of the tube when the r-f output of the oscillator is to be thus modulated. The attenuator system, at the right, is one of the parts which will be discussed later.

A complete schematic diagram for the same signal generator is shown by Fig. 12. The r-f oscillator is at the upper left. At the lower left is the a-f oscillator for modulation, which was shown by itself in Fig. 4. To the right of the r-f oscillator are the six sets of coils and six trimmers for tuning in the six frequency bands handled by this instrument. The lower sections of the coils are shown, by the arrows, as having adjustable powdered iron cores. These are the trimming adjustments used at the low-frequency ends of the bands, while the capacitor trimmers are used at the high-frequency ends of the bands. All of these trimmers are calibration adjustments. At the lower right is shown the d-c power supply system, with its full-wave rectifier, filter, and voltage regulating tube.

Buffer Stages. — Oscillators used at very high frequencies may employ types of oscillator tubes which do not lend themselves to load isolation by electron coupling, in which case it is usual practice to feed the output of the oscillator to a tube or stage which prevents reaction of the final load on the oscillator frequency. The

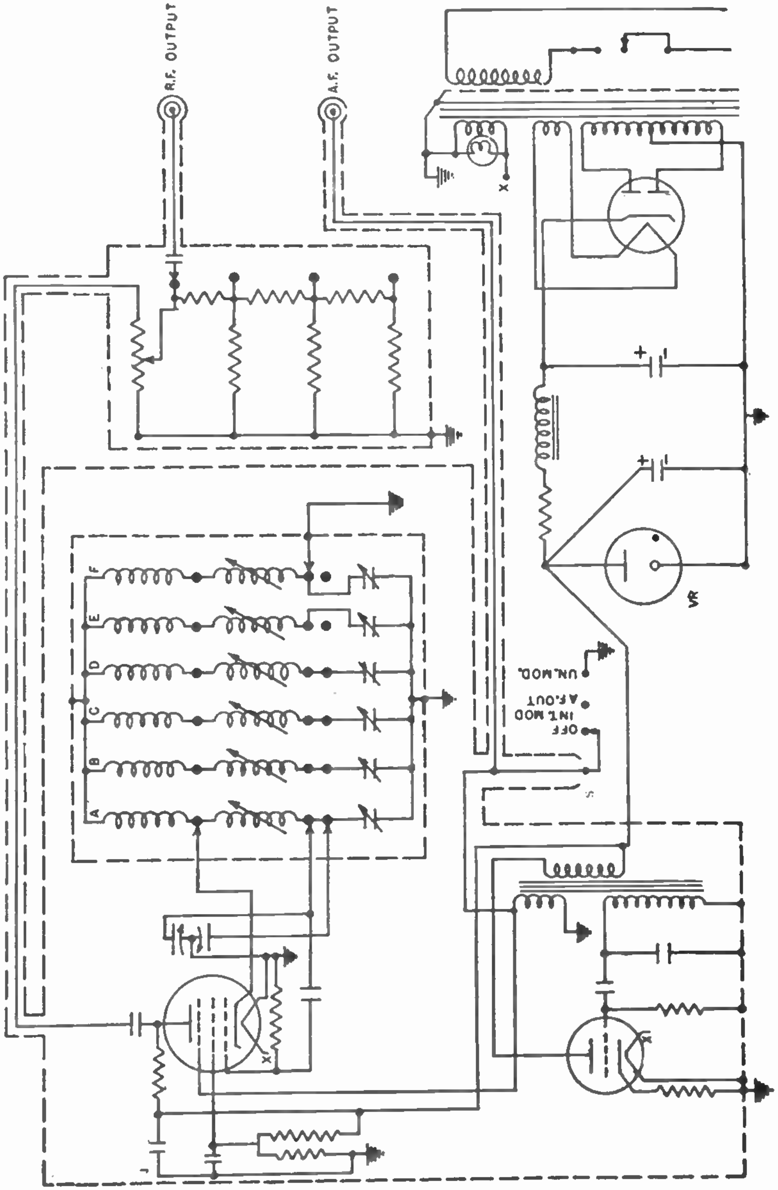


Fig. 12.—The complete schematic circuit diagram for the Triplett signal generator.

intermediate tubes or stages may or may not provide amplification of the oscillator output.

The r-f oscillator shown by Fig. 8 feeds its r-f output potentials to the grid of the cathode follower tube shown in Fig. 13. This follower causes some loss of amplification, but does insure load isolation. The output from the follower tube is taken from across the resistor which is between cathode and ground and is applied to one of the grids of a triode-hexode tube shown near the top of Fig. 14. This grid is the one used as a signal grid when the triode-hexode is employed as a converter. Here the grid is being used as an amplifier, with the final output going to a multiplier or attenuator. The grids nearest the cathodes are used for introduction of modulating potentials. The lower tube in this diagram is a reactance modulator used for frequency-modulation of the r-f output.

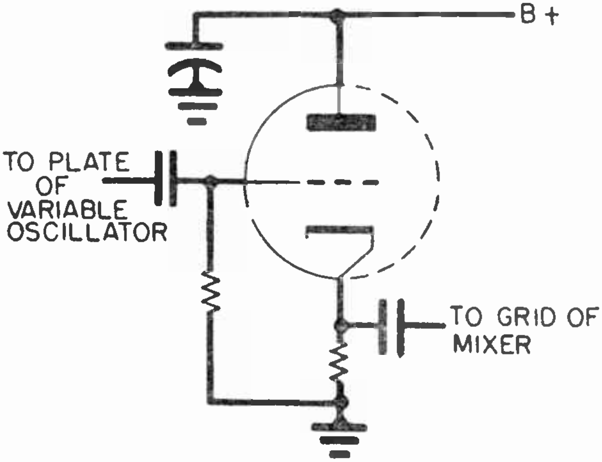


Fig. 13.—The cathode follower in the output circuit of the r-f oscillator in a Hickok signal generator.

In other generators the output of the r-f oscillator may go to the signal grid of a pentagrid converter tube, with audio-frequency modulation or other modulation put into the grid ordinarily used as an oscillator grid when the tube is employed as a converter in a superheterodyne receiver. Any arrangement whose chief purpose is to prevent the load on the final output from affecting the oscillation frequency may be called a *buffer stage.* If the stage also provides amplification it may be called a *buffer amplifier.*

Frequency Drift.—There are effects other than that of the external load which tend to vary the oscillation frequency. Temperature change is one of the things which may cause the frequency to vary. When a generator is first turned on all of its parts are "cold," which means that they are approximately at room temperature. As the generator remains turned on the currents in the various parts cause heating of the parts, with resulting expansion. The heating brings about changes of resistances, inductances and capacitances which are in the tuned circuits and in the tubes, and there will be greater or less change in the oscillation frequency.

One way of guarding against temperature effects is to let the generator remain turned on for between ten minutes and a half hour before assuming that the generated frequency is the same as that indicated by the tuning dial, thus giving everything time to make all of the changes that are going to be made. Generators always are calibrated with their parts at normal working temperature, and calibrations apply only at this temperature. Temperature effects are lessened in some instruments by using capacitors, and sometimes inductors, having compensating "inverse" temperature coefficients. Regulation of d-c plate and screen potential may help to stabilize the frequency, because the plate resistance of tubes varies with changes of plate and screen potential, and with consequent changes of plate current. Small plate and screen currents in oscillator tubes may help matters, because the small currents cause less heating of all parts. Adequate ventilation is necessary.

Changes of capacitance between tube elements and between conductors in general may be allowed to have minimum effect by using for the tuned oscillator circuits relatively large tuning capacitances and small tuning inductances. Then changes in tube and circuit capacitances make but small percentage changes in the total capacitance of the tuned circuits.

Aging of oscillator tubes has some effect on frequency. This effect is lessened by working the tubes well below their maximum rated abilities. With small plate currents there always is plenty of space charge in the tubes, and changes of electron emission from the cathode as the tube grows older in use then will have little effect on performance. New oscillator tubes ordinarily are aged for some time before the generator is calibrated.

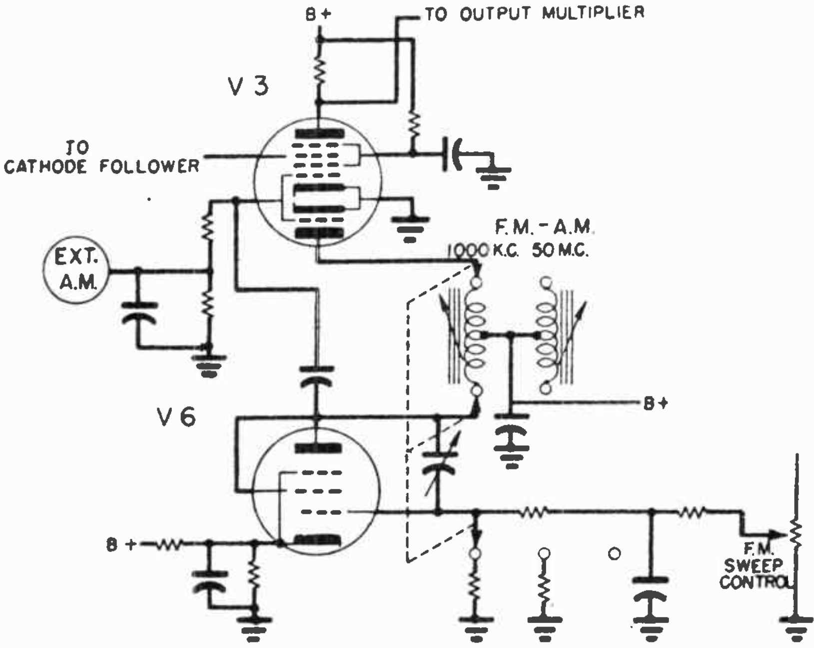


Fig. 14.—The modulation mixer circuit and the frequency-modulation system in a Hickok signal generator.

Shielding and Filtering.—In addition to protecting the oscillator from frequency variations due to the external load, it is necessary to protect the circuit being tested. Sensitive load circuits which are outside the signal generator may be affected by electric and magnetic fields escaping from the generator other than at the terminals or cable intended for the output.

In most signal generators the main reliance is placed upon metallic shielding enclosures. In most instruments there is a shielding enclosure containing the tuning coils and trimmers for the several frequency bands, together with the switching arrangement for band selection. The r-f oscillator tube may or may not be inside of the same enclosure. In nearly all cases there is a shielding enclosure for the output attenuator resistance network and the switch that controls the degree of attenuation. Quite often the interior of the generator cabinet is separated into two main compartments by a metallic shelf, or a horizontal or vertical metallic panel. The d-c power supply system, sometimes the a-f modulating system, and other parts which are not likely to cause radiation are all together in one compartment, with the entire r-f system in the other compartment. There is, of course, a metallic cabinet which encloses the entire signal generator and which acts as a shield for all of the parts within it.

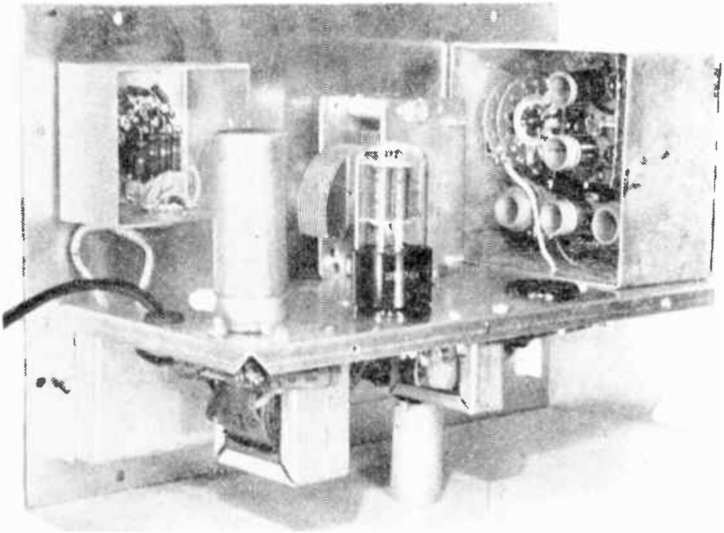


Fig. 15.—Shielding in a radio-service type of signal generator.

Fig. 15 shows the parts of a small signal generator that has been removed from the metal cabinet, and it also shows the dividing shelf partition. Individual shields are used for the tuning coils and band selector switch, and for the output attenuator resistors and their controls. The covers of the shielding boxes have been taken off to expose the parts within each of them.

Unless the power line is filtered and shielded it may carry much high frequency into the building wiring and into other instruments being operated from the same line circuit. Usually there is an electrostatic shield between the primary and secondary windings of the power transformer, with this shield grounded. In addition there usually will be a bypass capacitor connected from each side of the incoming line to ground. Sometimes there are r-f choke coils in each side of the power line, with the bypass capacitors on the ends of the chokes which are toward the transformer. In a few cases we may find low-pass filters in both sides of the power line, with each filter consisting of an r-f choke coil having capacitor bypasses to ground from each side of each coil. Most of these power line filtering arrangements may be seen in one or more of the circuit diagrams in this chapter.

Output Controls.—The r-f output potential from the oscillator or oscillator-amplifier system varies naturally with the operating frequency. From most generators there will be maximum output potential in a frequency band above the lowest, but below the highest. There will be some variation of output potential between the low and high frequency ends of most or all of the bands. Nearly always there will be minimum output potential in the highest frequency band or in a band near the highest one.

The output from the oscillator system at any given frequency may be intentionally weakened or controlled before reaching the final output terminal or jack of the generator. This is done by passing the oscillator output through an attenuator circuit consisting of resistors whose overall value is varied by switching and by the use of a rheostat or potentiometer.

A number of signal generators contain what is called a ladder type attenuator. The arrangement of resistors in a ladder attenuator is shown clearly at the upper right in Fig. 12. A five-step

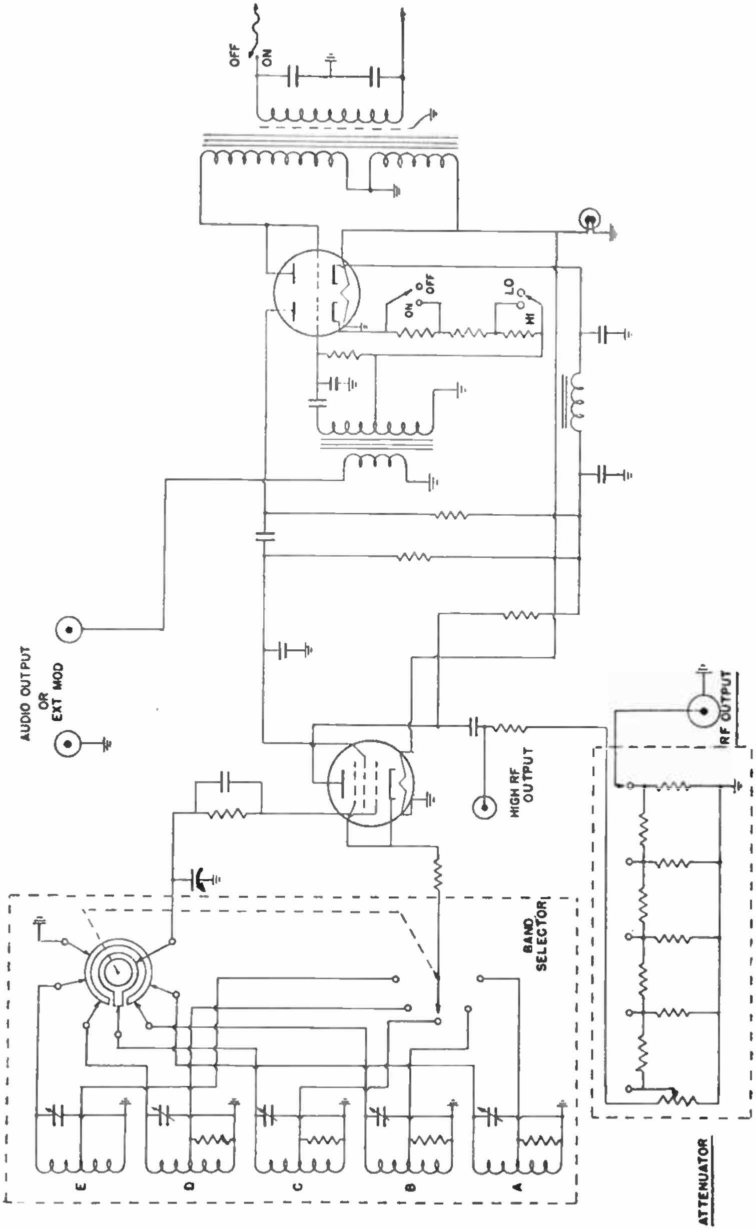


Fig. 16.—Schematic circuit diagram for one type of Radio City Products signal generator.

ladder attenuator is shown in Fig. 16, connected between the plate circuit of the oscillator tube and the r-f output jack. The attenuator system consists of a number of resistors in series with one another, and of other resistors from the junctions between the first ones and ground. The purpose of this arrangement is to maintain an impedance or effective resistance which remains nearly constant through most of the attenuation range when "looked at" from either the oscillator end or the r-f output end.

The output from the oscillator system goes to a voltage divider or potentiometer shown at the top of the attenuator in Fig. 12 and at the left-hand end in Fig. 16. The slider provides the input to the ladder circuit, with the r-f output switched to various points along the ladder. The step control switch often is marked "Multiplier" on the generator panel, although it really does not multiply the signal strength, but rather weakens it. The voltage divider control may be called the fine control, vernier control, or something like that. The voltage divider acts to vary the final output with the step control in any of its positions. The controls of the attenuation system sometimes are marked with microvolts or millivolts of approximate output, or may be used with curves or charts showing outputs. In some of the larger and costlier generators the output potential is continuously indicated by a meter connected into an electronic voltmeter circuit contained in the generator.

Many signal generators have attenuation systems quite similar to the faders and attenuators used with sound systems, and described in chapters dealing with public address. The type of attenuator circuit is not always clearly apparent from the manner in which a circuit diagram is drawn.

Between the oscillator output and the attenuator is a coupling capacitor of small capacitance. This capacitor helps to isolate the oscillator from the output load. In addition, its decrease of capacitive reactance with increase of frequency helps to make the r-f output of the generator more nearly uniform at all frequencies.

R-f input voltages to receiver antenna-ground circuits for testing were specified as follows in one of the earlier I.R.E. standards. Distant signal, 50 microvolts. Mean signal voltage, 5,000 microvolts (0.005 volt). Local signal, 100,000 microvolts (0.1 volt). Strong signal, 2 volts.

Audio-frequency Modulation.—Most of the types of oscillator circuits which are employed for production of radio frequencies may be used also for production of audio frequencies when suitable values of inductance and capacitance are in the tuned oscillatory circuits. Tuned grid, tuned plate, and Hartley oscillator circuits are quite common where the oscillation frequency remains constant, as at 400 cycles or thereabouts. When the audio frequency is to be adjustable over a wide range it is usual practice to employ a beat-frequency oscillator consisting of two radio-frequency oscillators whose frequencies beat together to produce a difference frequency in the audio range. Variation of frequency from one of the r-f oscillators varies the audio beat frequency.

In generators using an electron coupled r-f oscillator the a-f modulating potential from the a-f oscillator may be applied to one of the grids in the r-f oscillator tube. In Fig. 12 the modulating potential from a winding on the a-f oscillator transformer (lower left) goes to number *3* grid of the r-f oscillator tube (upper left). This is the grid normally used as a suppressor. Note that this a-f modulating grid is connected to ground through the transformer winding.

In Fig. 16 the a-f oscillator is the left-hand section of the double triode tube whose other section is used as a diode rectifier in the d-c power supply system. Output from the plate of the a-f oscillator is resistance-capacitance coupled to number *2* grid in the r-f oscillator tube which is near the center of the diagram. This grid, which normally is the screen, is supplied also with a constant direct potential from the power supply system so that it acts as a screen grid while also acting as an a-f modulating grid.

In Fig. 17 the output of the a-f oscillator triode (lower left) is taken from a winding on the oscillator transformer through the selector switch to grid number *3*, normally the suppressor, in the r-f oscillator pentode which is up above. In this generator the a-f potential is continuously variable as taken from the slider of the voltage divider connected to the output winding of the a-f oscillator transformer. Thus the percentage modulation of the r-f output may be adjusted within wide limits. In Fig. 16 two values of a-f potential are available by changing the value of resistance in the cathode lead of the a-f oscillator, and, by greatly increasing this cathode resistance the a-f oscillations are stopped to leave an unmodulated r-f output.

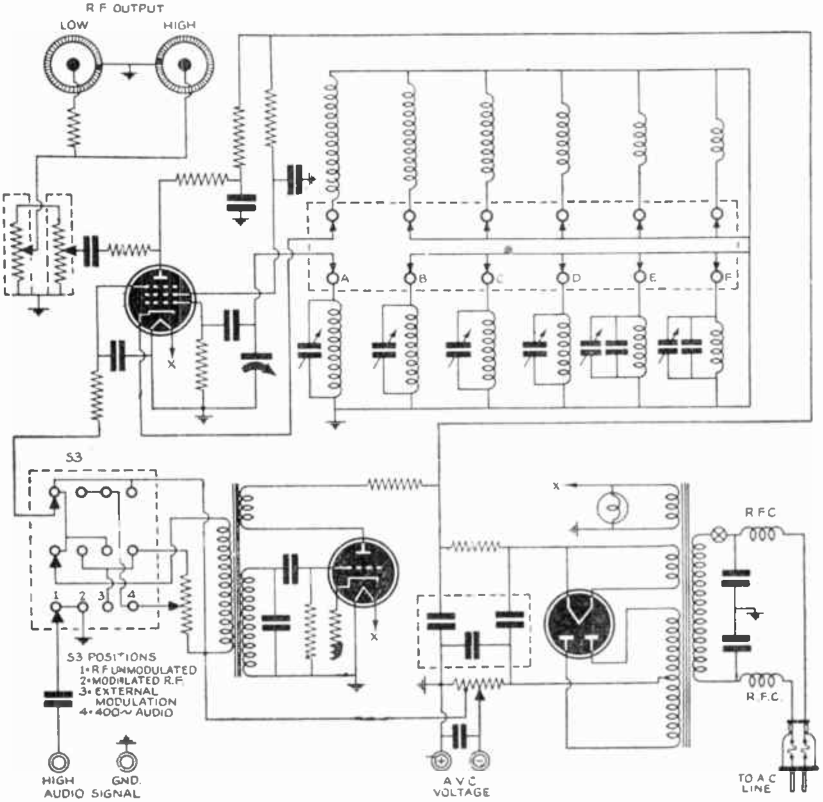


Fig. 17.—Schematic circuit diagram for a Precision Apparatus signal generator.

In all of the signal generators there are jacks or terminals from which may be taken the output of the audio oscillator, unaccompanied by radio frequency, for testing audio amplifiers and other sound systems or devices. In some generators the a-f output is made variable by taking it through the same attenuator system used for r-f output.

There is provision also for introducing a modulating potential of any frequency and amplitude taken from some external source. This external modulating source usually is connected to the same jacks or terminals as used for a-f output from the signal generator. The external modulating potential then goes through the same connections to the r-f oscillator system as are used for "internal modulation" supplied by the a-f oscillator within the generator. The external modulation frequency should not be more than one-tenth of the radio frequency being modulated.

When the audio oscillator furnishes a fixed frequency this frequency usually is a nominal 400 cycles. It seldom is exactly 400 cycles in service types of instruments, but may be twenty per cent or more either above or below 400 cycles.

Frequency Modulation.—A frequency modulating system as used in a signal generator is shown by Fig. 14. The lower tube, *V6*, is the reactance modulator tube which supplies the varying frequency for frequency deviation. The upper tube, *V3*, consists of a triode shown in the lower part of the envelope and, in the upper part of the same envelope, a section having four grids between cathode and plate. This section is called a hexode (six elements). The grid of the triode section of *V3* is directly connected to the grid nearest the cathode in the hexode section, so that any potentials developed on the triode grid will appear simultaneously on the first grid in the hexode. The third grid above the cathode in the hexode section, marked "To Cathode Follower," is enclosed by the two grids which are the screen. Any potential applied to this third enclosed grid will affect the electron stream in the hexode section, and the electron stream will be affected also by whatever potential appears on the grid nearest the cathode, which is connected to the triode grid. When there is one alternating potential on the number one grid and the triode grid, and another alternating potential on the number three enclosed grid, the plate current will be varied by both of these alternating potentials. That is to say, the hexode section will act as a mixer, and the output into its plate circuit will contain frequencies which are the sum and the difference of the separate alternating potentials applied to number one and number three grids.

The triode section of *V3* is used as an oscillator for producing a frequency of either 1,000 kc or of 50 mc, depending on which of the two tuning coils is connected into the plate circuit of this triode section. The reactance tube, *V6,* is producing a varying frequency which will cause deviations in the final output. The varying frequency from this reactance tube goes from its plate through a coupling capacitor to the grids nearest the cathodes in *V3* up above, and modulates the oscillator. Now we have an oscillator frequency of either 1,000 kc or 50 mc which is deviat-

Fig. 18.—The panel of the Hickok signal generator.

ing in accordance with the input from the reactance tube. That is, we have either a 1,000-kc or a 50-mc signal which is frequency modulated.

This frequency-modulated signal from the triode oscillator is being applied to the first grid of the hexode section. The third grid of the hexode section is receiving an unmodulated r-f signal from the cathode follower of Fig. 13, which, in turn, is getting its signal frequency from the r-f oscillator of Fig. 8. In the plate output of the hexode section of *V3* there will be frequencies equal to the sum and the difference of the f-m signal on number one grid and the r-f signal on number three grid, and these output frequencies will be frequency-modulated.

The radio-frequency oscillator is adjusted to deliver a frequency which is either the sum or the difference of the desired final output frequency and the f-m oscillator frequency. As an example, were it desired to have a 10-mc frequency-modulated output for i-f alignment in an f-m receiver, we would use the 50 mc f-m oscillator frequency and would adjust the r-f oscillator (unmodulated) for either 40 mc or 60 mc. The 40-mc frequency is equal to the f-m oscillator frequency, 50 mc, minus the desired output frequency, 10 mc. The 60-mc frequency is the sum of 50 mc and 10 mc. The panel controls used for these adjustments are shown on the picture of Fig. 18.

The 1,000 kc f-m oscillator frequency is used for such purposes as aligning the i-f stages of an amplitude-modulated receiver with an oscillograph being used to indicate changes in the receiver or detector output. Then the r-f oscillator of the generator is adjusted to furnish the sum or difference frequency of the desired intermediate frequency, such as 456 kc, and the 1,000 kc frequency of the f-m oscillator in the signal generator.

The degree or extent of frequency deviation is determined by the amplitude of the alternating potential applied to the control grid, number one grid, of the reactance tube *V6*. This amplitude is controlled by the potentiometer marked "FM Sweep Control." When using the f-m oscillator in *V3* at 50 mc the frequency applied to the reactance tube control grid is 400 cycles taken from the audio oscillator of the signal generator. The deviation then is variable from zero to 450 kc. When using the f-m oscillator at

1,000 kc the frequency applied to the reactance tube grid is 60 cycles, taken from the a-c circuit for heaters in the tubes of the generator. The deviation then may be varied from zero to 30 kilocycles.

Audio-frequency Generator. — In Fig. 19 is pictured a generator designed for the production of audio frequencies alone. This

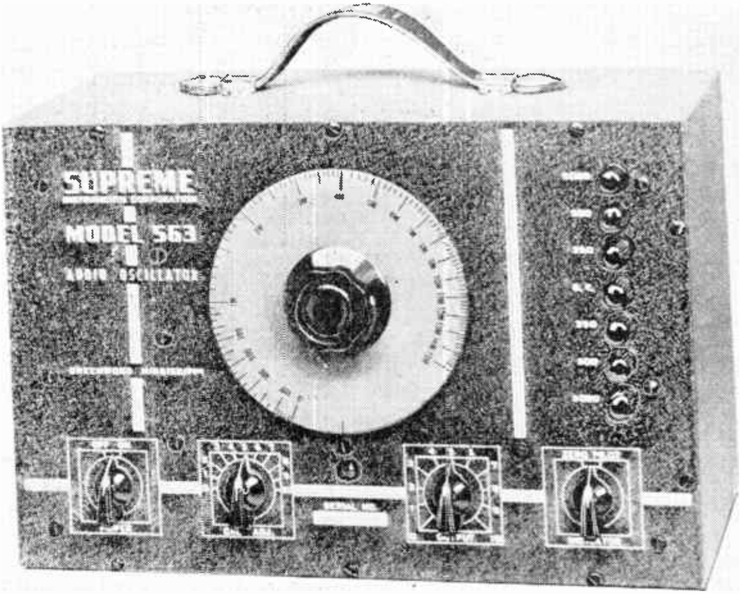


Fig. 19.—Panel controls of the Supreme audio-frequency generator.

generator will furnish frequencies continuously variable from 30 to 15,000 cycles, at potentials or amplitudes which also are continuously variable.

A schematic circuit diagram of the audio generator is shown by Fig. 20. There are two complete high-frequency oscillators shown at the top and bottom on the left. The frequency of the upper oscillator is variable over only a relatively small percentage of its average operating frequency; this by means of the variable capacitor marked "Cal Adj," for calibration adjustment. The frequency of the lower oscillator is adjusted by a variable capacitor operated from the large dial in the center of the front panel.

The high-frequency output of the upper oscillator is resistance-capacitance coupled to the grid of the following triode, which is a mixer tube. The high-frequency output of the lower oscillator goes through the tuned transformer coupling into the cathode lead of the mixer tube. The electron stream from cathode to plate in the mixer tube is varied in frequency by both of the high frequencies at the same time, and in the output of the mixer there appears a frequency which is equal to the difference between the two incoming high frequencies. The principle is the same as when combining the r-f signal frequency and the local oscillator frequency in the mixer or converter tube of a superheterodyne receiver. The arrangement of Fig. 20 is called a *beat-frequency oscillator* because its output frequency, from the mixer tube, is the beat frequency produced by beating together the two higher frequencies.

When the two high-frequency oscillators operate at exactly the same frequency there is no difference-frequency, and the output from the mixer is at zero frequency. When the frequency of one of the high-frequency oscillators then is varied there will be an increasing difference between the two, and the mixer output frequency, which is the difference-frequency, will increase proportionately. Thus the adjustment of one of the high-frequency oscillators produces a continuously varying output beat frequency from the mixer. When the difference between the two high frequencies is within the audio range, the mixer output frequency will be an audio frequency.

The mixer output is coupled to the grid of the following a-f amplifier tube, whose plate circuit contains the primary of the output transformer at the upper right in the diagram. The secondary of the output transformer is center tapped, and tapped at equal electrical distances either side of center to provide connections when working with push-pull amplifiers. The taps provide various output impedances which may be used for matching the input impedances of apparatus being tested.

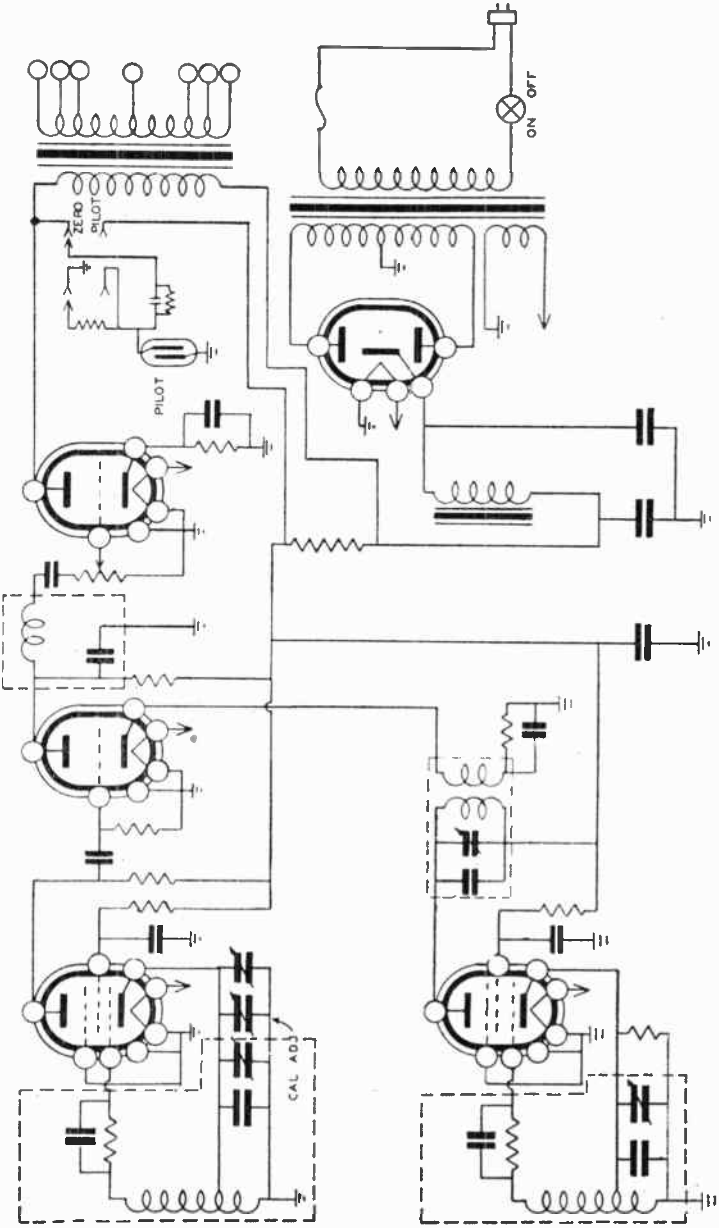


Fig. 20.—Schematic circuit diagram of the Supreme beat-frequency audio generator.

Because there would be no audible output from this generator at zero audio frequency, a small neon lamp is arranged to indicate the condition of zero beat. After the generator warms up, and with the main tuning dial set to zero frequency marking, the calibration adjustment is varied by its control on the front panel until the neon lamp ceases to glow, or until there are long intervals between flashes of the lamp. This shows that both oscillators are operating at the same frequency, and that the output frequency is zero to correspond with the setting of the main dial. Then this main dial may be set to whatever audio frequency is desired, and the output control is adjusted for the desired potential or amplitude.

Tests With Signal Generators. — Signal generators are probably used more often for alignment of receivers than for any other purpose. Detailed instructions for alignment procedures are given in chapters dealing with superheterodyne, shortwave, and frequency-modulation receivers. A few additional points will be mentioned here.

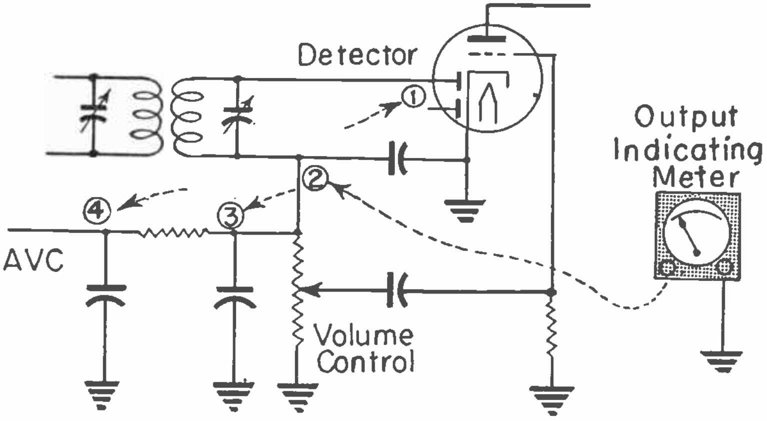


Fig. 21.—Connections for i-f, r-f, and oscillator alignment with unmodulated output from a signal generator.

Alignment of i-f stages, the oscillator, and r-f stages may be carried out with unmodulated output from the r-f signal generator by using suitable output indicators. An electronic voltmeter, set for measuring alternating potential, may be connected between the detector diode plates and ground to indicate output from the i-f amplifier while alignment adjustments are being made. A high-resistance d-c voltmeter may be used with its positive side to ground or chassis and its negative side connected to the detector diode plates, or to any point along the avc bus or in the avc filter system. An electronic voltmeter may be used similarly; set for measurement of negative direct potentials, and connected between ground and any of the points just mentioned. These points are shown by Fig. 21. Alignment with unmodulated r-f output from the signal generator sometimes is desirable when there is to be no sound from the receiver, without having to disconnect the loud speaker or the audio amplifying system.

The i-f transformers sometimes are aligned with the local oscillator of the receiver made inactive during the alignment. The oscillator is conveniently stopped by connecting the stator plate section of the oscillator tuning capacitor to ground, or to the rotor plate section of this capacitor. Then the signal generator, set for the intermediate frequency, is connected to the signal grid of the converter tube. Output from the audio system of the receiver may be indicated by any of the usual output meters which respond to audio frequency, with the generator output modulated with audio frequency. The generator may be used unmodulated when the indicators for output are as described in the preceding paragraph.

If the receiver has an electron-ray tube for adjustment of the tuning, with this tube actuated or controlled from the avc voltage, as is usual practice, alignment adjustments may be made to produce the narrowest shadow line on the target of the electron-ray tube. This is equivalent to taking output indications from the avc voltage during alignment adjustments.

During alignment adjustments it is usual practice to continually reduce the output from the signal generator as the alignment proceeds, thus preventing increase of negative grid bias on amplifier tubes controlled by the avc system. If the avc system is allowed to operate, as it will when using a stronger signal than necessary from the generator, the tuning apparently will be broadened and it will become difficult to identify the points of maximum output. The maximum will appear to remain without much change while trimmers are turned quite a ways one way and the other.

During normal operation of a receiver the signals coming to the antenna usually are strong enough to make the avc system operate. Therefore, when alignment is made with generator signals so weak as to prevent avc operation, the adjustments are not made under truly normal operating conditions. To simulate normal operation during alignment, the avc bus sometimes is temporarily disconnected from the diode detector circuit and the avc filter system, and a fixed bias voltage is applied to the avc bus. This bias voltage is connected with its negative side to the avc line and its positive to ground. The correct potential for the fixed bias will be in the neighborhood of the avc bias voltage produced with mean or average r-f signal voltage applied between the receiver antenna post and ground. As mentioned earlier in this chapter, such a signal has an a-c potential of 5,000 microvolts or 0.005 volt. If the output of the signal generator is calibrated, a signal of this value may be applied to the receiver and the resulting avc bias voltage measured with an electronic voltmeter or highly sensitive d-c voltmeter. Then the avc bus is disconnected, as mentioned above, and a fixed bias voltage of the measured value is inserted.

From the signal generator pictured by Fig. 1 there may be obtained a direct potential of adjustable value for use as a fixed bias instead of the avc bias during alignment. The Precision Apparatus Company states that, when the normal avc bias is inconvenient to measure, the fixed bias may be set to between 5 and 10 volts for receivers of low sensitivity, to between 7 and 15 volts for those of moderate sensitivity, and to between 10 and 20 volts for receivers of high sensitivity.

Image Response. — The image frequency, in superheterodyne reception, is a radio frequency which differs from the tuned signal frequency by twice the intermediate frequency. For instance, if a receiver is tuned to 1,000 kc, and uses an intermediate frequency of 456 kc, the image frequency will be 1,912 kc, which is the sum of 1,000 kc and of two times 456 kc, or 912 kc. This assumes that the oscillator frequency is being maintained above the tuned signal frequency. If the oscillator frequency is maintained below the tuned frequency, then the image will be below the tuned frequency by twice the intermediate frequency.

If the signal generator output is accurately calibrated the image response may be determined as follows: Connect an output meter to the receiver. Connect the signal generator between receiver antenna and ground. Tune the receiver and generator to the same frequency, and set the generator output for a fairly large reading on the output meter. Make a note of the generator output potential. Do not alter the receiver tuning, but retune the generator to the image frequency. Adjust the generator output to give the same reading as before on the output meter. The ratio of the two generator outputs is the image ratio. Fig. 22 shows the connections.

If the generator is not calibrated for output, but the output meter is calibrated, read the meter with receiver and generator tuned to the same frequency. Then, without altering the receiver tuning or the generator attenuator setting, retune the generator to the image frequency and again read the meter. The two meter readings give an approximate image ratio, but the ratio will not be exact for the reason that the generator output will change between the two frequencies to which it is tuned.

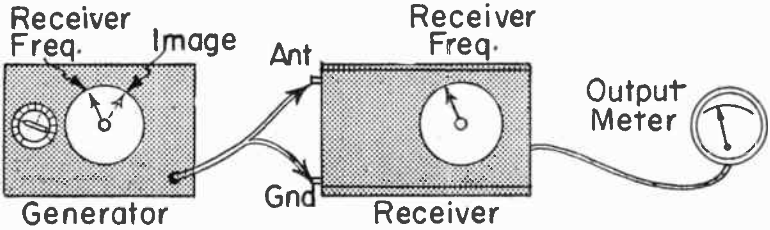


Fig. 22.—Checking the image response of a superheterodyne receiver.

Check Tuning of Coils. — Sometimes there is a question of whether the antenna coupler and the oscillator tuned circuit tune together throughout the tuned range of frequencies in a band. A check may be made with two test probes, one magnetic and the other non-magnetic. The magnetic probe must be of iron which will not have large eddy currents at high frequencies. A powdered iron core or part of such a core from an inductively tuned i-f transformer or other inductively tuned coil will serve very well. The non-magnetic probe may consist of any small piece of copper, brass or aluminum on the end of an insulating rod, which may be an alignment screwdriver made entirely of insulation. Both the powdered iron "slug" and the non-magnetic metal should be wrapped with Scotch tape or other high-grade insulation to prevent shorting any exposed leads which may be inside the tuning coils.

Connect the signal generator to the antenna and ground of the receiver, with an output meter connected to the receiver. Set the generator at a frequency near the lower end of the band, and tune the receiver to obtain maximum reading on the output meter. That is, tune generator and receiver accurately to the same frequency.

Now insert the magnetic probe into the antenna and oscillator coils. The output meter should show a decreased reading. If the reading increases there is too little capacitance or inductance in the tuned circuit being checked. Then insert the non-magnetic probe into the coils. Again the output meter should show a lower reading. If the output goes up there is too much capacitance or inductance in the tuned circuit being tested. Too little capacitance would call for increasing the capacitance in a trimmer capacitor or padder capacitor, or for turning a tuning slug farther into the coil. Too much capacitance would call for the opposite adjustments.

The tests then should be repeated with the generator and receiver tuned together to a frequency near the high end of the band. The same indications and remedies apply as at the lower frequency. Tests may be made also at frequencies in between the ends of the bands, also at the coils of any other tuned stages. It may not be possible to make any adjustments which keep the various tuned circuits precisely tracked throughout the whole frequency range, but differences may be made as small as possible.

Selectivity Check. — It is possible to get an approximate check, not an exact measurement, of receiver selectivity by using an output meter on the receiver and tuning generator and receiver to the same frequency, so that the output meter gives maximum reading. The receiver tuning is not altered, but the generator tuning is varied both ways from the original tuned frequency while observing the readings of the output meter. In the standard broadcast band it would be desirable that output indications drop to relatively low values five kc each way from resonance when the broadcast transmitters each occupy an r-f band ten kc wide.

Avc Action. — If the output of the signal generator is calibrated it may be used for checking or measuring the performance of the automatic volume control system. An output meter should be connected to the receiver, and the generator used with a-f modulated output. Generator and receiver are tuned to the same frequency, the generator output is set at some low value, and the receiver volume control adjusted to give the lowest clearly readable indication on the output meter. The tuning and the volume control are to remain as now set. The generator output is increased in fairly small steps, and for each output potential there is noted the resulting reading of the output meter. If the corresponding values are plotted on a curve it will be seen that the receiver audio output rises rapidly with the first increases of generator output, but that the receiver output then rises more slowly with equal increases of generator output after the automatic volume control system commences to act.

Intermediate and Oscillator Frequencies. — To measure the intermediate frequency of a receiver, and the oscillator frequency for any given setting of the main tuning dial, proceed as follows. Fig. 23 shows connections for one type of oscillator circuit.

Connect the signal generator to the receiver antenna and ground. Set the generator at some even number of kilocycles or megacycles, such as 1,000 kilocycles, and tune the receiver as accurately as possible to the generator signal. For accurate tuning it is necessary to use some form of output meter on the receiver.

Now turn off the receiver. Connect the signal generator to ground and to the cathode of the oscillator tube or converter tube. Connect an electronic voltmeter, set for a-c measurement, to ground and to the oscillator grid or to the stator plates of the oscillator tuning capacitor. Tune the signal generator to get a maximum reading on the voltmeter. This generator frequency is the approximate oscillator frequency which exists when the receiver is tuned to the original radio frequency, such as 1,000 kilocycles. The difference between this generator frequency and the original tuned frequency, such as 1,000 kilocycles, is the approximate intermediate frequency of the receiver.

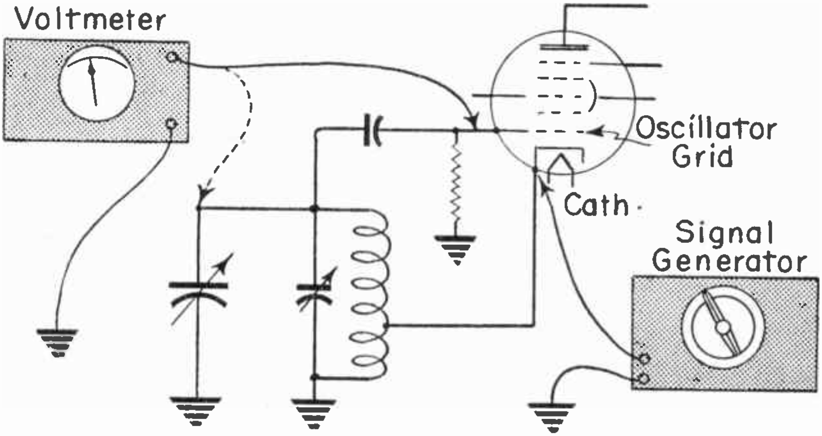


Fig. 23.—Checking intermediate frequency and oscillator frequency.

It is not reasonable to expect to read frequencies on a service type of signal generator to within a few kilocycles, but, knowing the intermediate frequencies in general use, the approximate values determined will be close enough for identification of the intended intermediate frequency, and close enough to show whether or not the intermediate frequency system is badly mistuned and operating far from the correct frequency.

Calibration of Signal Generators. — The instructions furnished with signal generators give explicit directions for recalibration adjustment of the instruments, and since the adjustments differ for the various makes and types of generators no general rules can be stated. Calibration usually must be corrected when a radio-frequency oscillator tube is replaced.

The calibration of a signal generator may be checked as follows. Couple the generator very loosely to the antenna-ground circuit of the receiver. Loose coupling may be had with capacitors of not more than 50 mmfd in series with both the antenna and ground leads, or it may be sufficient to lay the output cable of the generator near the receiver antenna post or near a loop antenna. Turn on the generator and set it for unmodulated output. Turn on the receiver and tune it accurately to a station of known frequency. Tune the generator very slowly back and forth across the receiver tuned frequency.

Whistles will be heard, due to beating or heterodyning of the received broadcast signal frequency and the varying generator frequency. At a certain region of the generator tuning the whistle will decrease in pitch (audio frequency) and then increase again. Set the generator tuning in between the whistles, or at the lowest possible audible note, or at the point where there is no audible note in between the whistles, this latter being zero beat condition. Then the generator frequency is very nearly the same as the frequency to which the receiver is tuned, and this known frequency may be compared with the frequency indication of the generator tuning dial.

In the standard broadcast bands it is convenient to tune in signals from the broadcast stations. In the short-wave bands it is possible to use the standard frequency signals from station WWV of the National Bureau of Standards. WWV transmits day and night, continuously. There are signals at frequencies of 2.5, 5, 10, 15, 20, 25, and 35 megacycles, which are modulated with an audio frequency of 440 cycles. There are voice announcements at each hour and half hour. All timing and all frequencies are accurate to better than one part in 10,000,000.

Audio-frequency Tests. — A generator capable of furnishing a wide range of audio frequencies at controlled potential or amplitude may be used for testing complete a-f amplifiers, separate stages, couplings and other units, also for testing loud speakers, for checking frequencies at which cabinets and sound projectors produce resonances, and as a source of alternating potential used with bridges for measurement of resistances, capacitances and inductances.

The a-f generator may be connected between ground or chassis and points numbered in the typical audio amplifying system shown by Fig. 24. At *1*, the detector diode plate, and at *2*, the high side of the volume control, the output of the amplifying system, as shown by the output meter or as heard from the loud speaker, will be varied by operation of the volume control. Output normally will be somewhat less with the connection at *1* than at *2*. With the connection at *3* the output still will be varied by operation of the volume control, because of the changing resistance between the slider and the lower grounded end of the control resistance, and between the slider and the detector diode plates. With the generator connected to *4*, the grid of the a-f amplifier tube, the output no longer is controlled by the volume control, and the output will be greater than at any of the following points.

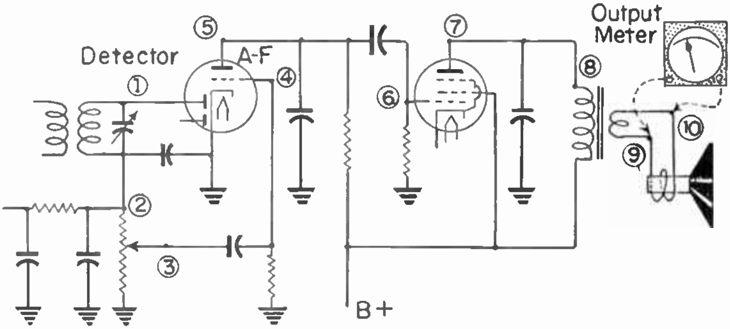


Fig. 24.—Points at which a-f potential may be introduced when testing audio amplifying and reproducing systems.

When a connection is made to *5*, the plate of the a-f tube, there *must* be in series between the plate and the lead from the generator a capacitor of high enough working voltage to stand the plate voltage. The capacitor should be of capacitance great enough to have low reactance at the audio frequency or frequencies being used. Sometimes there is such a blocking capacitor built into the signal generator output, otherwise it must be inserted externally.

At *6*, the control grid of the output tube, the final output from the amplifier will be considerably less than with the connection at *4* or *5*, and will have been less at *5* than at *4*, all because of not having the amplification or gain of the a-f amplifier tube. At the output tube plate, point *7*, there again must be a blocking capacitor in series with the high side lead from the generator. The final output now will be less than with the connection at *6*, because of not having the amplification of the tube. At point *8*, the high side of the output transformer primary, conditions are the same as at *7;* a blocking capacitor must be used.

With the generator connected between ground and points *9* or *10*, the voice coil leads for the speaker, there would be no output because the voice coil circuit is not grounded. For checking the voice coil and speaker it would be necessary to feed the generator output into the primary of a speaker coupling transformer whose secondary matches the voice coil impedance. Checks at points *7* and *8* may be made with the receiver or amplifier turned off, there then being no need for a blocking capacitor.

If there is output shown by the output meter, or heard from the loud speaker, with the generator connected to any of the points shown, and if the output voltage, power, or sound, appears to be normal, all of the parts are working between the point of connection and the loud speaker or output meter. It is possible also to work backward, making the first generator connection at *8* or *7* and progressing through decreasing numbers to point *1*. Again the parts between the point of connection and the output meter or speaker are in working order so long as there is a normal final output. With this order of connections the output meter readings or the sound from the speaker will increase as successive connections are made to points which do not include and which do include a tube having amplification.

Gain in an audio amplifier or stage may be measured in much the same way used for gain in r-f stages, by obtaining ratios of input and output potentials at various frequencies, or by measuring output potentials at various frequencies with a constant input potential or amplitude at all frequencies.

Fidelity, or relative output at various audio frequencies, is measured with the audio generator connected to the input of the a-f amplifier. In Fig. 24 the input would be between point *2* and ground. With any other voltage divider input to the audio system the input would be across the resistance of the divider. With input to the primary of a transformer there should be a reasonable match between the output impedance of the generator and the input impedance of the transformer. When there is a difference, the load impedance should be higher than the generator output impedance.

The generator output potential or amplitude is maintained at a constant value while the frequency is varied. Output amplitude may be measured with a high-resistance rectifier type of voltmeter or else an electronic voltmeter kept connected across either the generator output terminals or the load input terminals. Then the amplifier output is read from an output meter calibrated in volts, watts, or decibels as the generator frequency is varied. Outputs are plotted in terms of frequency on a curve. The output at 400 cycles usually is taken as a reference and considered as unity on the scale for the curve, with outputs at other frequencies shown as being above or below that for 400 cycles.

REVIEW QUESTIONS

1. Which of the following must be present in every signal generator; amplifier, converter, oscillator, or rectifier?
2. With crystal control is it possible to have continuously variable output frequencies? What frequencies may be had in addition to that of the crystal?
3. Explain the advantages of electron coupling, and describe one method of obtaining such coupling.
4. What audio frequency is most often used for modulation of r-f output in signal generators?
5. What type of oscillator is employed in a signal generator designed especially for producing continuously variable audio frequencies?
6. Describe a method of using the signal generator for checking image response of a superheterodyne receiver.
7. When using magnetic and non-magnetic coil probes for checking tracking will output meter readings increase or decrease with insertion of the probes when tracking is correct?
8. Explain how the signal generator is employed when checking the action of automatic volume control?

Chapter 10

TUBE TESTING

Undoubtedly it is true that radio technicians use more tube testers than any other one kind of instrument. One reason is that tubes deteriorate during normal use of any and every type of radio apparatus, and it is a common rule to test all of the tubes before proceeding to look for trouble elsewhere.

Often it is said that no tube tester can indicate tube condition as well as by placing the tube in the receiver wherein it is to operate, and listening to the loud speaker. But a tube might be

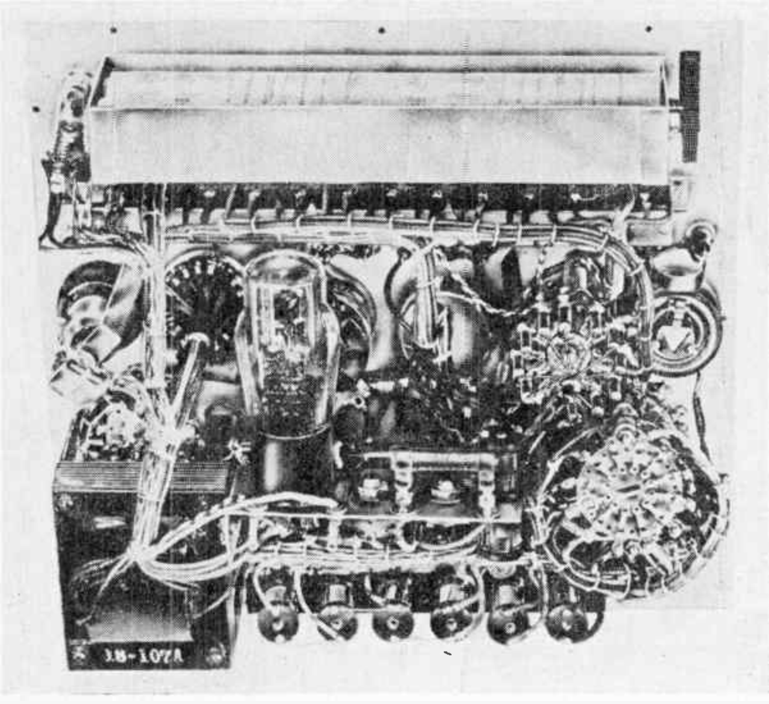


Fig. 1.—The underside of the panel in one type of Precision Apparatus tube tester.

on the verge of failure and still seem all right with the volume control turned up. A given tube may work well in the standard broadcast band and fail in a short-wave band, it may be satisfactory in an insensitive receiver and fail in some other receiver, it may be a good oscillator in one circuit and fail to oscillate in another.

A tube tester should be capable of making accurate and rapid checks on hundreds of types of tubes, operating with more tnan dozen heater or filament voltages, and made with eight or ten different kinds of bases, having the elements connected to base pins in every imaginable combination.

The method of testing depends largely on the kind of tube. Power rectifiers and diodes are designed merely to deliver direct current when subjected to alternating potential. All other radio receiver tubes are intended either to amplify a varying potential applied to their control grids, to oscillate and produce high-frequency alternating currents, to act as mixers or converters, or to do two or more of these things at the same time.

To test a rectifier or diode we simply measure the rectified current in a specified load when a specified alternating potential is applied to the rectifier. This really is a check on the ability of the cathode to emit a copious supply of electrons when there is a certain difference of potential between cathode and plate. For tubes having one or more grids, in addition to cathode and plate, we still may test the emission ability of the cathode by connecting together all of the other elements so that they act like a single plate or anode. With tubes having control grids we might measure also the amplification factor, the plate resistance, or both. Both of these may be checked at the same time by measuring the mutual conductance or grid-plate transconductance, which is equal to the amplification factor divided by the plate resistance.

Mutual Conductance.—For any tube having a control grid the mutual conductance is the constant which tells better than any other one whether the tube will or will not perform satisfactorily. Mutual conductance, when given in micromhos, indicates the number of microamperes of alternating current change which will be produced in the plate circuit when one volt of alternating potential is applied to the control grid. Mutual conductance or grid-plate transconductance means the same as microamperes (plate current) per volt (grid potential).

If a tube is so operated as to have a mutual conductance of 2,000 micromhos, if a one-volt a-c signal is applied to the control grid, and if there is no resistance in the plate circuit, there will be in the plate circuit an alternating component of 2,000 microamperes, which is equal to 2 milliamperes. Even with actual plate circuits, which do have resistance, the alternating plate current will be proportional to mutual conductance.

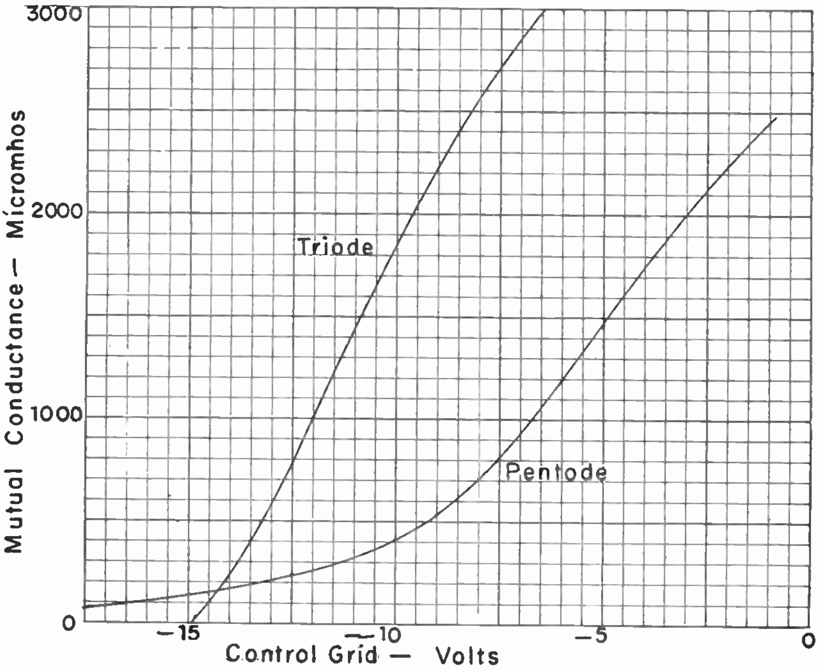


Fig. 2.—Relations of mutual conductance to control grid bias in a triode and in a pentode tube.

By examining tube characteristics we should find that the mutual conductance of triodes increases with greater plate currents, with higher plate voltages, and when the grid is made less negative. With pentodes the plate voltage has little effect on mutual conductance or transconductance, but this constant is increased by higher screen voltages, by greater plate currents, and by making the control grid less negative. Fig. 2 shows how mutual conductance varies with changes of control grid voltage, or bias, when other voltages remain unchanged in a typical triode and in a remote cutoff pentode.

If we set up a circuit such as shown by Fig. 3 it is possible to check mutual conductance. By means of the voltage divider across the a-c source we may apply a suitable a-c potential to the control grid. The voltage divider across the d-c power supply allows for applying a suitable grid bias *Eg*, screen voltage *Es*, and plate voltage *Ep*. Capacitors marked *Cb* are bypasses for alternating currents. In the plate circuit is a filter system permitting the alternating component of plate current to go through capacitor *Ca* and the a-c meter, while the direct component goes through the choke coil *L*. By adjusting the applied voltages for the type of tube there will be an alternating plate current proportional to mutual conductance for the operating voltages. Numbered dial scales on the voltage dividers would permit settings for each type of tube to be identified. The meter scale may be calibrated in micromhos of mutual conductance.

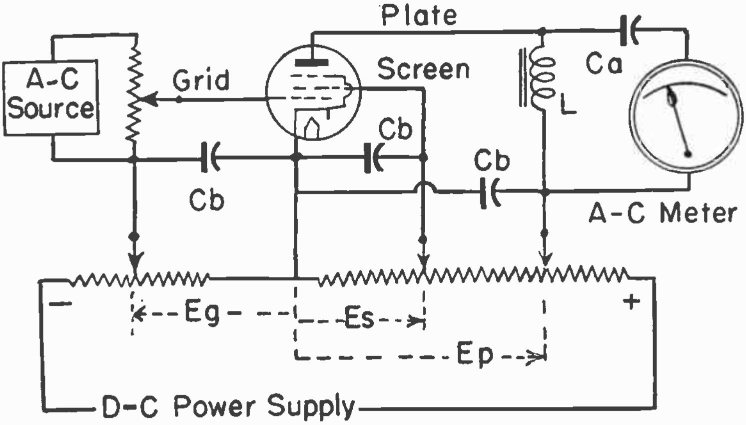


Fig. 3.—A circuit for measurement of mutual conductance.

If the mutual conductance readings are to match those given in tube manufacturers' data all of the applied voltages as well as the plate circuit load must be exactly as listed in the same ratings. This is not really necessary, because mutual conductance values for any voltages available in the tester may be selected and used as the standards of performance on this particular instrument. The fact that there is no one standard mutual conductance or transconductance is evident from Fig. 2.

Cathode Emission.—With a circuit whose general principle is shown by Fig. 4 it is possible to check the emission ability of the tube cathode. All of the elements except the cathode and heater are connected together and to one side of the secondary winding of a transformer whose primary goes to the power line. The other side of the secondary is connected through voltage adjusting resistor *R* and the indicating meter to the cathode of the tube. Electron flow is in the directions shown by arrows. The tube being tested acts as a rectifier, permitting only a direct electron flow in the measuring circuit. Consequently, the indicating meter is a d-c type. The shunt resistor *S* allows more or less of the total cathode electron flow to go through the meter. Resistors *R* and *S* are adjusted to suit the type of tube being tested, and to bring the meter reading onto a suitable part of the meter scale for a tube having satisfactory emission.

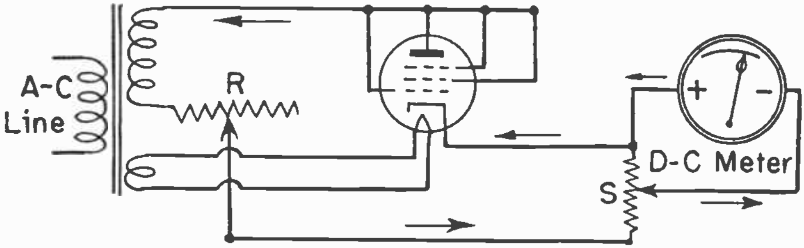


Fig. 4.—A circuit for measurement of cathode emission.

The effective a-c potential from the secondary of the transformer usually is 30 volts. Resistor *R* may be 5,000 ohms when testing diodes such as used for detectors, automatic volume control, and similar purposes wherein the rectified current is small. This resistance may be 1,000 ohms for filament-cathode tubes or battery operated tubes wherein the emission must be limited to a safe value. For all other types of tubes the value at *R* may be 200 ohms.

The meter scale usually is divided into several sections; abnormally low emission currents reading in a section marked "Bad," "Poor," "Replace," or something like that, while normal currents cause readings in a section marked something like "Good" or "Normal." The division between normal currents and those below normal is based on percentages of rated mutual conductance for amplifiers, usually on 70 per cent of the emission for a tube of rated average mutual conductance, and on 60 per cent for converters. Diodes and rectifiers of the vacuum types will give a normal reading when their currents (rectified) are not more than 20 per cent below those of normal tubes.

Any rate of emission greater than the minimum for an average new tube should provide enough electrons for normal rated mutual conductance. Still greater emission does not mean that the mutual conductance is proportionately greater, but only that there will be available more than enough electrons for normal operation. Deficient emission affects mutual conductance because then the plate resistance of the tube is increased, and, because mutual conductance is equal to amplification factor divided by plate resistance, the mutual conductance becomes lower. Some types of cathode defects allow excessive emission from limited areas, and a high total emission, although the emission may not be distributed with enough uniformity to permit effective grid control. Occasionally it will be found too, that a tube having less than normal emission still will operate satisfactorily in some receivers.

There are various kinds of modified emission tests, or modified conductance tests, in use. For example, all elements except the control grid, cathode, and heater may be connected together to act as a plate, with the control grid maintained at zero or some negative bias so that the grid really has some control over the rate of cathode emission.

Additional Tests.—All tube testers have switching arrangements, sometimes very elaborate and complete, by means of which potentials suitable for the different elements may be connected to any terminals of each of the various sockets which are provided to take the many types of tube bases in use. Fig. 5 shows switching arrangements used in one style of service tube tester. The switch marked *Circuit "A"* controls series resistors for applying suitable testing voltages and for controlling meter readings for the several general classes of tubes. The *"B"*

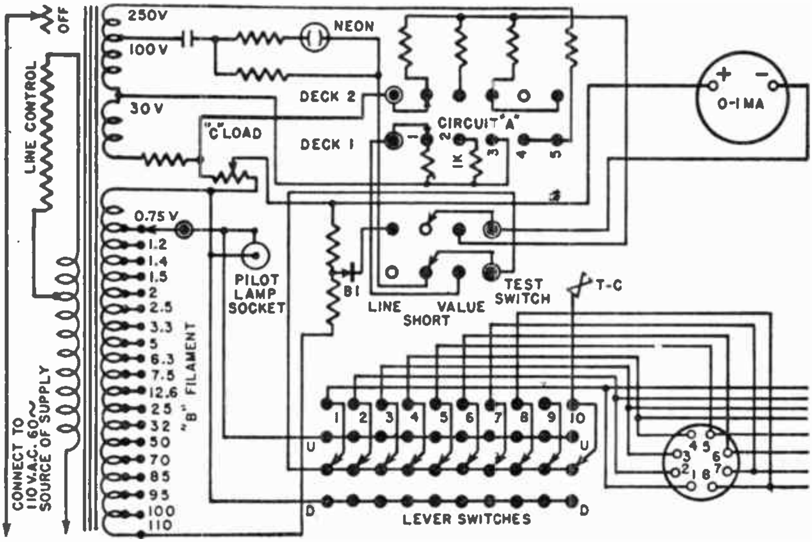


Fig. 5.—The complete wiring diagram for one type of Triplett tube tester.

Filament switch selects potential differences from 0.75 volt to 110 volts in nineteen steps for filaments and heaters. Voltage divider *"C"* is the meter shunt. The *Test Switch* in the center of the diagram completes circuits which allow adjusting all applied voltages to eliminate effects of line-voltage variations, which allow measurement of tube performance, and which allow testing all of the tube elements for short circuits.

A complete instrument may provide for a number of tests in addition to those for mutual conductance or cathode emission. One additional test indicates short circuits between elements; this general function usually including a check on current leakage between heater and cathode. There may be another test for element connections which are open-circuited or disconnected from the base pins, and one for loose connections which would cause noisy operation. In some of the more elaborate instruments it is possible to read plate currents and screen grid currents.

There may be a separate test for excessive gas which will cause ionization in vacuum types of tubes.

In addition to providing sockets and suitable potentials for all rectifiers, amplifiers and oscillators, some instruments have provision for observing the action of electron-ray tuning indicator tubes, and for checking continuity in pilot or dial lamps and in various types of ballast resistor tubes.

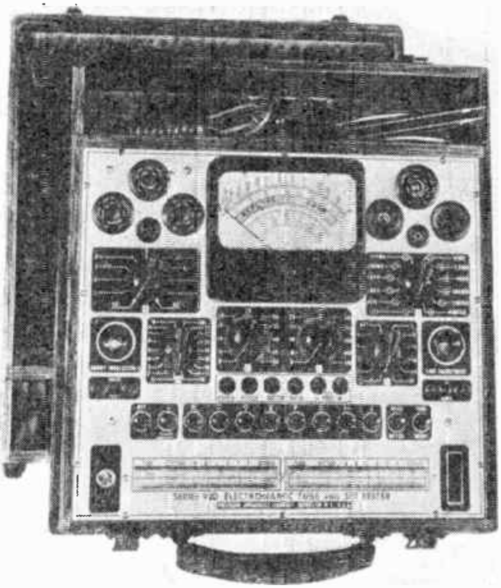


Fig. 6.—Panel controls of a Precision Apparatus tube tester.

A number of manufacturers supply models in which a multimeter and an ohmmeter with multiple resistance ranges are combined with the tube tester. Usually the same meter is used for tube testing and for a voltmeter, current meter, power output meter, and decibel meter. Fig. 6 shows the panel controls and adjustments for one instrument which provides most of the tests just mentioned.

Mutual Conductance Testing.—There are two basic methods of checking mutual conductance. One is carried out with direct potentials applied to the control grid and with direct currents read from a plate circuit meter. This is called a *static mutual conductance* test. The other method employs an alternating potential on the control grid, and resulting alternating currents are read in the plate circuit. This is called a *dynamic mutual conductance* test.

Fig. 7 shows the principle of the static test, called also a "grid shift" test. The switch *S* normally is held in the upper full-line position, connecting the tube grid to point *a* on the voltage divider. In making the test this switch is depressed to the broken-line position, which connects the grid to point *b* on the voltage divider, and makes the grid less negative. Making the grid less negative allows the plate current to increase, somewhat as indicated by the full-line and broken-line pointers drawn on the d-c meter in the plate circuit. Plate voltage is adjusted at *R*. A screen voltage would be similarly adjusted.

If the shift of grid voltage is not too great the resulting change of plate current may be taken as an approximate indication of mutual conductance. The number of micromhos is found from multiplying the number of milliamperes of change of plate current by 1,000, then dividing this result by the number of volts change of grid potential. Both the greater and lesser grid potential must be such as to keep the tube operating on the straight portion of its characteristic curve with the plate voltage in use. Accuracy is improved by readjusting the plate voltage with the grid shift switch depressed so that this plate voltage is the same

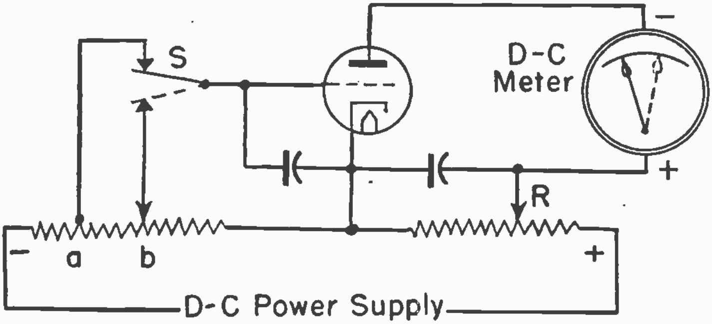


Fig. 7.—A static test or grid-shift test for mutual conductance.

as before the switch is depressed. With a screen grid, the two screen voltages would be maintained at the same value.

In dynamic mutual conductance testers, whose principle is shown by Fig. 3, there usually are several meter ranges, such as for maximums of 3,000, 6,000 and 15,000 micromhos. The alternating grid potential is inversely proportional to the range used. For example, were the grid potential to be 0.5 volt for the 6,000-micromho range, the grid potential would be 1.0 volt for the 3,000-micromho range, and 0.2 volt for the 15,000 micromho range. The grid potential may be at a 60-cycle line frequency or may be of some higher frequency as provided from a full-wave rectifier circuit or from an oscillator. Meters may be of either the rectifier type or else the dynamometer type. Connections for a rectifier meter are shown by Fig. 3.

In one type of Weston Tubechecker alternating potentials are applied to all elements of the tube being tested, but by using a high frequency, 5,000 cycles, for the control grid and a relatively low frequency, 60 cycles, for other potentials there is

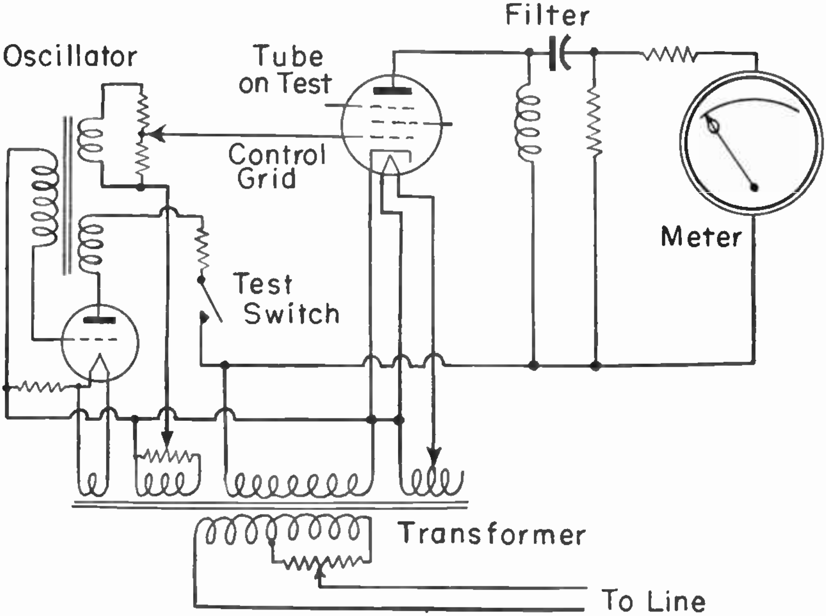


Fig. 8.—Simplified diagram of the Weston Tubechecker employing a 5000-cycle grid potential.

secured much the same effect as though those other potentials were direct or of steady value. That is, the difference between 5,000 cycles on the grid and 60 cycles on plate and screen gives the same ratio as would 83.3 cycles on the grid and a direct potential on plate and screen.

A simplified diagram of the testing circuit is shown by Fig. 8. The oscillator system which provides the 5,000-cycle grid signal is at the left. The triode oscillator operates with inductive feedback from plate to grid through the transformer. The high-frequency grid potential is taken from a third winding on this transformer. The plate circuit of the oscillator is completed by closing the test switch when making mutual conductance measurements. In the plate circuit of the tube being tested is a filter system which passes to the meter the 5,000-cycle plate current component which results from the high-frequency grid signal, and which bypasses the 60-cycle variations around the meter.

The mode of operation is shown by Fig. 9. The circuit connections are such that the 60-cycle potentials on plate and screen, and the 60-cycle potentials on the control grid are in opposite phase, as shown by the two graphs at the left. During the half-cycle in which the plate becomes positive the control grid becomes negative, which is the normal relation of the potentials during operation of the tube. During the half-cycle in which the control grid becomes positive the plate and screen are negative, with the result that there is no current or electron flow in the plate circuit during this half-cycle.

The oscillator is so connected that it generates high-frequency grid potential only while the grid is negative and while the plate and screen are positive in the tube being tested. The oscillator potential during a half cycle is shown at the upper right in Fig. 9, and the combined oscillator and 60-cycle negative grid potentials are shown just below. The resulting filtered high-frequency plate current which actuates the meter is indicated at the lower right. These pulses of high-frequency plate current occur during half of each cycle of the 60-cycle frequency, or repeat 60 times per second and last during 1/120 second each time. The meter dial is graduated and calibrated to read in micromhos of mutual conductance.

In any dynamic mutual conductance tester it is essential that the alternating grid potential be of the precise value for which the meter calibration and the entire circuit are arranged. For testing triodes it is essential that the plate potential be of the exactly correct value, while for pentodes and tetrodes the screen potential must be precisely adjusted. Variations of any of the potentials just mentioned will cause serious differences between actual and indicated mutual conductances.

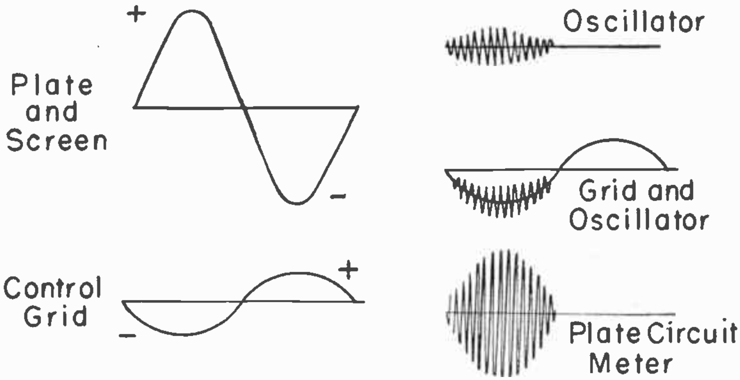


Fig. 9.—Phase relations of high- and low-frequency potentials in the Weston Tubechecker.

The meter scales of mutual conductance testers usually have "Good-Bad" divisions in addition to graduations in units of mutual conductance. The "Good-Bad" sections are chiefly for the benefit of customers who wish to observe the results of tube tests. The division between good and bad usually is around 70 per cent of the normal mutual conductance.

Shorted Element Test.—A tube always should be tested for short circuits between elements before proceeding to the tests for performance, because current through a short circuit may seriously damage the meter or other parts of the tester. Short tests ordinarily are made after the filament-cathode or heater cathode of the tested tube has reached normal operating temperature; this because expansion of heated elements may cause contacts and short circuits which would not exist with the tube cold. It is common practice to tap the tube lightly, with your finger tip, while making the short circuit test, thus discovering whether loosely supported elements may make contact when the tube is vibrated or jarred in service.

Short circuit tests nearly always are made with a small neon lamp as the indicator. The lamp is connected in series with the tube elements and a source of 100 to 120 volts either alternating or direct potential, as shown by Fig. 10. Switching allows all elements except one being checked to be connected to one side of the test circuit, while that one element is connected to the other side. Then a short circuit between the one separated element and any other will let current flow through the neon lamp and light it. The test proceeds by connecting successive elements to one side of the circuit while all others are returned to the other side.

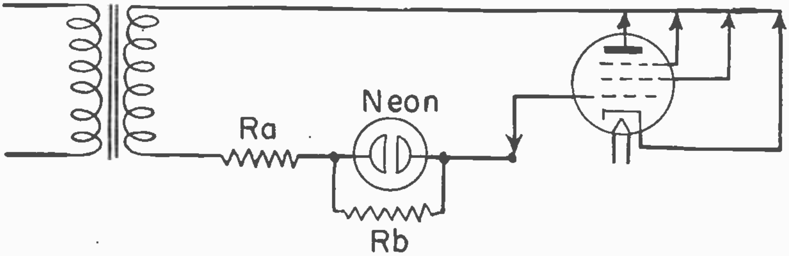


Fig. 10.—One method of testing for short-circuited elements.

When the test is made between a heated cathode and another element, with alternating potential applied to the test circuit, the tube will act as a rectifier and allow electron flow from cathode to the other element during half-cycles in which the other element is made positive with reference to the cathode. Then one of the electrodes in the neon lamp will glow while the other one remains dark. Such a glow does not indicate a short circuit. If there is a short circuit between cathode and the other element both electrodes will glow in the neon lamp. When the test is between cathode and heater there should be no glow on either plate when the insulation in the tube prevents electron flow between these two elements.

The sensitivity of the short circuit test usually is made such that there is glow in the neon lamp with any leakage resistance of less than one-quarter megohm with an applied potential of 100 to 120 volts. Resistor *Ra* of Fig. 10 prevents flow of excessive current in the neon lamp when there is a low-resistance short circuit. Resistor *Rb* prevents glow of the electrodes with the very small alternating currents which may pass through capacitances in wiring and between other parts of the tester. Resistor *Rb* sometimes is replaced by a small capacitor.

Gas Tests.—Some tube testers, but not many, have special means for detecting the presence of excessive gas in the envelopes of vacuum types of tubes. When there is excessive gas, and when a normally high operating plate potential is applied to the tube, electrons traveling from cathode to plate will collide with atoms of the gas. The collisions knock one or more electrons off some of the atoms of gas, leaving those atoms positive. They are called positive ions, and the action is called ionization. With the control grid negative, the positive ions collect on the grid and neutralize some of the negative charge on the grid, thus changing the grid potential. If enough positive ions reach the grid, negative electrons to neutralize these ions must come from the grid. Then there is electron flow into the grid from the external grid circuit, as shown by Fig. 11. Note that this flow of electrons in the grid circuit is in a direction the opposite of a flow which would exist were the grid made positive, for then there would be flow of electrons from cathode to grid and from the grid into the external grid circuit.

The reversed electron flow in the grid circuit may be called "gas current," since it is due to gas in the tube. This current may be measured with a sensitive d-c microammeter in the grid circuit, as shown by the left-hand diagram. In receiving types of voltage amplifier tubes the gas current will be less than one microampere when there is no more than a normal amount of gas. With most power tubes the gas current will be no more

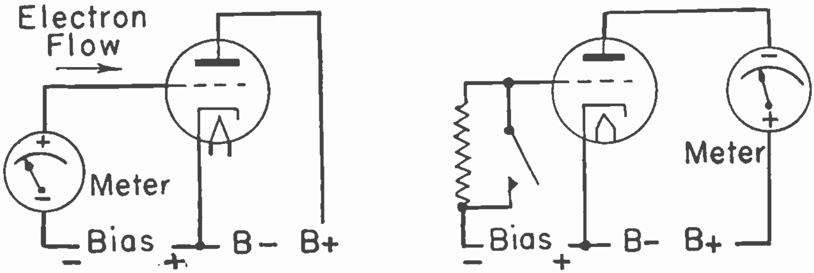


Fig. 11.—Methods of testing for excessive gas in tubes.

than two or three microamperes, although there are different limits for different types of tubes. Another method, shown at the right, is to place a resistor of one or more megohms in series with the grid circuit, and to provide a switch for temporarily short-circuiting all or part of this resistor. Operation of the switch will cause changes of plate current, indicated by a d-c meter in the plate circuit. How much the plate current may change with a good tube depends on the type of tube. Excessive change of plate current indicates excessive gas in the tube.

Converter Tests.—If we divide the number of microamperes of alternating plate current by the number of alternating grid volts causing the plate current in an amplifier tube, the result is mutual conductance or grid-plate transconductance in micromhos. If we are working with a converter tube and divide the number of microamperes of output intermediate-frequency current by the number of alternating volts on the r-f signal grid, the result is called *conversion transconductance*. This conversion transconductance of converters is a constant just as important as is the mutual conductance of amplifiers.

To be able to measure conversion transconductance it would be necessary to have the oscillator section of the converter in operation at the time of applying an alternating potential to the signal grid. Consequently, it is simpler, and is the general practice, to make separate mutual conductance tests on the mixer section and on the oscillator section of converters. The mixer section is tested by using the signal grid for the input alternating potential and the plate for the output current. The oscillator section is tested by using the oscillator grid for the input alternating potential while using for the output current whatever elements are regularly employed as oscillator plate or oscillator anode. The screen grid is maintained at a suitable positive potential during both tests.

When testing the mixer section the control grid bias may be the same as used for normal operation in a receiver. During the test of the oscillator section the oscillator grid bias usually is made zero. The mutual conductance reading when testing the oscillator section will normally be two to ten times the normal conversion transconductance in micromhos.

Whether a tube will oscillate in regular service depends not only on the constants or characteristics of the tube itself, but also on the frequencies at which it is to be used and on the whole design of the circuits in which the tube will be used. A tube which will oscillate in some receivers or circuits may fail to oscillate in others.

Operation of Tube Testers.—The great variety of tubes which have to be tested, and the several kinds of tests which may be employed, have prevented the development of any one instrument which may be called a standard type of tube tester. Practically all commercially produced tube testers are calibrated or adjusted to indicate tube condition in accordance with standards set up for the one particular instrument as they are related to rated characteristics and constants of tubes.

As a result of these conditions it is impossible to give general instructions for operation of all tube testers. Each instrument should be handled in strict accordance with the instructions issued by its manufacturer, and the controls should be set up and used for each type of tube in accordance with charts of test settings issued by the manufacturer.

REVIEW QUESTIONS

1. Which characteristics are most often measured by tube testers; amplification factor, mutual conductance, plate resistance, or cathode emission?
2. On what percentage of average mutual conductance is based the minimum average cathode emission current?
3. Does the grid shift method of tube testing check dynamic or static mutual conductance? What kind of potential must be applied to the grid for checking the other kind of mutual conductance?
4. Explain the switching principle usually employed for testing short circuits between elements of tubes.
5. Does the so-called gas current mean a flow of electrons toward or away from the control grid in the external grid circuit?
6. Are converter tubes usually tested for conversion transconductance, or by making separate mutual conductance tests on each section of the tube?
7. How is it possible to apply negative potential to a grid while applying positive potential to the plate when using alternating potential for testing?
8. In emission testing with a 30-volt a-c supply the series resistors usually are of 200 ohms, 1,000 ohms, and 5,000 ohms resistance. Which resistance is used when testing detector diodes?

Chapter 11

CATHODE-RAY OSCILLOSCOPES OR OSCILLOGRAPHS

In all explanations and discussions of radio principles and their applications we employ curves or graphs to show how potentials and currents should or should not vary during alternating cycles and during changes of frequency. The cathode-ray oscilloscope or oscillograph actually produces such curves as a luminous line which is formed and shaped on a screen by variations of actual potentials and currents in radio circuits.

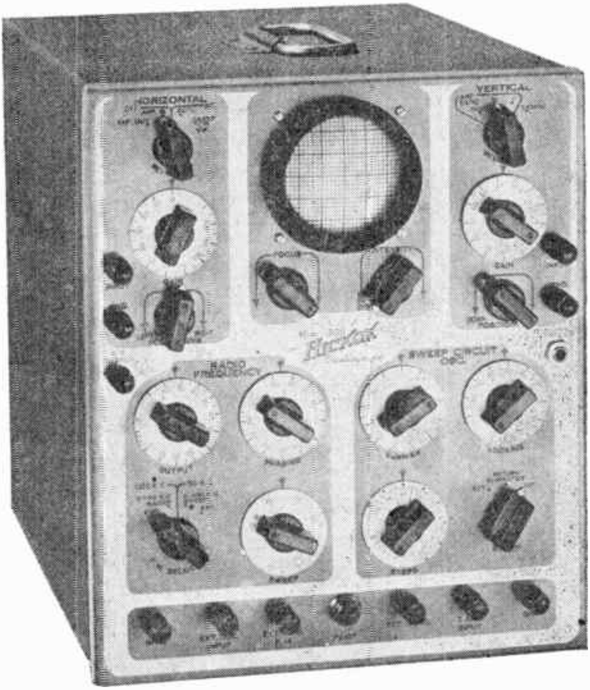


Fig. 1.—A Hickok oscillograph with which is combined a frequency-modulated signal generator.

The luminous traces will show what is happening during cycles whose time is but a few millionths of a second. Or they will show on a single curve such things as the gain of a tuned circuit at all the frequencies in a band many kilocycles wide. If you make adjustments or alterations in the radio circuits connected to the oscilloscope the luminous curves will change their form to show instantly the effect of everything you do.

The words oscilloscope and oscillograph are two names for the same instrument. This instrument is used for tests on every kind of radio receiver; standard broadcast, short-wave, frequency-modulation, and television. It is used for checking performance at radio frequencies, intermediate frequencies, and audio frequencies. What the oscilloscope will do in all these fields depends on the knowledge, skill, and experience of the operator perhaps more than with any other instrument. Although these chapters will explain most of the uses for this remarkable instrument in radio work, they will come far from describing everything that you can do. The more you use the oscilloscope the more of its abilities you will discover.

Here are a few of the uses of the oscilloscope or oscillograph in radio: We may inspect waveforms; simple, complex, or modulated. We may detect distortion and find in which part of the tested apparatus it originates. The causes for hum and noise may be located. The oscilloscope will measure peak voltages at low or high frequencies, and will measure gain by the stage or overall. Frequencies may be measured or compared with an accuracy of a small fraction of a cycle. Phase differences may be shown. We may watch the effects on gain and on band width as adjustments are altered in tuned circuits. During the process called visual alignment, as applied to both amplitude-modulated and frequency-modulated receivers, the oscilloscope allows adjustment for the best possible forms of resonance curves for the i-f and r-f stages.

Cathode-ray Tube.—The basis of the oscilloscope or oscillograph is the cathode-ray tube such as pictured by the cut-open view of Fig. 2. The tube shown here actually is about 17 inches long, and its diameter at the big end is about 5¼ inches. On the end of the base are connection pins *1* for the elements, and a locating key *2*. The base collar is marked *3*, the internal glass stem is

4, the getter for removing the last traces of gas is marked *5*, and the glass press is *6*.

There is a heater *7* which is inside of the cathode support *8*. The supports marked *9* carry the control grid *10* and a focusing electrode *11*, with an additional supporting collar at *12*, and at *13* another electrode which pulls electrons from the cathode and accelerates them to high velocity.

At *14* and *15* are supports for two pairs of deflecting plates, *16* and *17*, which deflect or bend the stream of electrons coming through the spaces between these plates. A contact spring *18* makes connection with the static shield *19* which is within the glass envelope *20*.

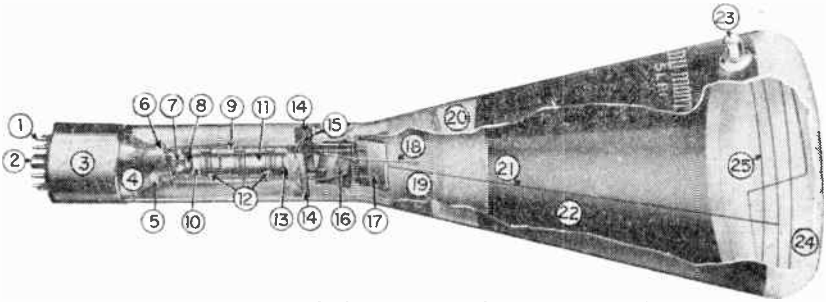


Fig. 2.—A DuMont cathode-ray tube such as used in oscillographs.

The stream of electrons issuing from the cathode and coming through the several electrodes, and between the deflecting plates, is formed into a beam of small diameter represented by the line *21*. As shown, this electron beam has been deflected downward by one of the pairs of plates. The part numbered *22* is a conductive coating which acts as still another high-potential electrode whose terminal is *23*.

The electrons in the beam strike against a coating *24* which is on the inside of the flattened large end of the tube. Wherever the beam strikes this coating, which is called the screen, there is formed a small, round, bright spot of light that shows clearly from the outside of the tube. The beam is deflected or bent, up, down, or sideways, by potential differences applied to the deflecting plates. The end of the beam, and the luminous spot, travel over the screen in directions which correspond to the potential differences. When a spot on the screen is made to glow by the beam, that spot remains luminous for a fraction of a second. If the potentials on the deflecting plates are changing rapidly every point of the screen over which passes the end of the beam will continue to glow until the beam gets back to the same place during the following cycle. Instead of seeing a moving spot of light we then see a continuous line of light on the screen. This continuous line, as at *25* in Fig. 2, traces out the variations of potentials in the form of a curve such as would appear on a graph.

If we could look from the big end of the cathode-ray tube, right through the screen and toward the cathode, the electron beam would be coming toward us and in between the deflecting plates, as in Fig. 3. The beam is composed wholly of electrons, which are negative. If, as in diagram *A*, the left-hand plate is made negative it will repel the electrons, and if the right-hand plate is positive at the same time it will attract the electrons. The beam will be deflected to the right and the luminous spot will be formed on the right-hand side of the screen.

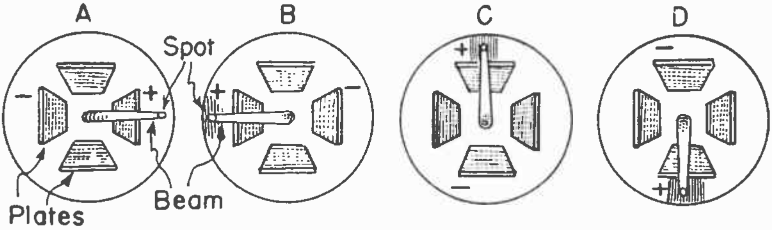


Fig. 3.—The beam is deflected by potential differences on the deflection plates, in a direction corresponding to polarities.

In diagram *B* the polarities of the right- and left-hand plates have been reversed. The beam and the luminous spot are deflected to the left. At *C* the upper deflecting plate is positive and the bottom one negative. The beam is repelled by the lower plate, attracted by the top plate, and the spot is formed at the top of the screen. At *D* the polarities of top and bottom plates are reversed, and the spot is formed near the bottom of the screen.

How far the spot is shifted sideways depends on the potential difference between the right- and left-hand deflecting plates. How far the spot is shifted up or down depends on the potential difference between the top and bottom plates. In which direction the spot is shifted away from the center depends on the relative polarities of the deflecting plates.

The beam and spot are moved sideways, or horizontally, by the right- and left-hand plates, which are called the horizontal deflection plates. Movement up and down, or vertically is controlled by the top and bottom plates, which are called the vertical deflection plates.

If there are potential differences at the same time between both the horizontal plates and the vertical plates the spot will be moved both horizontally and vertically at the same time. Consequently, the spot may move to any point on the entire surface of the screen, depending on the polarities and potential differences of the deflecting plates.

Now assume that we have an alternating potential for which one cycle usually is represented as at the left in Fig. 4. If this potential is obtained from the secondary winding of a transformer, as at the center, the upper terminal will be positive and the lower one negative during one half-cycle, while during the other half-cycle the upper terminal will be negative and the lower one positive. If the terminals of the transformer are connected to the vertical deflection plates of the cathode-ray tube the luminous spot will be caused to move up and down, and to form a straight vertical line on the screen, as at the right.

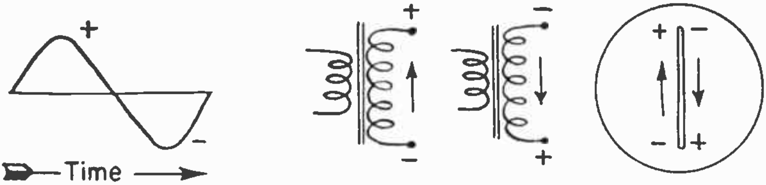


Fig. 4.—An alternating voltage may furnish vertical deflection potentials.

The greater the amplitude, or the greater the peak voltages in the alternating potential, the greater will be the maximum difference of potential between vertical deflecting plates and the farther the luminous spot will move first upward and then downward. The vertical height of the luminous trace thus will be proportional to the peak value of the applied potential. The electron beam has no measurable weight, and has no inertia. It will follow the changes of potential on the deflecting plates even at frequencies higher than 100 megacycles.

To extend the operation of the cathode-ray tube beyond its ability to show peak amplitudes we shall apply to the horizontal deflecting plates a potential which varies as shown by Fig. 5. This potential commences at a negative value, increases uniformly with time as it passes through zero and to a positive value, then very suddenly drops back to the original negative value.

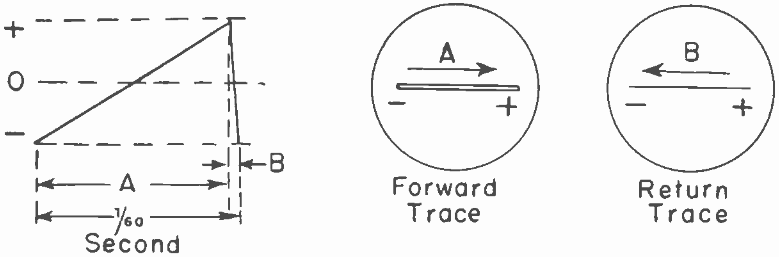


Fig. 5.—This horizontal deflecting potential increases at a uniform rate during most of each cycle.

We shall assume that this series of changes occurs during 1/60 second of time. The steady change from negative to positive takes an interval of time shown as *A*, and the sudden return takes the interval of time shown as *B*. The two intervals together make up 1/60 second.

If this kind of potential, or potential difference, is applied to the horizontal deflecting plates the luminous spot will travel at a speed uniform with time across the screen from left to right, and will take the time interval *A*. This is called the forward trace. Then the spot will return to the left in the short time interval *B*. This is called the return trace or retrace. During the forward trace the beam moves slowly enough to make the line brightly luminous. But the beam makes the return trace at such high speed that the line hardly is visible as light.

The next step will be to apply to the vertical deflecting plates the alternating potential of Fig. 4 while applying to the horizontal deflecting plates the potential of Fig. 5. The alternating potential will be assumed to have a frequency of 60 cycles per second, so that the one cycle requires a period of 1/60 second.

What happens may be understood from Fig. 6. At instant *a* the horizontal plates are holding the beam all the way to the left on the screen. The vertical potential difference is zero, leaving the spot at the center of the screen so far as vertical deflection is concerned. At instant *b* the horizontal deflection has carried the beam one-fourth of the distance from left to right, while vertical deflection has driven the beam to the top of the screen. At *c* the beam has been carried half way from left to right, but the vertical potential difference has dropped back to zero. At *d* the beam is three-fourths of the way across, while vertical deflection has driven the beam to the bottom of its travel. At *e* the spot has gotten as far to the right as it is going to get, for here the return trace commences, and vertical deflection has allowed the spot to get almost back to the center. Between instants *e* and *f*, while vertical deflection returns to zero, the beam is driven all the way back to the left.

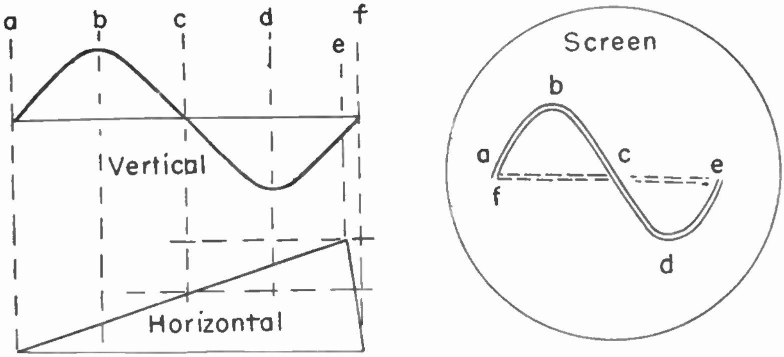


Fig. 6.—Vertical and horizontal deflecting potentials trace the waveform on the screen.

On the screen of the cathode-ray tube has been traced a reproduction of the curve which we have learned to associate with one sine-wave cycle of alternating potential. A little bit of the right-hand end of the curve is cut off because of the time needed for the return trace. The curve actually has been drawn or traced by the potential applied to the vertical deflection plates.

Ordinarily the cycles of alternating potential on the vertical plates would continue at the rate of 60 times a second. If we continue also the rising and falling potential on the horizontal plates, as in Fig. 7, the trace of the sine-wave curve will be formed on the screen at the rate of 60 times a second. With screen coatings such as most often used, some brightness will remain all along the trace between passages of the beam and the spot, and the whole curve will be continually illuminated. But at the low frequency of 60 cycles per second most of the illusion of steady illumination of the whole trace results from the characteristic of our eyes called persistence of vision. This means that, when a bright light appears and then goes out, we seem to see the light for about 1/20 second after it no longer is there.

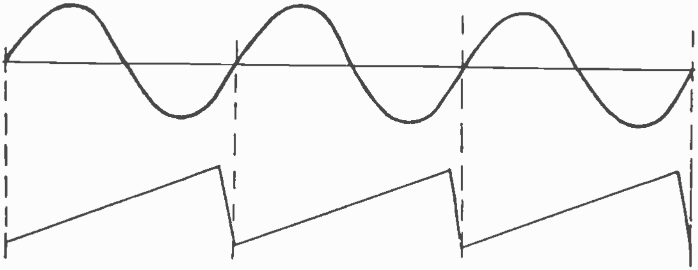


Fig. 7.—Vertical and horizontal deflecting potentials continue, keeping in step or in synchronization with each other.

Power and Control Circuits. — In Fig. 8 is represented a cathode-ray tube, the d-c power supply, and some of the controls, as used in many oscilloscopes designed for radio service work. At the top is the cathode-ray tube. At the left-hand end is the electron emitting cathode partially enclosed by the control grid. This grid, by its potential in relation to the cathode, controls the rate of electron emission just as in any tube having a cathode and a control grid. Next come the tubular first and second anodes whose functions are to give electrons a high velocity toward the screen and to focus the electron beam so that the beam strikes the screen on a small spot. Beyond the electrodes are the vertical and horizontal deflection plates, whose functions have been explained.

In the tube shown here one of the vertical plates and one of the horizontal plates are connected inside the tube to the second anode. In other tubes there may be separate external terminal connections for all deflecting plates and anodes.

At the bottom of the diagram is shown the d-c power supply. There is a high-voltage half-wave rectifier and a low-voltage full-

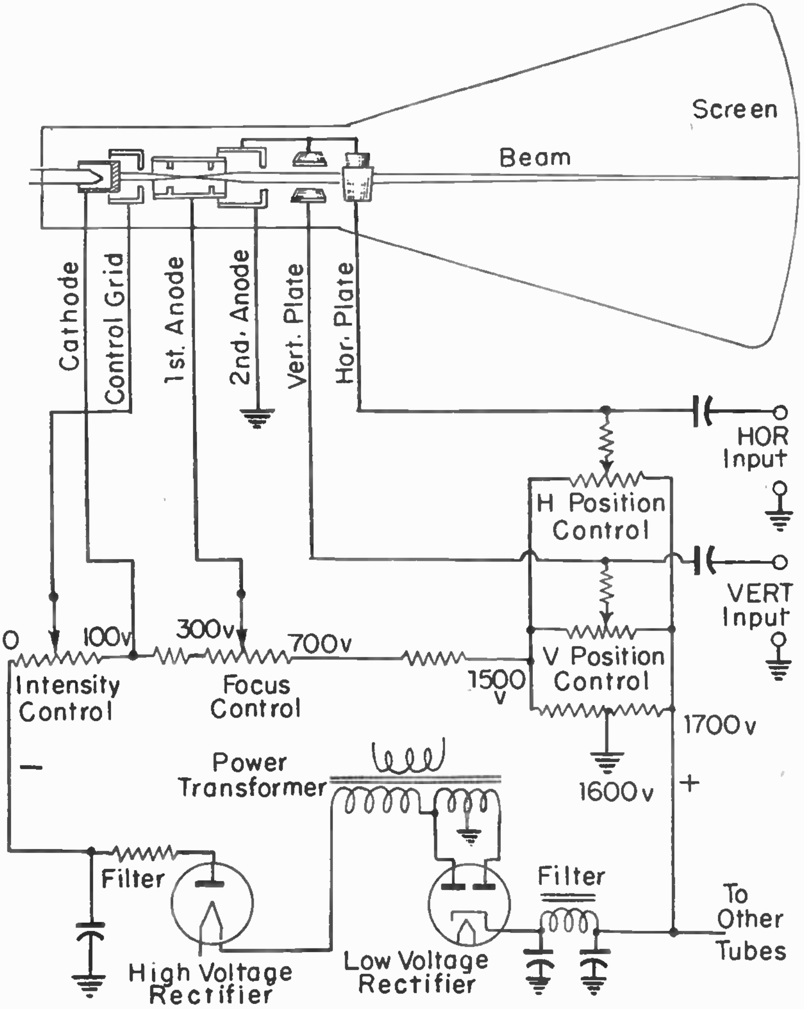


Fig. 8.—A cathode-ray tube with its power supply and control circuits.

wave rectifier. The two are in series so that the total potential difference available for the cathode-ray tube is the sum of the potentials of the rectifiers. The low voltage rectifier furnishes current for the cathode-ray tube and also for whatever amplifier and oscillator tubes may be used in the complete instrument. The high-voltage rectifier carries only the very small currents required by the cathode-ray tube.

In any rectifier the plate or plates are negative and the cathode is positive. The negative plate of the high-voltage rectifier is connected to the left-hand end of the voltage-divider system of resistors, while the positive cathode of the low-voltage rectifier is connected through its filter to the right-hand end of the voltage divider system. The total potential difference across the voltage divider system is shown as being 1700 volts. In many instruments this voltage is higher, while on others it may be lower. Typical voltages at various points along the divider are marked on the diagram.

The control grid of the cathode-ray tube is connected to the slider of a so-called potentiometer across which there is a potential difference of 100 volts. The cathode is connected to the positive side of this potentiometer. Adjustment of the slider will make the grid of any potential up to 100 volts negative with reference to the cathode. This adjustment, called the *intensity control*, regulates the rate of electron emission from the cathode, determines the electron density in the beam, and thus controls the brightness of the luminous spot on the screen.

The first anode of the cathode-ray tube is connected to the slider of a potentiometer whose end potentials are 300 and 700 volts in this diagram. Adjustment of the potential of the first anode, when the potential of the second anode remains constant, makes the electron beam either spread or contract and determines the distance at which the beam comes to a sharp point or focus. This adjustment, called the *focus control*, is used to make the beam form a small, bright spot where the beam strikes the screen of the cathode-ray tube.

The second anode, in this particular diagram, is grounded to the chassis. By referring to the voltage values marked on the divider system you will see that ground is at a potential of 1600 volts and that the cathode is at a potential of 100 volts. Thus the second anode is at a potential 1500 volts positive with reference to the cathode.

Now we come to the *horizontal position control* and the *vertical position control*, which are potentiometers connected in parallel across the right-hand section of the voltage divider system. The purpose of these two position controls is to bring the luminous spot to any desired position on the screen while no external potentials, such as those of Figs. 6 and 7, are being applied. Such movement of the spot, and of any trace being formed by the spot, permits bringing almost any portion of the trace to whatever position on the screen allows the best examination.

Note that there is a ground connection, at 1600 volts, to the center of the section of the voltage divider across which the position control potentiometers are connected. Thus the center connection is at the same potential as the grounded second anode, and, because one plate of each pair is connected to this second anode, the center connection at 1600 volts is at the same potential as one of each pair of plates. The left-hand end of the voltage divider section is at 1500 volts, and the right-hand end is at 1700 volts. These same voltages are at the ends of the control potentiometers. The sliders of these potentiometers are connected to the remaining plates in the deflecting pairs.

It is apparent that moving the slider of either position control will change the potential on the connected deflecting plate to any value between 1500 and 1700 volts. When set at 1600 volts the potentials of these connected plates are the same as the potential of the opposite plates in each pair, which is 1600 volts. Then moving the sliders either way will make the potentials of their connected deflecting plates either negative or positive with reference to the opposite plates. Thus the electron beam and the luminous spot may be given deflection upward, downward, to the left, or to the right—independently of any external potentials being applied.

The external potential which is to control horizontal travel of the luminous spot (Fig. 5) is applied to the two terminals marked horizontal input in Fig. 8. The potential which is to control vertical travel of the spot is applied to the terminals marked vertical input. One terminal of each of these pairs connects through a capacitor to a corresponding deflecting plate. The other terminal of each pair connects through ground to the second anode and to the opposite plates in the deflecting system.

Deflection Sensitivity.—The distance that the luminous spot is moved across the screen for a given potential difference between a pair of deflecting plates is a measure of the *deflection sensitivity* of the cathode-ray tube. Sensitivity may be measured in inches or in millimeters of distance per volt of direct potential or per volt of peak amplitude. Sensitivities of oscilloscope tubes usually are somewhere between 0.005 and 0.040 inch per volt.

The greater the potential difference between the second anode and the cathode, with other factors unchanged, the less is the sensitivity or the deflection. This is because the higher potential on the second anode gives the electrons greater velocity, and more deflecting voltage or a stronger electric field is then needed to bend them from their straight course. Reducing the potential on the second anode increases the deflection, but at the same time it makes the luminous spot much less bright. It is necessary to compromise between sensitivity and spot brightness.

The pair of plates nearer the base of the tube, which is the pair farthest from the screen, have somewhat greater sensitivity or deflection per volt than have the pair nearer the screen.

Screens.—The screen material most often used in cathode-ray tubes for oscilloscopes is of a kind which produces a bright green trace. This material is called *phosphor* No. 1. It has what is called medium persistence, meaning that the light remains for a medium length of time after the spot passes. Medium persistence means that the brightness decreases to about one-third of maximum in about 0.003 second, and to one-tenth in about 0.014 second.

Phosphors giving a bright blue trace sometimes are used when the traces are to be photographed. These are phosphors No. 5 and No. 11. They have shorter persistence than the No. 1 green phosphor. The green phosphor also gives good results in photography of traces for most of the work done in radio.

Sweep Oscillators.—A potential varying as shown in Fig. 5 and at the bottom of Fig. 7 serves to sweep the electron beam and spot from left to right and back again when this potential is applied to the horizontal deflection plates. This potential is said to be of *sawtooth* waveform. It is generated by a special type of oscillator which most often is called the *sweep oscillator*, sometimes is called the sawtooth oscillator, and more correctly would be called the time base oscillator because it produces a potential changing uniformly with time and serving as a base on which to view and judge the varying potentials applied to the vertical deflection plates. Sweep oscillators are a part of nearly all oscilloscopes and oscillographs.

There are many types of sweep oscillator circuits in use. Some of them employ high-vacuum triodes and pentodes, while others employ a gas triode as the oscillator tube. The principle of a gas-triode oscillator is shown by Fig. 9. A gas-filled tube has the property of being non-conductive until the plate potential rises to some certain value, and of then breaking down and permitting plate current to flow with a potential drop of only a few volts in the tube. The plate potential at which break-down occurs depends on the grid-cathode potential difference. The more negative the grid with reference to the cathode, the higher must be the plate potential for break-down.

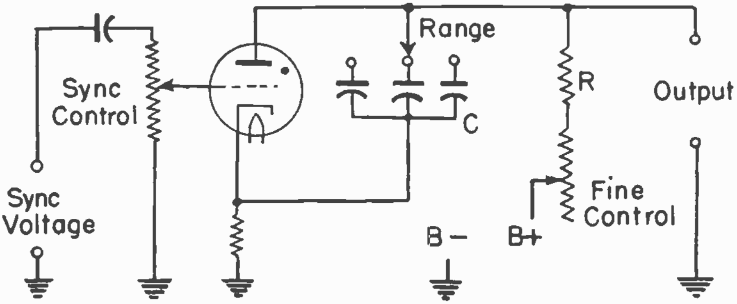


Fig. 9.—A sweep oscillator employing a gas triode.

Referring to Fig. 9, one of the capacitors *C* is charged by electron flow passing from B— to ground, through the resistor in the tube cathode lead, and to the lower capacitor plate. Electrons from the upper plate of the capacitor flow through resistor *R* and the rheostat marked *fine control* to B+. How rapidly the capacitor is charged to some certain potential depends on the time constant of the capacitor and the resistors in the charging circuit. The greater the capacitance and the greater the total resistance the longer will be the time for reaching any given voltage across the capacitor. The voltage across the capacitor is also the voltage between plate and cathode of the gas triode.

The relatively slow and steady increase of capacitor voltage is applied through the output terminals more or less directly to the horizontal deflecting plates of the cathode-ray tube. This increase of voltage comes to an end when the voltage between plate and cathode of the gas triode reaches the break-down value. Then the capacitor discharges very suddenly through the gas triode. This sudden discharge produces the change of potential that returns the beam to the left in the cathode-ray tube.

One cycle of this oscillator includes one charge and the following discharge of the capacitor. The time for the cycle is little more than the charging time. Therefore, the frequency is varied by varying the charging time. The charging time may be increased, and the sweep frequency lowered, by turning the range switch to bring into the circuit a capacitor of greater capacitance, or the frequency may be raised by bringing in a capacitor of less capacitance. With any given capacitor or capacitance in circuit the charging time and frequency may be varied by adjustment of the fine control resistance. More resistance will increase the charging time and lower the frequency, less resistance will raise the sweep frequency. The range switch is used to select some band of sweep frequencies, such as from 80 to 800 cycles per second. Then the fine control is adjusted for any one frequency in this band.

At the left-hand side of the diagram are a synchronizing (abbreviated *sync*) control potentiometer and input terminals. The slider of the potentiometer is connected to the grid of the gas triode. When some external varying or alternating potential is connected to the sync terminals the potential of the tube grid will vary with this external potential, and to an extent determined by the adjustment of the sync control. Supposing that the external synchronizing potential has a frequency of 100 cycles per second, just as an example. Even though the fine control has been adjusted to give the oscillator some frequency slightly greater than 100 cycles, oscillations will be forced to have a frequency of just 100 cycles—this because every positive pulse of synchronizing potential will make the grid enough less negative to allow breakdown of the gas triode and discharge of the capacitor. Thus the sweep frequency may be synchronized or brought into exact time with any frequency applied to the sync terminals.

Sweep oscillators of the high-vacuum type operate similarly to the gas-filled oscillators to the extent of charging and discharging a capacitor whose voltage is used for the horizontal sweep. Charging proceeds while the tube is non-conductive because of a highly negative control grid bias. Discharge occurs when the control grid suddenly is made positive during a brief period. The discharge current may be utilized in the cathode circuit of the tube to again make the control grid highly negative, by means of cathode bias, whereupon the charging commences once more.

Amplifiers. — Not many of the potentials in audio-, intermediate-, and radio-frequency circuits of radio apparatus are great enough to produce sufficient deflection of the cathode-ray beam when applied directly to the deflecting plates. Consequently, it is necessary to use one or more stages of voltage amplification in series with both the vertical deflection plates and the horizontal deflection plates.

Fig. 10 shows the essential parts of vertical and horizontal amplifying stages, together with a sweep oscillator and many of the controls generally found in oscilloscopes or oscillographs. At the upper left is the vertical amplifier tube, a pentode. The potential to act on the vertical deflecting plates of the cathode-ray tube, shown at the upper right, is applied to the vertical input jacks or terminals. One terminal is grounded. The other leads through capacitor *Cb*, which keeps direct currents out of the amplifier, and to a potentiometer whose slider goes to the control grid of the pentode. This potentiometer, often called the vertical *gain control*, regulates the amount of input potential applied to the tube grid. In the plate circuit of the amplifier are a resistor *Rb* and inductor *Lb* in series. The inductor reactance increases with rise of frequency and helps to maintain a more uniform output over a wide range of frequencies. The amplifier output goes through coupling capacitor *Cc* to one of the vertical deflection plates of the cathode-ray tube. Often there is a switch or a link which allows disconnecting the amplifier and making a direct connection to the deflection plate.

At the bottom of the diagram is the horizontal amplifier, which is identical in construction to the vertical amplifier. The output goes to one of the horizontal deflecting plates in the cathode-ray tube.

In the center of the diagram is a sweep oscillator, whose frequency is controlled by adjustment of resistor R and selection of a charging capacitor at C, all as previously explained. The oscillator frequency is synchronized with that of some potential which is applied to the potentiometer in the grid circuit of this tube. The strength or amplitude of the synchronizing potential is regulated by adjustment of this sync amplitude potentiometer.

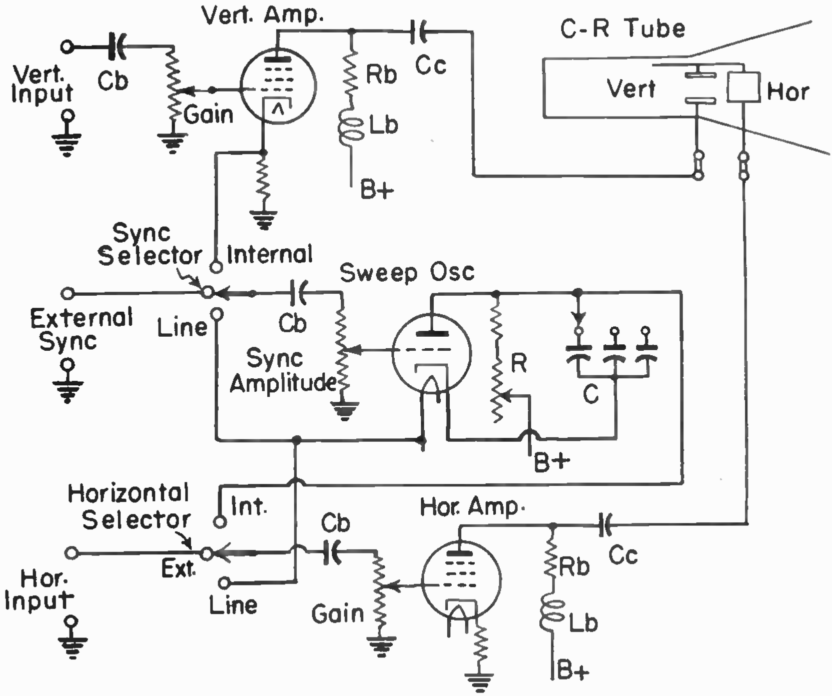


Fig. 10.—Vertical and horizontal amplifiers, and a sweep oscillator, together with their principal controls.

Input to the sync amplitude potentiometer is from a three-position sync selector switch. With this switch in its upper position, marked *Internal* for internal synchronization, the potential for synchronizing the sweep frequency is taken from a connection on the cathode of the vertical amplifier tube. Consequently, the sweep is synchronized with whatever frequency may be applied to the vertical input terminals and fed through the vertical amplifier to the vertical deflection plates.

In the center position of the sync selector switch the grid input of the sweep oscillator is connected to one of the terminals marked external synch. Then the sweep frequency will be synchronized with the frequency of any potential applied between the external sync terminals.

In the lower position of the sync selector switch the grid input is connected to the heater circuit of the amplifiers and oscillator, or to any other point at which there is a low voltage at the frequency of the power line from which the oscilloscope is being operated. On a 60-cycle line this would mean a 60-cycle sync frequency.

The input to the control grid of the horizontal amplifier tube is shown as coming from another three-position selector switch. In the upper position, marked *Internal*, the input to this amplifier is the output of the sweep oscillator, and the internally generated sweep frequency will be applied through the amplifier to the horizontal deflection plates of the cathode-ray tube. In the center position of the switch the amplifier is connected to one of the terminals marked horizontal input. Then any potential applied between the horizontal input terminals will be amplified and sent to the deflection plates. In the lower position of this selector switch the amplifier input is connected to the low voltage at power line frequency, and the horizontal deflection will follow this line frequency.

The arrangement shown by Fig. 10 is merely typical of general practice, and does not apply to any particular instrument. It does illustrate switching controls and terminals which may be available on an oscilloscope. The switching methods may be quite different from those shown here, although serving the same purposes. The line positions of the selector switches often are omitted and there is furnished an external terminal connected internally to the line frequency. Then this terminal may be connected to the external sync terminal or to the horizontal input terminal, or to both, and there will be the same results as with the switching illustrated.

An additional feature found on some instruments is provision for modulating or varying the intensity and brilliance of the trace in accordance with some external frequency. This allows making the trace brighter in certain selected portions of cycles being applied to the deflection plates, and of dimming or blanking out other portions. If the external potential consists of brief pulses at some known frequency, and known intervening time periods, the pulses will show up on a lower frequency being applied to the deflecting plates and will identify time intervals on the traces.

Operating Precautions.—The voltages employed on the cathode-ray tubes in oscilloscopes or oscillographs are dangerously high,

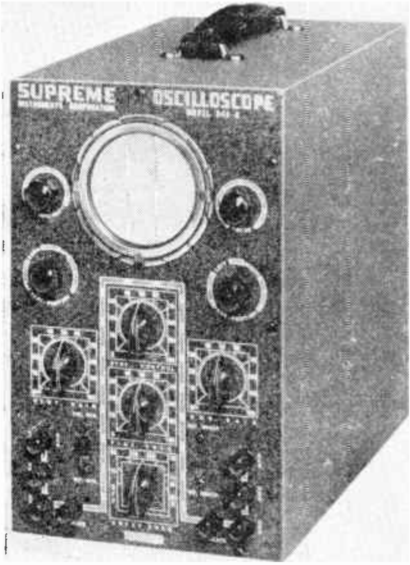


Fig. 11.—A Supreme Instruments oscilloscope with all controls and connections on the front panel.

sometimes being as much as 4,000 volts and always being at least many hundreds of volts. The instrument never should be operated while removed from its case. Before opening the case pull the line plug from the power supply or line receptacle. Don't get your fingers near the terminals of high-voltage capacitors until you have discharged them by connecting both terminals together and to ground with metal having a well-insulated handle. Don't assume that any parts are at low voltage, even though they should be; something may have gone wrong with internal connections.

Controls and Terminals.—The various selector switches, also knobs or pointers for potentiometers and rheostats, and the binding posts or jacks required during operation usually are arranged on the front panel of the oscilloscope or oscillograph, as may be seen from the pictures in Figs. 1 and 11. All of these control elements have been shown, with one method of connection, in Figs. 8, 9 and 10.

In Fig. 8 were shown four controls, all of which are potentiometers adjusted by knobs or pointers which rotate over dial scales. These controls are (1) *intensity*, (2) *focus*, (3) *vertical position*, sometimes called *vertical centering*, and (4) *horizontal position*, sometimes called *horizontal centering*.

In Fig. 9 were shown two controls for sweep frequency. One is a selector switch for capacitors, which may be called a *range* switch or a *coarse frequency* switch. The other is a rheostat for making small variations of sweep frequency. This often is called a *fine frequency* control or a *vernier* control.

Most of the remaining control elements were shown by Fig. 10. There are two *gain controls*, one vertical and one horizontal, which are potentiometers operated by knobs or pointers with dials. There is one potentiometer control for amplitude of the synchronizing potential, which may be marked *sync amplitude, sync control, sync adjust, sweep sync*, or something of this nature. There are two selector switches; one marked *sync selector* and the other marked *horizontal selector*. These switches and their positions may be marked in a variety of ways. Sometimes there will be a selector switch for connecting the deflecting plates either to the amplifier outputs or else to external binding posts. Finally there are binding posts or jacks for *vertical input, horizontal input, external synchronizing,* and sometimes for a low-voltage line-frequency take-off. Placed conveniently to these terminals may be various numbers of posts or jacks connected to the chassis ground.

The controls mentioned are those usually found on instruments used in radio servicing and laboratory work. The more elaborate and complete instruments will have additional controls. Now we shall proceed to discuss the use of the controls and terminals which have been specifically mentioned.

Vertical and Horizontal Input.—The potential to be observed or measured usually is connected to the vertical input terminals, one of which is grounded. If the horizontal deflection is to be from the sweep oscillator turn the selector switch or switches to the internal position. If horizontal deflection is to be from some external potential connect that potential to the horizontal input and set the selector switches at their external positions. For horizontal deflection at line frequency set the selector switches to the line position, or else connect a low voltage at line frequency across the horizontal input posts. This voltage may be taken from a post on the instrument, or from any step-down transformer.

If cords from an external potential are long, or if the frequency is high, use twisted pair, shielded cable with the shield to ground, or concentric cable with the external conductor to ground.

Input resistances with one-stage amplifiers usually are between 0.5 and 1.0 megohm, shunted with capacitance of 20 to 50 mmfd.

When making connections directly to the deflecting plates, rather than through the amplifiers, place in series with the plate connection a capacitor having voltage rating high enough for the applied potential, and of capacitance which may be 0.25 to 0.5 mfd for low frequencies, and as small as 0.0005 for high radio frequencies, using a capacitance roughly proportional, or inversely proportional, to the frequency.

Intensity Control.—If the cathode-ray tube, or its screen material, is to have reasonably long life it is essential that the intensity control always be kept as low as will give a trace of satisfactory visibility. Keeping the face of the tube out of strong external light allows using less intensity. Preferably there should be a hood extending outward from the exposed end of the tube so that the screen is always in subdued light.

Never permit the spot to remain stationary on the screen for more than two or three seconds unless the intensity is so low as to make the spot nearly invisible. A bright stationary spot burns and darkens the screen permanently. Turn the intensity up only after there is deflection in one direction or both, which will keep the spot in motion. The on-off switch often is combined with the intensity control, just as it is combined with the volume control in many radio receivers.

Focusing Control.—The focusing control should be adjusted to produce the narrowest possible trace on the screen. Turning this control either way from the correct setting will widen the trace. The focusing control is adjusted in connection with adjustment of the intensity control, because every change of intensity will change the focusing of the electron beam.

Position or Centering Controls.—The horizontal position control may be used to move an entire trace either to the left or the right on the screen, and the vertical positioning control will move the trace either up or down on the screen. An entire trace or pattern may be centered on the screen if the pattern is not too large.

The position controls may be used in connection with the vertical and horizontal gain controls to enlarge any part of a complete pattern, with the gain controls, and to bring the enlarged part to the center of the screen, with the position controls.

Fig. 12 shows a trace resulting from severe distortion in the

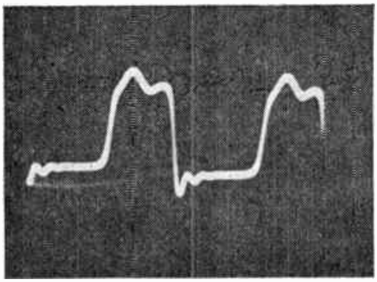


Fig. 12.—A screen trace showing audio distortion.

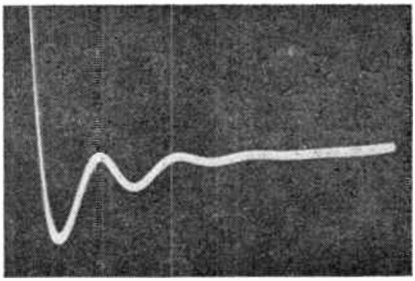


Fig. 13.—How part of the trace may be enlarged and centered.

output of an audio amplifier. It might be desired to examine in more detail the irregularity at the bottom, where the trace comes down and becomes horizontal for part of a cycle. This one portion of the trace may be enlarged by using the gain controls, while bringing it near the center of the screen and holding it there with the two position controls. The result of doing just this is shown by Fig. 13.

With the luminous spot originally in the center of the screen, the position controls usually are capable of moving it completely off the screen in any direction.

Graph Scale.—Most oscilloscopes are fitted with a piece of transparent material ruled with fine black lines spaced 1/10 inch apart horizontally and vertically, and with slightly heavier lines at half inches and full inches. This graph scale may be placed in front of the screen of the cathode-ray tube when it is desired to make observations or measurements of relative distances on traces. Fig. 14 shows such a scale in use.

To correctly center the trace pattern on the graph scale first

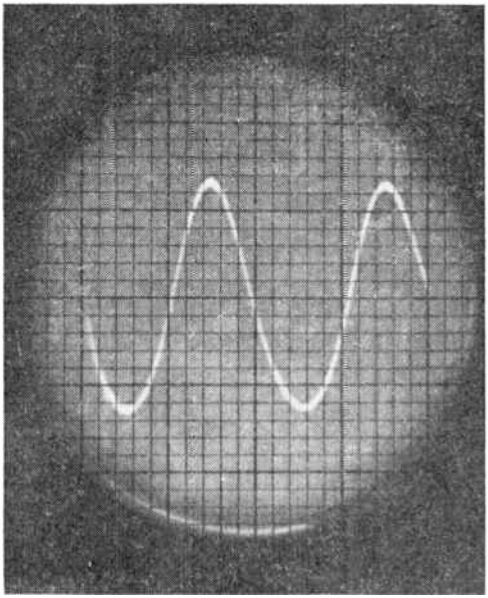


Fig. 14.—The graph scale as used in front of the screen.

turn the horizontal gain to zero but leave the vertical gain at some low value, and use the horizontal position control to bring the vertical trace line to the center of the scale. Then set the horizontal gain to a low value and reduce the vertical gain to zero while using the vertical position control to bring the horizontal trace line to the center of the scale. Relative amplitudes then will be shown correctly so long as the settings of the position controls and gain controls are not altered.

Gain Controls.—Increasing the vertical gain control spreads the trace pattern vertically without making any increase in the horiziontal dimension, while increasing the horizontal gain control spreads the pattern sideways without affecting its height. As a general rule the two gain controls should be set at about equal values on the dial scales unless it is desired to extend the pattern one way or the other for some particular kind of examination. If one control is set high and the other relatively low, the pattern may be made to look like something entirely different from the true waveform.

The frequencies of potentials applied to the vertical input may be as low as 20 or 30 cycles, or as high as many megacycles. It is practically impossible to have an amplifier with uniform gain over any such band of frequencies if there is to be any appreciable gain in the amplifier. The gain decreases with rising frequency, and drops below any useful value at a few hundred kilocycles in most instruments designed for service work. The same limitations apply to the horizontal amplifier, but here the gain always is ample for all sweep frequencies which may be generated by the internal sweep oscillator.

Sweep Frequency Controls.—Sweep frequencies generated internally in service type oscilloscopes or oscillographs usually will have a minimum somewhere between 3 and 20 cycles per second, and a maximum of 30 to 50 kilocycles. The range of frequencies is divided into three or more bands, any one of which is selected by cutting in a charging capacitor by the range switch or coarse frequency switch. Any frequency in the selected band than is produced by adjustment of the vernier or fine frequency potentiometer. The frequencies of sweep oscillators vary with changes of temperature and other factors, and are not constant enough to permit calibration of the vernier scale or to permit use of the oscillator as a standard for measurement of frequencies.

The sweep frequency is brought into the desired relation with any applied frequency by adjusting the coarse and fine frequency controls until there appears on the screen a stationary trace showing one cycle, some whole number of cycles or else some simple fraction of a cycle of the applied potential.

At the left in Fig. 15 is represented a sweep having the same frequency, and time period, as the applied vertical potential. On the screen will appear a trace showing just one cycle of the vertical potential. On the following cycle of vertical potential there will be another horizontal sweep just like the first one. Successive cycles will cause the spot to move over the same path, and the trace will appear stationary on the screen.

At the center of Fig. 15 is represented a sweep taking a time as long as for three cycles of applied vertical frequency. During any one horizontal sweep the spot will trace through three cycles of vertical potential, and during every following horizontal sweep the spot will trace through three cycles. The three cycles will appear on the screen, always in the same position, and the three-cycle pattern will appear stationary. Here the sweep frequency is one-third of the vertical frequency. The sweep might be 20 cycles and the vertical frequency 60 cycles per second.

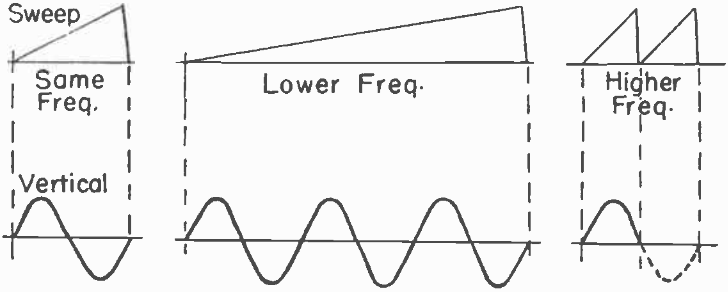


Fig. 15.—Relations between sweep frequencies and vertical frequencies.

The number of cycles appearing on the screen always may be found from dividing the applied vertical frequency by the horizontal sweep frequency.

At the right in Fig. 15 the sweep frequency is twice the vertical frequency; there will be two horizontal sweeps during each vertical cycle. During the first sweep there will be traced the first half-cycle of vertical potential. During the second sweep there will be traced the second half-cycle of vertical potential. The two half-cycles will appear together on the screen, because they are recurring at such short intervals that we see them continually, by persistence of vision and of screen material. Into just what parts the cycle is split depends on the phase relation of the sweep and vertical frequencies. One division is shown by Fig. 16. If you copy these two waves and place them end to end you will have one cycle.

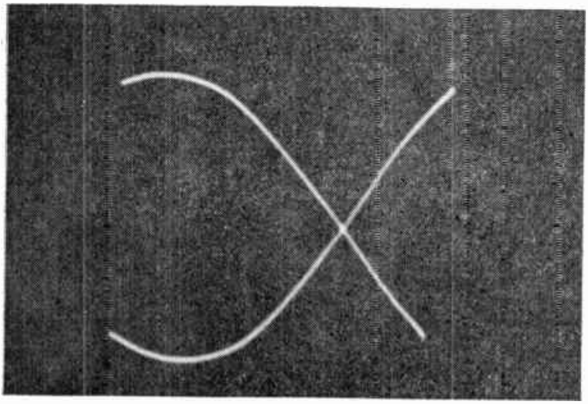


Fig. 16.—One cycle divided into two parts.

If the sweep frequency is made still higher each vertical cycle will be split into more sections, into as many as the sweep frequency is contained in the vertical frequency, and all of the sections will appear together. Such patterns are of no particular usefulness.

Almost always we use a sweep frequency which is ½, ⅓, ¼, or some other simple fraction of the applied vertical frequency, thus showing on the screen 2, 3, 4 or some other whole number of vertical cycles. There are several reasons for doing so. For one, we then may note the whole waveform of similar successive cycles and may identify complete cycles, which otherwise might be difficult with a distorted or complex waveform. Two cycles are shown in Figs. 12 and 14.

It is impossible to get one complete cycle, and no more, onto the screen; this because part of the end of the cycle will be in the retrace or return trace. This is evident from Fig. 17, where the retrace has been made visible and where it is clearly apparent that part of the last end of the curved line has been cut off. To avoid this cutting off we may bring at least two cycles onto the screen by lowering the sweep frequency, as in Fig. 14, and then enlarging and centering one of the cycles if a large pattern is needed for examination.

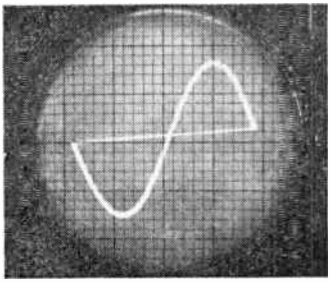


Fig. 17.—Part of one cycle is cut off by the retrace time.

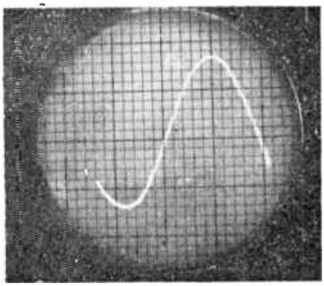


Fig. 18.—Displacement of cycle when sweep and vertical potentials are not in phase.

Where a single cycle starts and ends on the screen depends on the phase relation between horizontal and vertical frequencies. With a difference in phase a cycle may appear as in Fig. 18, or in some other form where beginning and end of the trace are not on the zero potential line. Some oscilloscopes or oscillographs have adjustments for phase. When there are no such adjustments provided, the phase relation usually may be altered by slight variations of the fine frequency or vernier control for sweep frequency, or by variation of the control for amplitude of synchronizing potential, or by using both of these controls.

Retrace Effects.—It has been mentioned that the time required for the retrace will cut some part from the end of a cycle when only one cycle is brought onto the screen. How much of the cycle is removed from the curve depends on the frequency of the vertical signal, the higher the frequency the greater the loss. This is because the time for retrace becomes a larger and larger part of the whole sweep cycle with increase of frequency. The retrace time itself remains fairly constant, but the time per sweep becomes shorter and shorter.

The higher the frequency the faster the electron beam and spot travel over the screen, and the higher the intensity control must be set to obtain satisfactory brilliancy of trace. At the highest sweep frequencies the intensity has to be turned so high that the retrace may become almost as clearly visible as the forward trace, and this makes it more difficult to interpret the meaning of the pattern.

When quite a few cycles of a high vertical frequency are brought onto the screen, by using a lower sweep frequency, several of the vertical cycles may occur during the retrace time. These hidden cycles may be made visible by momentarily increasing the intensity to make them show up.

Some oscilloscopes or oscillographs have provision for blanking the retrace. This is done by making the control grid of the cathode-ray tube so negative during the return time as to cut off the electron beam, just as it would be cut off by turning down the intensity control. A pulse of negative grid potential for blanking may be obtained from the sweep oscillator circuit. Blanking ordinarily is needed only when using high horizontal frequencies.

External Sweeps.—Any potential from an external source may be applied through the horizontal amplifier to the horizontal deflection plates of the cathode-ray tube to act as a horizontal sweep. The internal sweep oscillator then is not used. With the arrangement of Fig. 10 the sync selector switch would be set at the external sync position, but no connection would be made to the external sync post. The horizontal selector would be set at the external position, and the external sweep potential would be connected between the horizontal input posts.

Fig. 19 shows a trace resulting from application to the horizontal input of a 60-cycle sine-wave potential while there is applied to the vertical input a 360-cycle potential which is of approximately sine-wave form. Here we are using what may be called a *non-linear sweep* of sinusoidal wave form. Fig. 20 shows the trace which results from reversing the frequencies; with a 60-cycle potential applied to vertical input while a 360-cycle potential is applied to the horizontal input. We shall have more to say about traces of these general types when discussing frequency comparisons and measurements.

Synchronizing Controls. — When one alternating or varying potential is applied to the vertical deflection plates, and another alternating or varying potential is applied to the horizontal deflecting plates at the same time the trace on the screen will appear to stand still only when the frequencies of the two potentials are identical or else when one of them can be evenly divided into the other with no fraction left over. That is, the trace will appear to stand still when, for example, both frequencies are exactly 60 cycles or when one is 60 cycles and the other 360 cycles. In the latter combination 60 goes into 360 exactly 6 times. But if one frequency were 60¼ cycles the pattern would rotate or drift around the screen. The pattern would rotate when the one frequency is anywhere below 60 and above 30 cycles, but at 30 cycles would again stand still because 30 goes into 60 or into 360 with nothing left over. The pattern would rotate at any frequency above 60 and below 120 cycles, but at 120 cycles would again stand still.

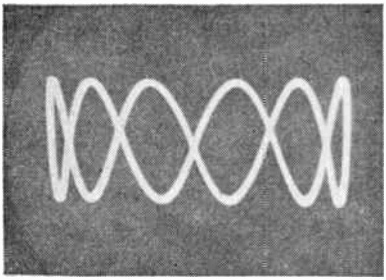


Fig. 19.—Trace with 60 cycles to horizontal input and 360 cycles to vertical input.

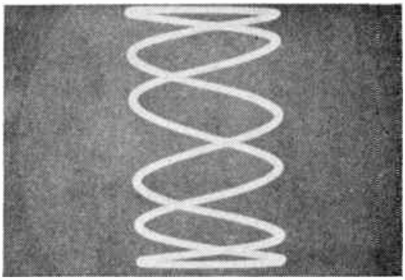


Fig. 20.—Trace with frequencies reversed; 360 cycles horizontal and 60 cycles vertical.

This general rule applies no matter what the waveform of either frequency. It applies when the horizontal potential comes from the sweep oscillator, or from any other source.

But when using the sweep oscillator we may apply a synchronizing potential which, if the natural frequency of the oscillator is not too much below the synchronizing frequency, will pull the oscillator into step with that synchronizing frequency or will force the oscillator frequency to become exactly the same as the synchronizing frequency. Then the pattern will stand still. This process sometimes is called *locking in* of the frequencies.

Going back to Fig. 10, a synchronizing potential can be taken from whatever potential is applied to the vertical input by setting the sync selector switch at internal or internal sync and setting the horizontal selector switch at internal. Then, if the oscillator frequency is adjusted by the sweep vernier or fine control until the oscillator frequency comes close to the applied vertical frequency, the oscillator frequency will come under the influence of the synchronizing potential and the pattern will become stationary on the screen.

How much of the synchronizing potential is applied to the sweep oscillator depends on the setting of the sync amplitude potentiometer whose slider goes to the control grid of the oscillator in Fig. 10. If the oscillator natural frequency is quite different from the synchronizing frequency there will be required more synchronizing potential than were the two frequencies originally closer together. Also, the higher the frequencies being observed, the higher the sync amplitude control will have to be turned to secure locking in.

The way to proceed is to turn the sync amplitude control very low, then use the sweep vernier or fine control to make the trace as nearly stationary as possible, and finally to turn the sync amplitude control up only far enough to hold the trace stationary. It will be found that some slight readjustment of the sweep frequency must be made when increasing the sync amplitude. The whole object is to keep the sync amplitude as low as will hold the trace stationary. Too much sync amplitude will distort the waveform of the trace, and may even change the sweep frequency enough to break the wave into several sections.

The sweep frequency may be synchronized by any alternating or varying potential applied to the external sync terminals when the sync selector switch is set at its external position. The external synchronizing potential applied to the posts might be taken from the same circuit or source that is furnishing the frequency applied to the vertical input, but there would be no particular object in doing so with an oscilloscope having provision for internal synchronization — which does exactly the same thing.

The sweep oscillator may be synchronized with the supply line frequency by setting the sync selector switch at its line position, but then the horizontal selector switch must be at its own internal position in order to connect the sweep oscillator to the horizontal amplifier. There is no object in synchronizing the sweep frequency unless the sweep oscillator output is connected to the horizontal amplifier or to something else which can use the sweep frequency. With the usual control arrangement, such as shown by Fig. 10, turning both the sync selector and the horizontal selector to their line positions would disconnect the output of the sweep oscillator and would apply line frequency to the horizontal amplifier.

A line position of the sync selector switch is useful only when the potential applied to the vertical input is some exact multiple or some simple fraction of line frequency. Synchronization from the supply line may be useful when it is known that the line frequency is nearly constant at its rated value, usually at 60 cycles, and when it is desired to have a synchronizing frequency of this known value.

REVIEW QUESTIONS

1. Is the electron beam in the cathode-ray tube moved vertically or horizontally by the plates on the right and left sides of the beam?
2. In an oscilloscope power unit having both half-wave and full-wave rectifiers which one is used for the high-voltage circuits?
3. Are deflection sensitivities at the tube plates on the order of 0.001, or 0.02, or 1.00 inch per volt?
4. What is the name or shape of the type of output wave from the sweep oscillator?
5. Mention safety precautions observed when operating oscilloscopes. Consider such items as opening the housing, capacitor terminals, etc.
6. Is the potential to be observed or measured usually applied to the horizontal or the vertical input terminals of the oscilloscope?
7. When the intensity control is re-adjusted what other control should be varied at the same time to maintain a sharply defined trace?
8. For observing the true proportions in the wave of input potential how should the two gain controls be adjusted, alike or different?

Chapter 12

OSCILLOSCOPE TESTS AND MEASUREMENTS

Before attempting to use an oscillograph or oscilloscope for checking the performance of radio apparatus you should become familiar with the action of all the controls on the particular instrument to be used. If the manufacturer furnishes an instruction book, follow its suggestions exactly. Otherwise read the instructions given in these chapters and, so far as possible, put them into practice as you read. Following is an outline of steps which may be followed in becoming acquainted with an instrument and its operation.

1. With the intensity control at its lowest position, or in the *Off* position when the off-on switch is attached to this control, set the other controls as follows.
   a. Focus control at about mid-position.
   b. Both the vertical and the horizontal position or centering controls at mid-position.
   c. Both the vertical and the horizontal gain controls at about one-fourth scale.
   d. Sync amplitude control near the bottom of its dial scale.
   e. Sync selector switch at its *Internal* position.
   f. Horizontal selector switch at *Internal* position.
   g. Coarse frequency or sweep range switch at band including the frequency of your line supply.
   h. Fine frequency or vernier control at about mid-position.
   i. To the vertical input and ground connect some low-voltage line-frequency source. This voltage may be taken from a 6.3 or 12.6-volt filament or heater circuit, or from a filament or heater tap on a power transformer. If the oscilloscope has a post or jack for 6 volts a-c, or some other low a-c voltage, connect this post or jack to the vertical input.
   j. Make no connections either to the horizontal input or to the external sync posts or jacks.
2. Turn the off-on switch on, or operate the intensity control to turn it on. Set the intensity control to about one-third scale and watch the screen for a luminous spot or luminous lines. If, after the spot appears, it settles down into only a spot rather than lines, turn off the instrument and recheck

your control settings. If nothing appears within about a half minute, turn the intensity control slowly higher until there is a spot or line.

3. Slowly turn the sweep vernier or fine frequency control until there is a clear pattern which moves slowly on the screen.
4. Advance the sync amplitude and readjust the sweep vernier until the pattern stands still. Use only enough sync amplitude to hold the pattern steady.
5. Try the effect of the focus control on line width and distinctness. Use this control to maintain the narrowest clear line.
6. Try the effect of the intensity control on line brightness. Notice the effect on distinctness or focusing of the line, and try readjusting the focus control. Keep the line only bright enough for a distinct pattern.
7. Operate the horizontal and vertical gain controls, observing the effect on width and height of pattern.
8. Operate the horizontal and vertical position or centering controls to find how far you can move the pattern in all directions.
9. Make it a habit not to leave a trace on the screen, and never leave a spot, between tests or observations. Turn the intensity control far enough down so that the screen is clear.

Waveform Inspection.—The potential whose waveform is to be examined ordinarily is applied to the vertical input and ground posts of the oscilloscope. The sweep frequency should be low enough to bring two or three cycles onto the screen. One of the cycles can be enlarged and centered, but this seldom is necessary.

It may be desirable to set the vertical and horizontal amplifiers for equal gains in order to observe the true waveform. This is done by applying any signal potential to the vertical input, setting the horizontal gain at zero and the vertical gain for the desired height of trace. This vertical height should be noted, as should also the exact position of the vertical gain control on its dial. Then apply the same signal potential to the horizontal input, set the vertical gain at zero, and adjust the horizontal gain to get the same length of trace as previously. The present setting of horizontal gain and the previously noted setting of vertical gain give equal horizontal and vertical gains.

When making waveform observations it is assumed that the horizontal sweep moves the spot at constant speed all the way from left to right, which means that the horizontal sweep is truly linear. Otherwise some cycles will be spread more than others. Usually the later cycles will be compressed. Linearity may be checked by bringing five or six cycles onto the screen then measuring the distances between peaks. These distances will be equal for all cycles with a linear sweep. Discrepancies in the first and last cycles mean nothing, since they are due chiefly to curvature of the screen end of the cathode-ray tube.

Audio-frequency Waveforms.—To observe the output of an audio-frequency amplifier connect the voice coil leads of the loud speaker to the vertical input of the oscilloscope. Another way is to disconnect one voice coil lead, connect between this lead and the other one a resistor whose resistance is very close to the voice coil impedance, and then connect the ends of this resistor to the vertical input.

An a-f signal potential of good waveform, as secured from a signal generator, is connected between the volume control slider and chassis ground, or is connected to the control grid of the first a-f amplifier and ground, or to the control grid and ground for any following a-f tube; depending on how much or how many stages of the amplifier are to be checked.

The a-f signal from the generator first should be connected directly to the vertical input of the oscilloscope, and its waveform examined. Any distortion will come through the amplifier and must be allowed for in final observations. Set the signal generator amplitude rather low, to allow for amplification in the audio amplifier being checked.

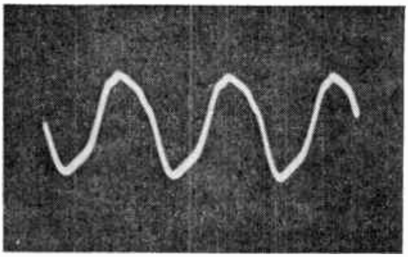


Fig. 1.—Audio distortion.

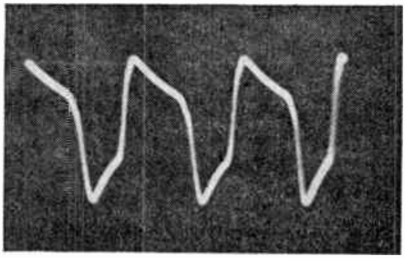


Fig. 2.—The distortion increases.

Fig. 1 shows overloading of an a-f amplifier tube due to a higher signal potential than can be handled with the existing plate and screen voltages and the existing control grid bias. The fault might be due to low screen voltage, excessively negative grid bias, or too high a setting of the volume control for the signal coming from the detector.

Fig. 2 shows the waveform resulting from turning the volume control still higher with no other changes in operating conditions. The input to the volume control was of approximate sine-wave form in both of these cases.

Fig. 3 shows what happens when the control grid bias is not sufficiently negative. This particular fault was due to a cathode bias resistor of too little resistance, reducing the bias from 7½ to 5 volts negative. There was an increase of volume, and of height of the trace, due to the greater plate current.

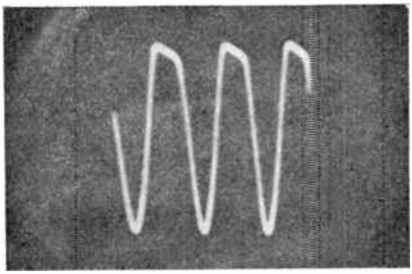


Fig. 3.—Not enough negative grid bias.

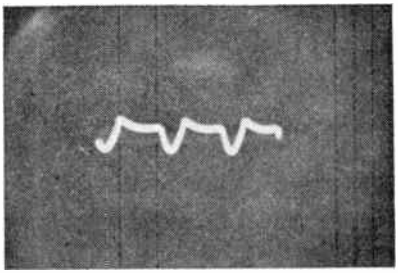


Fig. 4.—Plate voltage too low.

Fig. 4 shows the result of low plate voltage, which actually was due to excessive resistance in the circuit leading from the plate through the output transformer primary to B+. The volume is away down and there is severe distortion.

Fig. 5 shows the same distorted signal as illustrated by Fig. 4, but here the vertical gain of the oscilloscope is turned up. The waveform is unchanged, but the amplitude on the screen is increased.

Fig. 6 shows the same signal as illustrated by Figs 4 and 5, but here the leads to the vertical input and to ground of the oscilloscope have been reversed. The result is merely to turn the signal upside down. The same thing would happen with reversed connections to the voice coil leads or to any other points from which the amplifier output is being taken to the oscilloscope.

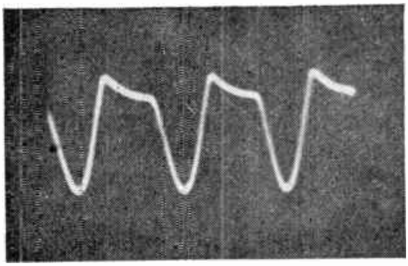


Fig. 5.—Vertical gain increased, but plate voltage too low.

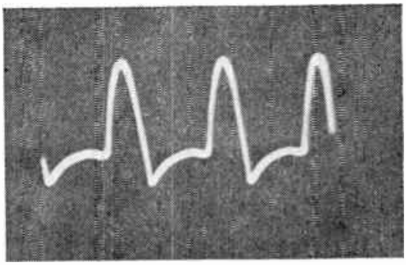


Fig. 6.—Trace inverted by reversing leads to vertical input.

With the oscilloscope connected to the voice coil leads, as at the left in Fig. 7, it is difficult or impossible to identify whether upward lines in the trace indicate increases or decreases of voltage at the plate end of the circuit, because we are working through the output coupling transformer. To make this identification the vertical input of the oscilloscope may be connected through a resistor of about a half-megohm resistance to the plate of the output tube, with the ground of the oscilloscope connected to a chassis ground.

Now we are measuring or observing changes of plate voltage. We must keep in mind that plate voltage and plate current, in

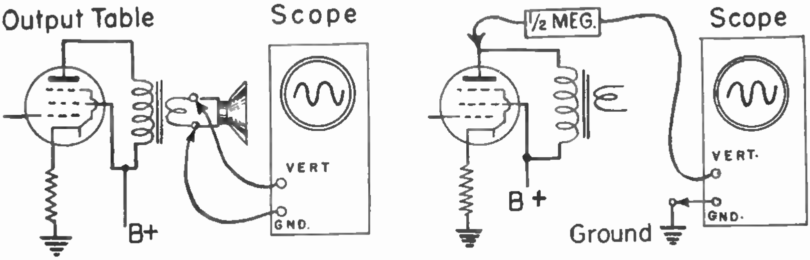


Fig. 7.—Connections of oscilloscope to voice coil (left) and to plate of output tube (right).

the tube, change oppositely. When there is an increase of plate current there must be an accompanying decrease of plate voltage, because more of the total B-supply potential is used up in the plate load when there is more current, and less remains across the tube.

As a result of plate voltage and current being in opposite phase, when we see a trace pattern such as Fig. 8 it indicates plate *current* cutoff which would be due to a grid bias excessively negative for the plate and screen voltages in use. The top of the trace curves are cut off, which means that the bottoms of the plate current curves are being cut off.

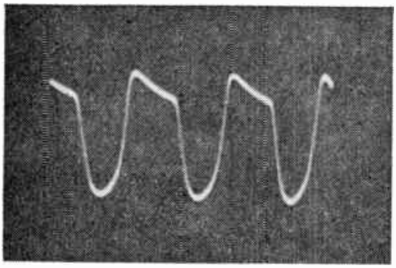


Fig. 8.—Insufficient control grid bias.

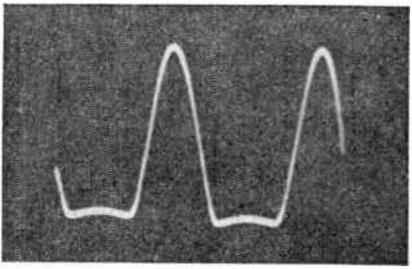


Fig. 9.—Insufficient plate voltage.

When we see a trace pattern such as that of Fig. 9, where the bottoms of the voltage curves are cut off, it means that the tops of the current curves are being cut off in the output of the tube. When the tops of current curves or waves are cut off it indicates saturation in the tube. Saturation means that the plate current cannot follow the control grid potential all the way, as this potential becomes less negative or possibly positive. The usual reason is a plate voltage too low for the signal being applied to the tube, and for the control grid bias in use.

Assuming that the signal is no greater than should be handled by the tube, the trace of Fig. 8 then would indicate too little negative control grid bias, and the one of Fig. 9 would mean plate voltage too low.

Screen voltage too low for the plate voltage and the signal causes a trace somewhat similar to the one indicating low plate voltage, in that the bottoms of the waves are cut off. **Fig. 10** shows a trace taken with screen voltage down to about half of its correct value.

It happens that a trace pattern almost identical with that for low screen voltage may result from using a loud speaker whose voice coil impedance is much too high to match the impedance of the speaker winding of the output transformer.

If both the control grid bias and either the screen or plate voltage are incorrect there may be cutting off of both the tops and bottoms of the waves in the trace pattern, as illustrated by Fig. 11. Since there should be certain related values of all three voltages, when any one of them is incorrect to any great degree it makes the others incorrect as well. When the first voltage is brought within the design limits of the amplifier being checked the whole trouble usually disappears.

When only one of the pair of tubes in a class B push-pull amplifier is checked there normally would be some cutting off of the tops of the waves, indicating plate current cutoff. When the outputs of the two tubes are combined for the loud speaker the apparent distortion will disappear and the output wave will follow the form of the input unless there actually is distortion in the amplifier.

There are two general methods for checking the operation of an audio amplifier stage-by-stage. One way is to connect the oscilloscope across the speaker voice coil and leave it there while connecting the input signal potential first to the control grid of the output tube, then the control grid of the preceding a-f amplifier, and so on back to the volume control. The other way is to connect the input signal to the volume control or detector load resistor and leave it there while connecting the vertical input of the oscilloscope successively to the control grid of the first a-f tube, then to the plate of this tube, and so on to the control grid then plate of each following tube in the amplifier. With either method any indicated distortion is caused by faults located between the input and the oscilloscope so long as the distortion is shown by the trace patterns.

Modulated R-f and I-f Waves.—The oscillograph or oscilloscope will show an amplitude-modulated high-frequency wave when the wave frequency is in the radio-frequency or intermediate-frequency ranges.

Fig. 12 shows connections which may be used for observing modulated waveforms. The r-f (or i-f) high side output of the signal generator is connected through a dummy antenna *D* either to the antenna post of the receiver for checking operation of both the r-f and i-f amplifiers with this one connection, or else is connected to the signal grid of the converter tube for checking only the i-f amplifier. The signal generator ground is connected to the receiver chassis ground through the usual blocking capacitor if there may be supply line potential on the chassis ground.

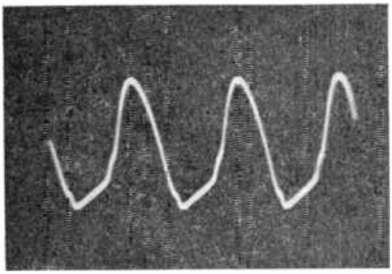


Fig. 10.—Screen voltage too low.

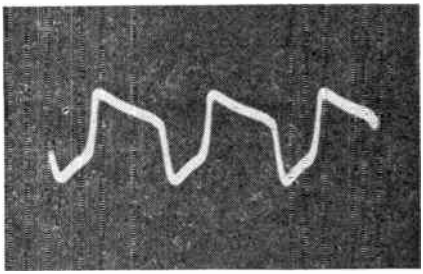


Fig. 11.—Too little grid bias and low voltage to plate or screen.

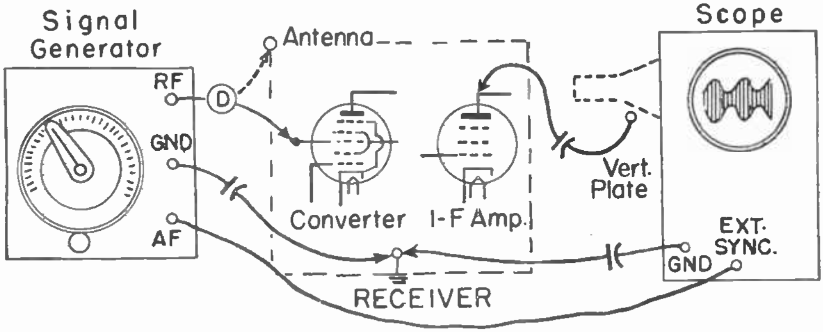


Fig. 12.—Connections for observation of r-f or i-f envelopes, either modulated or not modulated.

The vertical amplifier of the oscilloscope usually will not give distortionless amplification at frequencies in the r-f and i-f bands. Therefore, instead of making a connection to the vertical input posts of the oscilloscope a connection should be made from the plate of the last i-f amplifier tube of the receiver through a capacitor directly to the vertical deflection plate of the oscilloscope. The capacitor need be of no more than 0.0001 mfd capacitance, but must have a voltage rating amply high enough for the amplifier plate voltage. The ground of the oscilloscope is connected to the receiver chassis through a blocking capacitor which may be of almost any capacitance value greater than 0.001 mfd.

The sweep frequency is adjusted for the modulating frequency of the generator, which often is about 400 cycles. The sweep may be synchronized for a stationary pattern by using the regular sync amplitude control. Synchronization will be much more positive with the external sync post of the oscilloscope connected to the a-f output, at modulating frequency, of the signal generator. Then the sync selector switch of the oscilloscope is set for external synchronization.

Fig. 13 shows the trace pattern, as made with the setup of Fig. 12, with an intermediate frequency of 456 kilocycles amplitude-modulated at 400 cycles and applied to the converter signal grid.

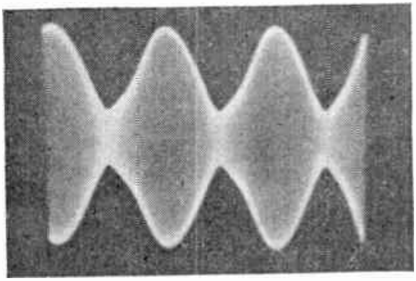


Fig. 13.—High-frequency wave modulated at audio frequency.

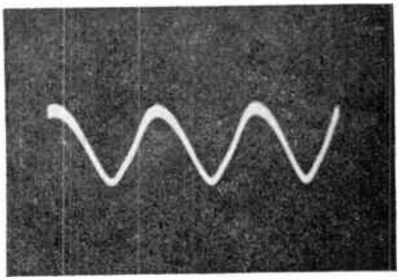


Fig. 14.—The demodulated audio wave from the detector.

The audio-frequency wave, which provides the upper and lower envelopes in Fig. 13, now may be observed by taking the lead off the plate of the i-f amplifier tube and connecting it to the detector load resistor or to the high side of the volume control. This connects the vertical deflecting plate of the oscilloscope to the detector output. No other connections changes are required, nor should they be made, and the output of the signal generator should not be altered. A picture of the demodulated wave made in this manner is shown by Fig. 14. Note that the waveform of this a-f signal is the same as the upper envelope of the modulated wave of Fig. 13, which indicates that there is no distortion in the detector stage. Were there any alternation of the waveform it would result from overload or from some incorrect operating condition in the detector stage.

Now the input from the signal generator may be shifted to the antenna post of the receiver, with the oscilloscope vertical deflecting plate connected to the plate of the last i-f amplifier tube. The generator and the receiver tuning dial must be tuned to the same frequency. The trace pattern should appear like the one shown by Fig. 13 if there is no trouble in the antenna and r-f stages of the receiver. The same radio frequency from the generator and in the receiver tuning will be indicated when the loops of the modulation envelope reach maximum height as either the generator tuning or receiver tuning is varied.

Fig. 13 shows modulation of about 60 per cent. Percentage modulation, as a fraction, may be determined by first measuring the vertical distance between envelope peaks where they are farthest apart, calling this the maximum amplitude, and then measuring the vertical distance between depressions where they are closest together, calling this the minimum amplitude. The next step is to subtract the minimum from the maximum amplitude, calling this the difference, and then to add the maximum

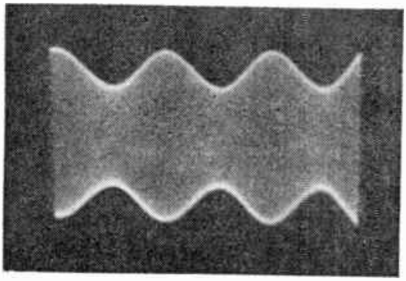


Fig. 15.—Smaller percentage modulation.

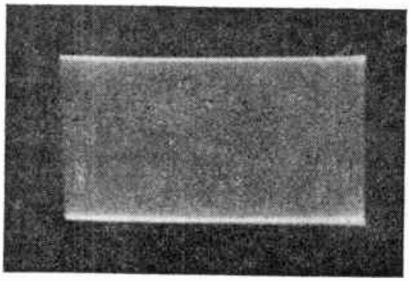


Fig. 16.—Unmodulated high-frequency wave.

and minimum values, calling this the sum. Finally, dividing the difference by the sum gives the modulation fraction, which may be multiplied by 100 to determine percentage of modulation.

Fig. 15 shows audio-frequency modulation of about 26 per cent, with the same high-frequency, either radio or intermediate, as before. Fig. 16 shows the high-frequency wave, either radio or intermediate frequency, with no modulation at all. Since the sweep frequency here is set for the frequency of the audio modulation, the separate alternations of the high-frequency wave are far too close together to be distinguished; they form merely a blur on the screen, with separation between top and bottom proportional to the high-frequency peak amplitude.

If there is distortion in the r-f or i-f system, which would cause irregularities in wave form were the unmodulated r-f or i-f waves to be observed, there will be horizontal streaks of lighter area intervening with darker bands on the unmodulated trace. That is, instead of having a trace like that of Fig. 16 where the only bright lines are at the top and bottom, there will be a pattern on the general order of the one shown by Fig. 17, with intermediate light streaks. The trouble in the case of Fig. 17 was due to harmonic frequencies.

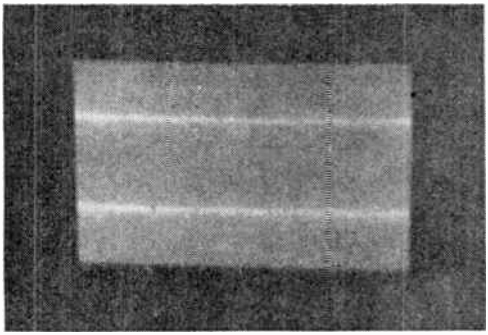


Fig. 17.—Distortion in r-f or i-f systems causes streaks in the unmodulated wave.

It is apparent that connection of the signal generator and the oscilloscope to various places in the receiver will show where faults are originating. Faults which cause incorrect patterns must be somewhere between the connections of generator and oscilloscope, and by bringing the two closer and closer together the trouble may be located as existing in some one stage or in a small section of the receiver.

Voltage Measurements.—If the horizontal gain control is set at zero and an alternating potential applied to the vertical input of the oscilloscope, the height of the vertical trace line will be proportional to the applied potential. The height corresponding to a certain voltage may be determined by applying a known voltage and measuring the trace. If the vertical gain control is readjusted the voltage proportion to height of trace will be affected because the amplifier does not respond uniformly with control settings. With the gain control at maximum most amplifiers are "flat" for all frequencies up to some certain limit, which may be anything from about 50 kilocycles to several hundred kilocycles, depending on the type of instrument and amplifier. At higher frequencies the gain falls off rapidly. If the measured potential is applied directly to the vertical deflection plates the frequency response will be uniform all the way from direct current up to a hundred megacycles or more, but then a considerable potential is required to get measurable deflection.

In practice the oscilloscope is limited to measurement of frequencies not much higher than the audio range when voltages are low, and is limited to fairly high potentials at all higher frequencies where potential measurements are to be made.

Hum Tracing.—The oscilloscope may be used for checking the existence and magnitude of hum voltage or ripple voltage at various points in the filter and voltage divider or voltage dropping systems of radio apparatus. To begin with the sweep frequency is adjusted to the frequency of the power supply line by applying a low potential at line frequency to the vertical input. Then the ground of the oscilloscope is connected to the receiver chassis ground. To the vertical input post of the oscilloscope is connected a test lead with a prod on the free end. In series with this prod lead should be a capacitor of 0.25 mfd or greater capacitance and of working voltage amply high for the maximum peak potential which may come from the rectifier tube. This potential should be assumed as equal at least to double the highest plate voltage for any tube in the receiver or other apparatus.

With the vertical gain control turned low touch the prod to the rectifier cathode lead or to the input of the filter system and adjust the vertical gain to allow observing the pattern of the rectifier output. With half-wave rectification there will be one peak per cycle, and with full-wave rectification there will be two peaks per cycle. Then move the prod successively to following points in the filter system, proceeding toward the filter output, and then along the voltage divider or voltage dropping resistors toward the connections for plates and screen grids of the various tubes.

The ripple voltage should lose its sharp peaks and become smaller and smaller, requiring higher and higher setting of the vertical gain to observe it at all. Since the d-c output of the filtering system never becomes pure direct current it always will be possible to observe some ripple at line frequency or double this frequency by turning the vertical gain high enough, but when high gain is needed the ripple voltage no longer will cause objectionable hum.

Frequency Comparison.—During the discussion of non-linear sweeps there were shown pictures of the two trace patterns which are drawn out in Fig. 18. The left-hand pattern was produced with 360 cycles applied to the vertical input of the oscilloscope, and 60 cycles applied to the horizontal input. The 60-cycle

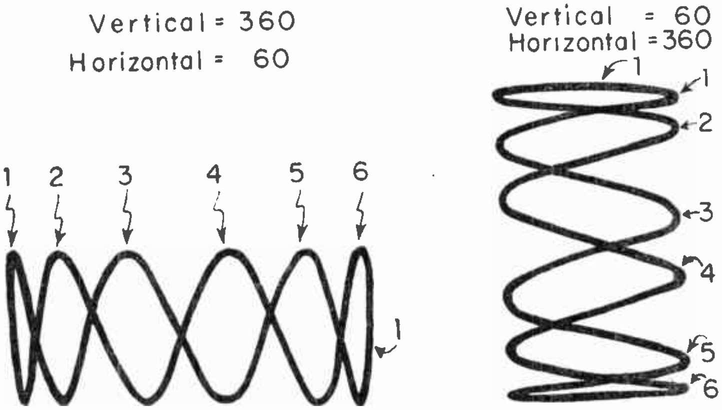


Fig. 18.—How frequencies are compared when their ratio is not more than 10 or 12 to 1.

potential produced the horizontal sweep frequency. The internal sweep oscillator was not being used. Note that there are six peaks or loops along the top of the pattern, and one loop on the side. The ratio of top (or bottom) loops to side loops is six to one. The ratio of vertical frequency to horizontal frequency is 360 to 60, which also is six to one.

In the right-hand pattern of Fig. 18 there is one loop at the top and six loops along either of the vertical sides. The ratio of loops, top to side, is one to six. This pattern was produced with 60 cycles on the vertical input and 360 cycles on the horizontal input. The ratio of vertical to horizontal frequency is 60 to 360, which is also one to six.

When any unknown frequency is applied to one input, either horizontal or vertical, and an adjustable known frequency is applied to the other input, the known frequency may be adjusted to produce a nearly stationary pattern or one that remains without movement. Then the ratio of the number of loops across the top or bottom of the pattern to the number of loops on either side is the same as the ratio of the vertical to the horizontal frequency.

Frequency ratios as great as ten to one or even twelve to one are quite easy to count in this manner. The known adjustable frequency may be secured from an accurately calibrated audio-frequency or radio-frequency signal generator. The supply line frequency, usually 60 cycles, may be used as the standard only when the unknown frequency is a multiple or a simple fraction of the line frequency, or very nearly so.

If the two frequencies are not simple multiples or fractions of each other the pattern will rotate on the screen, with one set of "cycles" moving toward the right and the other set moving toward the left. Any one peak will go all the way from any given position back to the same position once for each cycle that the frequencies differ. For example, were you using a known frequency of 1,000 cycles and were a peak to make the circuit in one second, the unknown frequency would be either 999 or else 1,001 cycles. Were the rotation to be twice per second the unknown would be either 998 or else 1,002 cycles, and so on for any speed of rotation. The direction of travel of the peaks depends on whether the unknown frequency is lower or higher than the known one. Usually it is well to let the pattern rotate very slowly to make certain that no two loops coincide and hide each other.

If the higher frequency is of distorted waveform, with sharp peaks and kinks, the counting will be easier than with a more nearly sine-wave form because of the spots which are brighter than the remainder of the trace pattern. Also, it will be easier to distinguish between loops traveling in opposite directions.

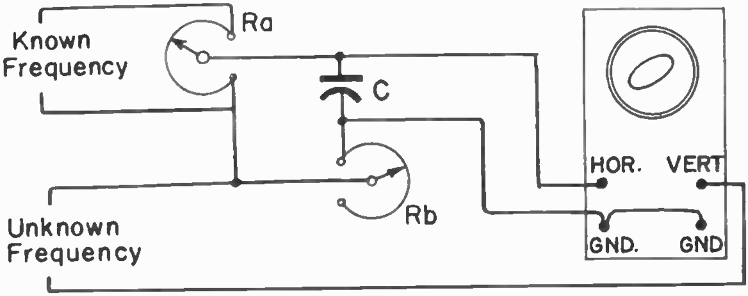


Fig. 19.—A phase-splitting circuit used for frequency comparisons.

For ratios greater than 10 or 12 to 1 the counting is made easier by using a phase splitting circuit which will make the trace pattern into a circle or an ellipse. One phase-splitting circuit is shown by Fig. 19. Resistor *Ra* may be a potentiometer of the volume control type having maximum resistance of 10,000 to 20,000 ohms, *Rb* may be a similar type having maximum resistance of about 50,000 ohms, and capacitor *C*, of the fixed

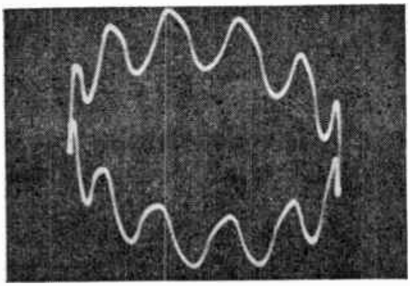


Fig. 20.—Frequency ratio of 12 to 1.

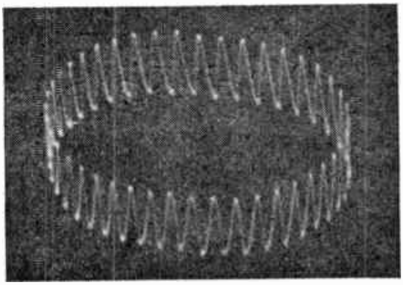


Fig. 21.—Frequency ratio of 43 to 1.

type, may have capacitance of 0.1 to 1.0 mfd. Adjustment of the two potentiometers, and of the gain controls on the oscilloscope, will allow making the trace pattern of elliptical or circular shape on the screen.

A pattern showing a frequency ratio of 12 to 1 is pictured in Fig. 20, and one showing a ratio of 43 to 1 is pictured in Fig. 21. The ellipse or circle will rotate so long as one frequency is a fractional multiple of the other, making one complete revolution per cycle of difference between the frequencies. When the multiplier is a whole number, or when one frequency is divisible into the other with no fractional remainder, the pattern will remain stationary.

The patterns formed by applying alternating potentials to both the horizontal and vertical inputs of the oscilloscope are called Lissajous figures or curves. The name is pronounced as though spelled lee-sah-zhoo, with the principal accent on the middle syllable.

Phase Shift.—When one alternating potential is connected to the horizontal input and a second alternating potential to the vertical input of the oscilloscope the trace will be a straight line if the two potentials are in phase, and will be a straight line also if they are in opposite phase or have a phase difference of 180°. The tilt of the line will depend on the relative amplitudes of the applied potentials and on the adjustments of the two gain controls.

If the two applied potentials are out of phase, but are not in opposite phase, the trace pattern will be an ellipse whose axes have slopes dependent on the relative amplitudes of the alternating potentials.

Phase Inversion.—It is a well known fact that when a signal or other potential applied between grid and cathode of an amplifying tube makes the grid more negative, the potential at the plate becomes more positive as measured with reference to the cathode. This is the action known as phase inversion in an amplifier stage. The phase of the signal is inverted, which means that the tops and bottoms of the wave are interchanged.

Fig. 22 shows a trace taken between control grid and cathode (or chassis ground) of an amplifier tube. The waveform is purposely distorted to allow distinguishing between top and bottom of the wave. Incidentally, this distortion was caused by insufficient plate voltage on the amplifier tube preceding the one from which traces were taken. Fig. 23 shows the signal in the plate circuit load. Here the cut off side of the wave is at the bottom, while in the grid circuit of the same tube the flattened side of the wave is at the top. The phase of the signal is inverted in passing through the tube.

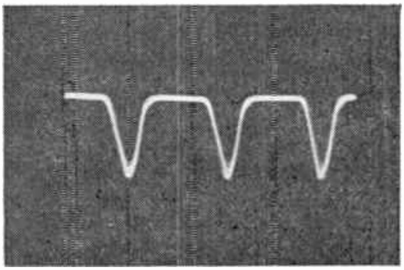


Fig. 22.—Phase observed in control grid input.

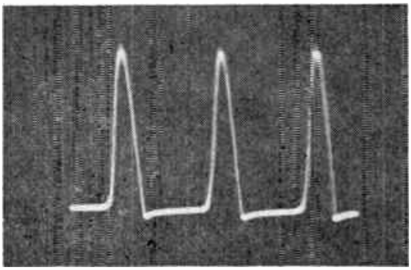


Fig. 23.—Phase inverted in plate circuit load.

Grid and plate waveforms are checked by using the internal sweep, adjusted to show several cycles of the signal, with the vertical input post of the oscilloscope connected through a half-megohm resistor to the tube grid and then to the plate. The vertical gain control is used to keep the vertical heights of the two traces on the screen. A check of this general type sometimes is made on the inverter tube of a resistance-coupled push-pull amplifier. The phase at the plate of the inverter tube should be opposite to the phase at the plate of the other push-pull amplifier tube of the pair. Such a check shows also whether the amplitudes of the two plate signals are equal, or nearly so, as they should be.

Using a Frequency Base.—Most of the tests so far described have been made with a linear time base supplied by the internal sweep oscillator. With this type of base the left-hand side of a trace represents a certain instant of time. The lapse of time then proceeds toward the right; every point toward the right representing an instant of time later than at point on the left, but earlier than those farther to the right.

Now we shall proceed to the use of what may be called a frequency base. Instead of horizontal distances on the trace pattern representing time intervals they will represent changes of frequency. At the left will be the lowest frequency being employed. Frequency will increase toward the right, and at the right-hand side of the trace will exist the highest frequency being employed. Thus we may observe changes of potential as they are caused by changes of frequency.

One of the most familiar of such trace patterns would be that showing a resonance curve, as in Fig. 24. Here the potential across the resonant circuit is small at frequencies well below the resonant frequency, increases to maximum at the resonant frequency, and decreases again at frequencies above resonance. The resonant frequency is in the center of the pattern, lower frequencies are toward the left and higher ones toward the right.

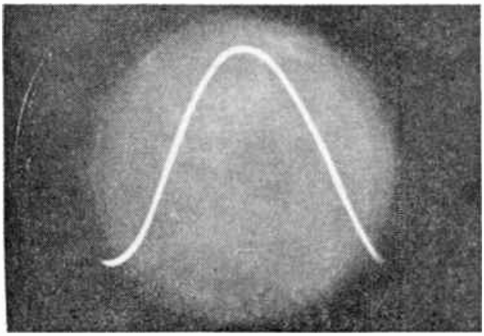


Fig. 24.—Resonance curve produced by using a frequency base.

For tests with the frequency base we require a frequency-modulated signal generator. The output of such a generator may be set for any frequency in the intermediate, standard broadcast, or short-wave bands. Then the frequency shift, frequency modulation, or frequency deviation may be adjusted for any value from a few kilocycles up to several hundred kilocycles. For example, were the main frequency dial to be set at 1,000 kilocycles and the deviation set for 20 kilocycles, the frequency would vary periodically between 980 kc and 1,020 kc. Starting from the 1,000-kc frequency, which may be called the center frequency or the resting frequency, there are downward deviations of 20 kc, ending at 980 kc, and upward deviations of 20 kc, ending at 1,020 kc.

When the output of the frequency-modulated generator is applied to the antenna, to the converter signal grid, or to any other point in a receiver to which a generator ordinarily is connected, there will be fed into the receiver a band of frequencies varying at regular intervals from a value equal to the center frequency minus the deviation through to a value equal to the center frequency plus the deviation.

The generator frequency ordinarily is made to pass through the entire band at a rate of 60, 400, or 1,000 times a second, although any other deviation rate may be used. This is saying that the deviation may occur at rates such as 60 cycles, 400 cycles, or 1,000 cycles per second, or at some other selected rate.

When the vertical input of the oscillograph or oscilloscope is connected to some plate circuit in the r-f or i-f system, or to any point carrying r-f or i-f signals, as shown by Fig. 25, the trace

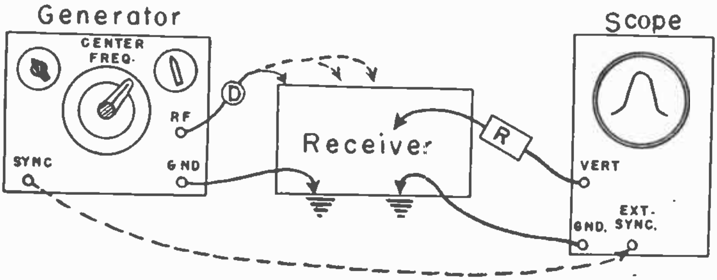


Fig. 25.—Connections for a frequency-modulated signal generator.

will show variations of output potential throughout the band of frequencies being covered by the generator signal.

The internal sweep oscillator is used, being adjusted to the rate of deviation, which has been mentioned as most often being 60, 400 or 1,000 cycles per second. If the signal generator has a post or jack marked *Sync* or something equivalent, this post is connected to the external sync post of the oscilloscope, as shown by a broken line, and the oscilloscope is set for external synchronization. This keeps the horizontal sweep rate the same as the deviation rate in the generator. Otherwise the internal synchronization may be used. Keep in mind that the horizontal sweep frequency is set for the rate at which the r-f or i-f frequencies swing through their band; it is not set for either the r-f or i-f center frequency, nor is it set for the deviation frequency which usually would be something between 10 and 200 kilocycles.

The deviation frequency always should be somewhat greater than the highest audio frequency which the receiver should handle. If, as often is the case, the highest audio frequency is 5,000 cycles then the deviation must be more than 5,000 cycles and usually would be 10,000 cycles. With high-fidelity receivers whose audio response may go to 15,000 cycles the deviation frequency should be at least 20,000 cycles. These deviations are for standard broadcast receivers.

Always keep the sync amplitude control of the oscilloscope as low as will hold the trace stationary on the screen, thus avoiding distorted traces.

Visual Alignment.—Although the oscilloscope or oscillograph, in connection with a frequency-modulated signal generator, may be used for examining all of the important characteristics of all types of resonant circuits, the most common use in radio servicing is for alignment of r-f, oscillator, and i-f stages of receivers. The oscilloscope and f-m generator are used for alignment of both amplitude-modulated and frequency-modulated receivers. Instructions immediately following are with reference to alignment of amplitude-modulated receivers in particular.

To begin with there should be noted the relations between the frequency setting of the sweep oscillator of the oscilloscope and the number of resonant curves as well as their arrangement on the trace pattern appearing on the screen.

The frequency from the signal generator changes from the lowest to the highest frequency, then from the highest back to the lowest frequency, and keeps this up at the rate which usually is 60, 400 or 1,000 cycles per second. One cycle of this frequency deviation may be considered as including all the changes from lowest to highest frequencies and back again.

Let's assume, merely for purposes of illustration, that the deviation rate is 60 times per second, or at a frequency of 60 cycles per second, also that the center frequency is the common intermediate frequency of 456 kc, and that the deviation frequency is 30 kc below and above the center frequency. As shown at the left in Fig. 26, one resonance curve will be formed during the increase of frequency from 426 to 486 kc, which extends from 30 kc below to 30 kc above the center frequency of 456 kc. A second resonance curve will be formed during the decrease of frequency from 486 kc back to 426 kc. The two curves are formed because the height of the trace represents potential in the resonant circuit, the potential is proportional to frequency, and whether the frequency is changing one direction or the other makes practically no difference in the potentials produced.

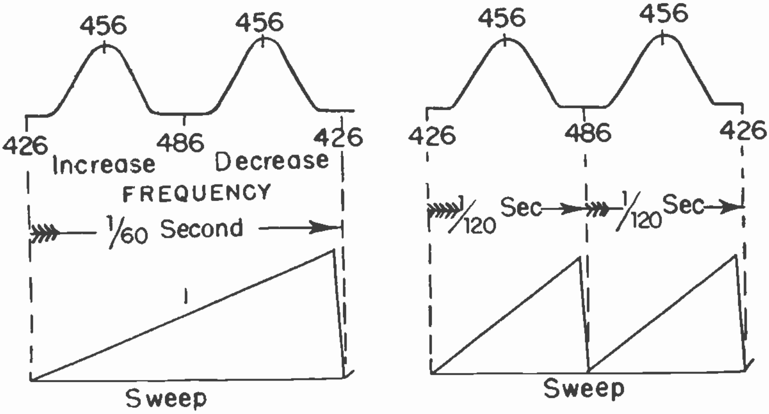


Fig. 26.—Relations between number of resonance curves on the screen and the sweep frequency.

If the horizontal sweep frequency is set at 60 cycles per second, and synchronized at this frequency as represented in this diagram, the two resonance curves will be formed during each horizontal sweep of the beam and the two will appear on the screen at the same time. Such a trace is shown by Fig. 27. The two curves are not identical in form, because there is some difference in the response or in the gain of the same circuit when frequency is increasing and when it is decreasing, but the two curves are very nearly alike when alignment adjustments are correct.

Supposing now that the sweep frequency is doubled, or is made 120 cycles per second so that each sweep takes only 1/120 second.

Then we have the condition shown at the right in Fig. 26. The resonance curve for increasing frequency will be formed during one sweep, and the curve for decreasing frequency will be formed during the following sweep, and this will continue. The two curves are traced and retraced so rapidly that we see them as existing together on the screen, and they will be superimposed on each other. Fig. 28 shows two superimposed resonance curves formed by using a horizontal sweep frequency equal to twice the deviation rate.

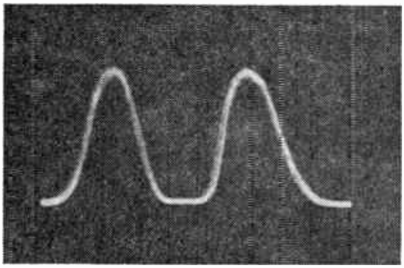


Fig. 27.—Two resonance curves formed during one horizontal sweep.

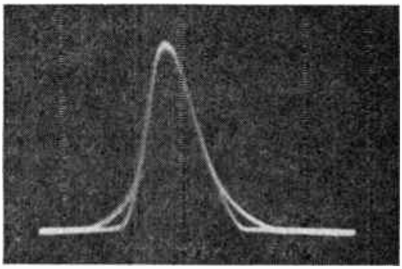


Fig. 28.—Resonance curves superimposed by doubling the sweep frequency.

If we wish to examine either of the separate resonance curves, either the one for increasing frequency or the one for decreasing frequency, the one desired curve may be centered on the screen by using the horizontal position control, and may be enlarged by

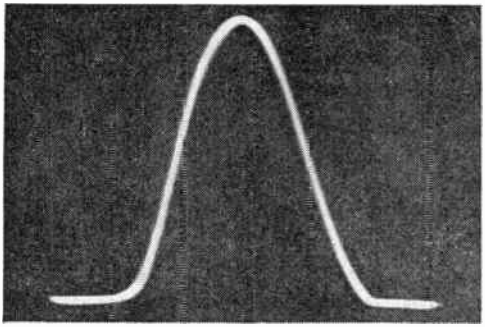


Fig. 29.—A single resonance curve enlarged and centered on the screen.

using the horizontal and vertical gain controls. Fig. 29 shows just such a single resonance curve. This particular curve was photographed after making all alignment adjustments, and shows the output from the detector with the input of the signal generator applied to the signal grid of the converter tube in the receiver. Oftentimes it is desirable to examine separately either one or both of the resonance curves when checking on causes for poor waveform due to overloading, regeneration and undesired oscillation, or other causes.

The deviation frequency, whether 10 or 100 kilocycles, has no important effect on the trace patterns just so long as the deviation is more then enough to cover the band of frequencies passed or amplified in the apparatus being tested. The greater the deviation frequency the narrower will be the resonance curves and the greater will be the flat horizontal trace lines in between the curves. The flat horizontal lines indicate frequencies at which there is zero or minimum gain.

The trace formed on the screen shows the audio-frequency voltage obtained through the detector from the modulated r-f or i-f signal coming from the signal generator. Therefore, the vertical input of the oscilloscope must be connected to the output of the detector. With a diode detector the vertical input is connected to the ungrounded end of the detector load resistor or to the ungrounded end of the volume control, with the oscilloscope ground connected to the receiver chassis ground.

If the detector is not a diode, and is resistance coupled to the following a-f amplifier tube, connect the vertical input to the detector plate, using a series blocking capacitor of about 0.25 mfd and of suitable voltage rating in case the detector plate voltage is higher than permissible for the oscilloscope input.

If the detector is not a diode and is coupled through a transformer or a choke (impedance coupling) to the following a-f tube the inductance in the detector plate circuit is to be replaced with a resistance. This is done by connecting a resistor of from 20,000 to 50,000 ohms from detector plate to B+, then either disconnecting one end of the transformer primary winding or one end of the coupling choke, or else bypassing the primary or the choke with a capacitor of 0.5 to 1.0 mfd. In all cases the vertical input of the oscilloscope is connected to the detector plate.

The high side of the f-m signal generator is connected through a fixed capacitor of about 0.005 mfd capacitance to suitable points in the receiver, with the generator low side to the receiver chassis ground, using a blocking capacitor in this ground lead for ac-dc receivers.

For alignment of the last i-f transformer the generator high side may be connected to the control grid of the preceding i-f amplifier tube. Then, for alignment of the next transformer toward the converter the generator high side is connected to the control grid of the i-f tube ahead of this transformer, and so on until the generator is connected to the signal grid of the converter tube. The main tuning dial of the signal generator is set for a center frequency which is the intermediate frequency of the receiver being aligned. If an error is made in this setting the i-f transformers will be aligned to the frequency at which the generator actually is set.

The signal generator output must not be amplitude-modulated at the same time that it is frequency-modulated, as by incorrect settings of generator controls. The effect of amplitude modulation on a trace produced with frequency modulation is shown by Fig. 30.

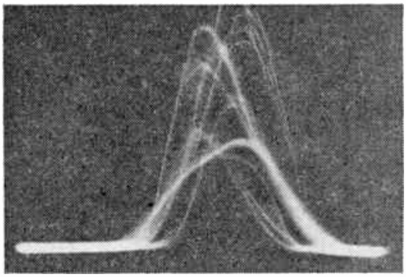


Fig. 30.—Effect of amplitude modulation with frequency-modulated input.

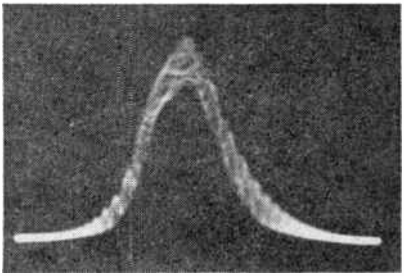


Fig. 31.—Effect of interfering station with frequency-modulated input.

The tuning dial of the receiver should be set at a point where no broadcast signal may be received. The effect of a received broadcast signal on the trace produced by frequency modulation from the signal generator is shown by Fig. 31. The likelihood of such interference may be lessened by keeping the volume control turned low, also by grounding the antenna post of the receiver, and, if necessary, by grounding the stator plates of the oscillator tuning capacitor to the receiver chassis or to the rotor plates. These methods may be used during i-f alignment.

The resonance curves pictured in this chapter are what may be called right side up. That is, the flat horizontal base line is at the bottom, with the curve rising to its peak or peaks and falling again above the base line. The polarity of the vertical input and amplifier in the oscilloscope may be such that all of the curves will be upside down, with the base line at the top and the curves extending downward. It is just as easy to make alignment adjustments with the curves in one direction, or polarity, as in the other. The upside down pattern results when the upward direction on the screen corresponds to positive, because the ungrounded end of a diode detector load resistor or volume control is negative with reference to its grounded end, and the vertical input is connected to this negative point.

When commencing any alignment adjustment it is instructive to use a sweep frequency which is a half, a third or even a quarter of the deviation rate in order to see several pairs of resonance curves at the same time and note any apparent irregularities. Then the sweep frequency may be changed so that it is equal to the deviation rate, so that the curve for increasing frequency and the one for decreasing frequency may be observed while separated. Fig. 32 shows two separate curves produced in this manner. Both curves are, of course, produced by the same circuit. They are of the double-hump type, because the trans-

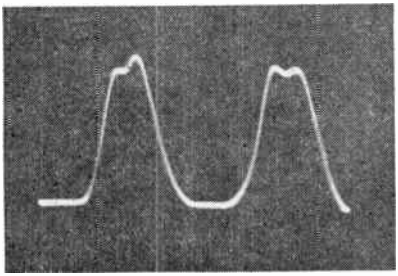


Fig. 32.—Two double-hump curves produced in a single horizontal sweep.

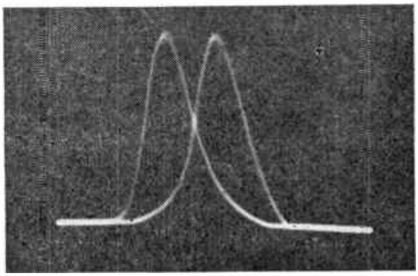


Fig. 33.—Effect of different frequencies in generator and receiver tuning.

former being aligned in this case was very closely coupled or over-coupled. The differences between peak heights are due to differences in gain with frequency increasing and decreasing.

Finally the sweep frequency may be made equal to twice the deviation rate in order to superimpose the two curves formed during each cycle of frequency change. Alignment usually is carried out with superimposed curves.

If the two superimposed curves do not coincide, but remain off-set to a greater or less extent, as in Fig. 33, either of two conditions is indicated. First, the receiver has been aligned to some frequency other than that assumed, and at which the signal generator has been set. Second, the receiver is aligned to the correct frequency but the generator is furnishing a different center frequency. The actual center frequency is that which occurs where the two curves intersect near the center of the trace pattern. If the generator frequency is incorrect, the curves will coincide when it is readjusted to match the frequency at which the receiver is aligned. If the generator frequency is correct and the receiver incorrectly aligned the curves will coincide when alignment is corrected. Bringing the curves together usually is a matter of adjusting the transformer primaries. The height of the separate curves or of the two when superimposed depends more on making a correct alignment of transformer secondaries in most receivers.

The object of the alignment is to so adjust the primaries and secondaries that the superimposed curves appear about as shown by Fig. 29 as to form, and so that there is maximum height of the curves for any given settings of generator output and oscilloscope vertical gain control. It is well to commence the work with a generator output low enough so that there can be no overloading of amplifier tubes, and with the vertical gain control only high enough to give traces of clearly recognizable shape. The height should increase as alignment proceeds, showing more gain. The vertical gain control may be reduced to keep the trace on the screen.

In order to keep the curves fairly well centered on the screen it is well to begin work with the sync amplitude control about a quarter of the way up on its scale, then make a careful adjustment of the sweep fine control or vernier to hold the curve in position. Thereafter slight variations of the sync amplitude will keep the curve and the base line in position.

If the deviation frequency of the generator, above and below the center frequency is continuously adjustable it may be set so that the flat base between curves just barely disappears. The deviation frequency then is approximately the same as the effective band pass of the amplifier. This is done, of course, with the sweep frequency equal to or less than the deviation rate. If it is impossible to obtain any horizontal base line between curves the effective band pass of the amplifier is greater than the deviation frequency of the generator. If there is a continuous straight horizontal base line all the way across all the curves it indicates that there is a great difference between the center frequency of the signal generator and the intermediate frequency to which the amplifier is adjusted.

After the i-f transformers are aligned the generator input may be shifted to the antenna post of the receiver for alignment of trimmers in the antenna coupling, the r-f stage, and the oscillator of the receiver. The generator frequency is first set near the top of the standard broadcast band, or any other band being used, and the receiver tuning dial is set at the same frequency. For adjustment of an oscillator padder, set the generator and receiver to a frequency near the bottom of the band being used. Alignment of trimmers and padders in these front end stages is made to obtain the same form of curve, like the one of Fig. 29, as obtained by alignment of the i-f transformers.

It is well to obtain experience with visual alignment by first going through all of the operations while using a receiver which has been satisfactorily aligned and which is in working order. If the receiver to be worked upon is not well aligned it may be easier to make the preliminary alignment with an amplitude-modulated signal generator and an output meter in the usual manner, then go over all of the alignment adjustments by the visual methods which have been explained. Usually you will be rather astonished at the lop-sided and off-center curves shown by the oscilloscope after making a presumably perfect alignment with the output meter method. The results obtained with visual alignment, especially on high quality receivers, usually are well worth the effort of using this method.

F-m Receiver Alignment.—The general method of aligning the i-f transformers of a frequency-modulation receiver is no different from the method used with amplitude-modulation receivers, as has been described in preceding pages.

The signal generator high side is connected to the signal grid of the converter tube, or to the control grid of any one of the i-f tubes, through a fixed capacitor of about 0.005 mfd capacitance. The generator center frequency is adjusted to the intermediate frequency used by the receiver. This intermediate frequency usually is 10 or more megacycles in receivers of recent design. Because f-m receivers must be designed to handle or amplify bands of frequencies much wider than a-m receivers the frequency deviation should be set for 100 or more kilocycles. A 200-kc deviation is quite commonly employed. The generator low side is connected to the chassis ground of the receiver, always using a series blocking capacitor of voltage rating higher than the line voltage with ac-dc receivers. The receiver dial is set at a point where no broadcasting station can be received. The antenna should be disconnected.

If the receiver has a limiter tube operated with a grid resistor for bias the vertical input of the oscilloscope is connected to the limiter grid or to the grid end of the grid resistor through a resistor of 0.1 to 0.5 megohm resistance. The oscilloscope ground is connected to the receiver chassis ground. If the signal generator has a synchronizing output for the deviation rate it is connected to the external sync post of the oscilloscope and the sync selector is set for external synchronization. Otherwise the internal synchronization of the oscilloscope may be used.

The i-f transformers are aligned just as previously described for a-m receivers. Curve shapes and heights or amplitudes should be like those previously shown for i-f alignment. Two superimposed curves are obtained with a sweep frequency twice the deviation rate. Two separated curves will appear with a sweep frequency equal to the deviation rate, and two sets or pairs of curves will be seen when the sweep frequency is half the deviation rate.

For alignment of the discriminator transformer the signal generator high side is connected to the converter signal grid, where it usually is connected at the end of i-f alignment. The generator remains set at the intermediate frequency and with the same deviation as for i-f alignment.

The vertical input of the oscilloscope may be connected to the cathode or ungrounded side of the discriminator load resistors, which is the side connected through the filter system to the volume control. When connected here there should be a resistor of 0.1 to 0.5 megohm in series. With most receivers the vertical input may be connected to the ungrounded side of the volume control potentiometer, with no resistor in series.

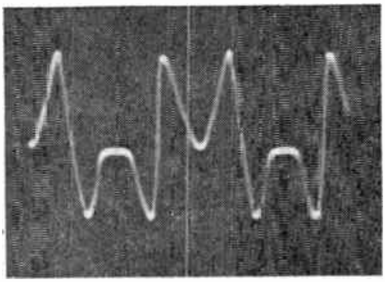


Fig. 34.—Two complete cycles of discriminator output.

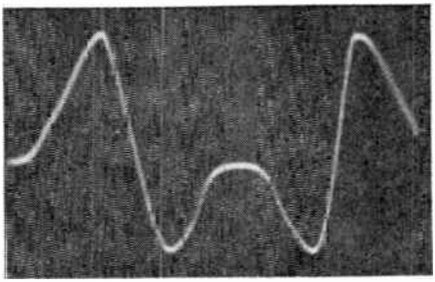


Fig. 35.—One cycle of discriminator output.

If the sweep frequency now is set at half the deviation rate, as at 30 cycles when the deviation rate is 60 cycles per second, there will appear on the screen two complete cycles of audio voltage changes, as shown by Fig. 34. A single complete cycle, as in Fig. 35, will appear when the sweep frequency is equal to the deviation rate. Alignment of the discriminator transformer usually is carried out by using a sweep frequency of twice the deviation rate. Then a half-cycle of deviation including a full upward sweep of audio voltage and the other half-cycle including the downward sweep will be superimposed with the two voltage traces crossing about as shown by Fig. 36.

In making such traces as these with a deviation frequency of about 200 kc we are using a deviation which goes far beyond the maximum which will occur in f-m broadcast signals, which is 75 kc. With frequency signal deviation no greater than 75 kc the audio voltages produced in the receiver will extend no farther than the straight portions of the crossed lines above and below their point of crossing.

The primary of the discriminator transformer is aligned or adjusted to secure the longest straight parts of the crossed curves while at the same time keeping the straight portions of the lines of nearly equal length. The secondary of this transformer is adjusted to bring the point of crossing midway along the straight parts of the curves. This adjustment insures that the transformer is tuned to the center frequency. It will be necessary to work back and forth between primary and secondary adjustments to

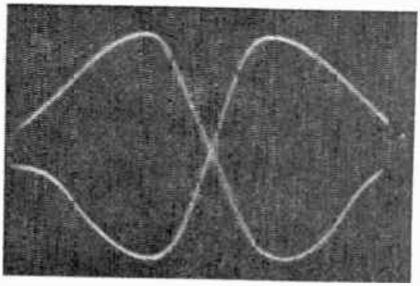


Fig. 36.—The crossed curves used for discriminator aligament.

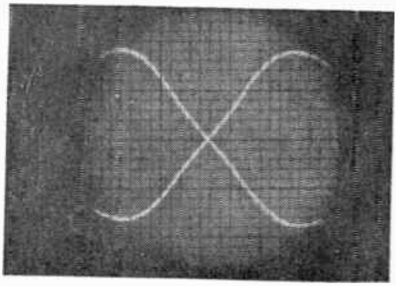


Fig. 37.—Curve shapes may be observed with the graph screen.

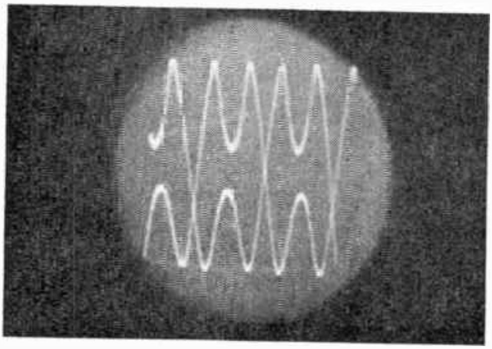


Fig. 38.—Effect of 45-cycle sweep with 60-cycle deviation rate.

obtain a symmetrical pattern meeting the requirements of long straight portions crossing midway of their length.

In checking the general form and proportions of the crossed curves it is convenient to use the cross section transparency in front of the cathode-ray screen, as has been done in Fig. 37.

Kinks, blurring of traces, and other irregularities in waveform due to incorrect voltages and other faults in the receiver stages will show up on the discriminator curves just as on the curves taken during i-f alignment. This is true also of interference from broadcasting stations and of using amplitude modulation in the generator signal.

Sweep frequencies other than those which are equal to the deviation rate, or else half or double this rate, will give peculiar patterns which sometimes may appear useful although they should not be used for alignment. For example, using a sweep frequency which is three-fourths of the deviation rate will give a trace pattern such as shown by Fig. 38, where there are several crossings of discriminator curves.

REVIEW QUESTIONS

1. Is it desirable to use a large or small synchronizing voltage, to turn the sync amplitude control high or low?
2. Mention the points in an audio-frequency amplifier between which the oscillo-input may be connected for checking amplifier performance.
3. When connecting the observed input potential directly to the oscilloscope plates is the advantage in greater deflection, less distortion, or what?
4. For most observations is the sweep frequency made less than the observed frequency, equal to the observed frequency, or greater than the observed frequency?
5. When tracing hum or ripple voltage the 60-cycle line supply and a half-wave rectifier to what frequency should the sweep oscillator be adjusted?
6. State the reason for using a phase-splitting circuit for frequency comparisons. Is this circuit necessary for observing low or high frequencies?
7. During visual alignment is it desirable to commence by observing several pairs of resonance curves in one trace, or only a single pair?
8. During visual alignment of a discriminator what is the usual relation between sweep frequency and deviation rate?

INDEX