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ELECTRONIC COMPONENT TESTS & MEASUREMENTS

by ROBERT G. MIDDLETON

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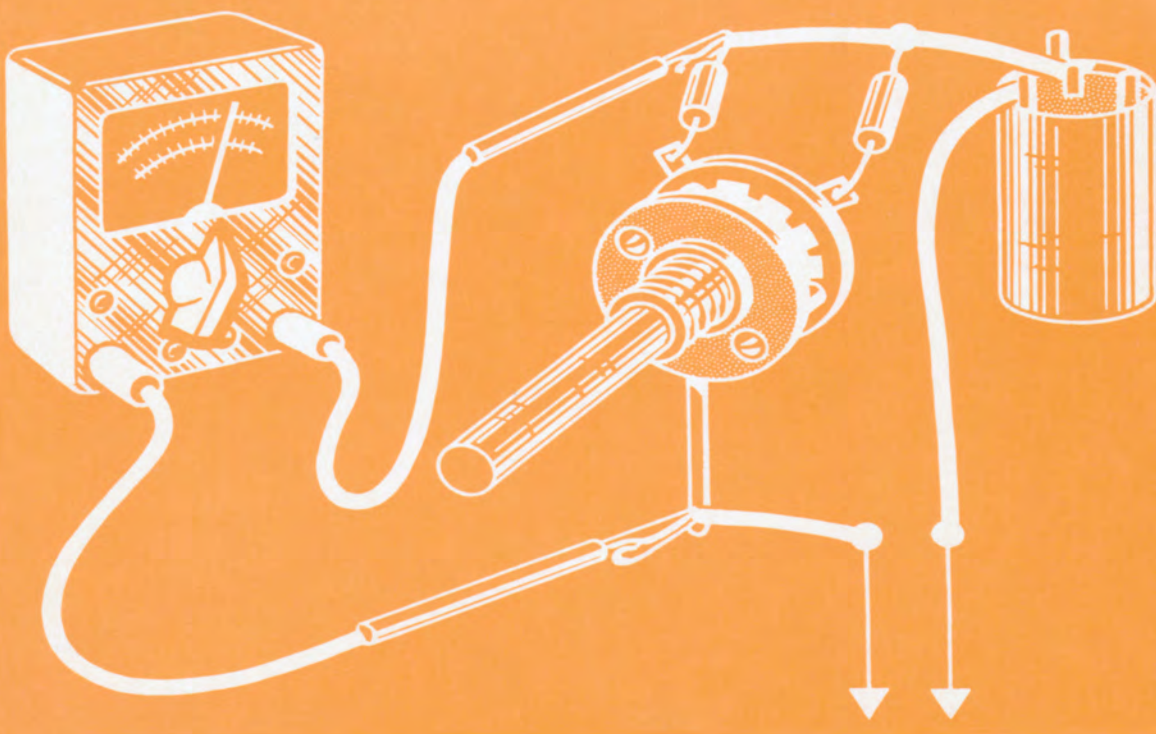

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by ROBERT G. MIDDLETON

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ELECTRONIC COMPONENT
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Preface

Most electronic components can be classified as resistive, capacitive, or inductive in nature. There is no such thing as a pure resistance, capacitance, or inductance; these are theoretical concepts which are never fully realized in actual practice.

It is not the purpose of this book to belabor these points—quite the contrary, the component tests discussed herein ignore all such "fine points," except when they must be considered in order to evaluate test results realistically.

Much time (generally wasted in trial and error experimenting) can be saved by properly testing components. This book furnishes the necessary theoretical knowledge and procedures and techniques for testing practically any type of electronic component.

Test setups are described for resistive, capacitive, inductive, high-frequency, and gaseous components. Also included are test procedures for components with distributed parameters, used when lumped parameters cannot be assumed.

The tests are as simple as it is possible to make them, and the most sophisticated test instrument needed is an oscilloscope. At times, even the simplest testing of components will tax your electronic know-how to the utmost, but this text avoids complexities as much as possible. However, for routine component tests, in which a few of the ordinarily hidden complexities are inescapable, it is hoped that explanations of these test procedures will serve to minimize their difficulties and thus make life more simple for the man at the test bench.

BOB MIDDLETON

October, 1963

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SECTION 1

Resistive Components

All electronic components are resistive to some extent. However, resistive components as such are defined as those in which the resistive parameter is predominant. Typical resistive components are carbon-composition and wirewound resistors, potentiometers, vacuum tubes, crystal diodes, transistors, thermistors, voltage-regulator tubes, neon bulbs, thyratrons, and audio transformers. Fixed resistors and potentiometers are obviously resistive components. On the other hand, beginners tend to overlook the fact that a vacuum tube is also a resistive component. The distinction is simply this: a composition resistor is a passive device, whereas a vacuum tube is an active device.

VACUUM TUBES

A vacuum tube is classified as a resistive component because the heater has resistance and in addition, a vacuum diode has a plate resistance in typical operation. The diode may have a plate resistance from 600 ohms to infinity, depending on the plate voltage that is applied. A triode also has a plate resistance, and, in addition, it has a grid-input resistance that is very high unless the tube is defective. A tetrode also has a screen-grid resistance. These resistances are of basic concern in tube testing. Of course, a tube also has capacitance; a vacuum diode has plate (interelectrode) capacitance, and a triode has grid-input (interelectrode) capacitance. The capacitance parameters are less prominent than the resistance parameters in most situations; hence, a vacuum tube is usually regarded as a resistive component.

SEMICONDUCTORS

Transistors, likewise, are essentially resistive components. A transistor can be regarded in the first analysis as two crystal diodes connected back-to-back. Note that the term *transistor* implies the words *transfer* and *resistance.* These resistances and their variations under different applied voltages are of basic concern in transistor testing. Transistors also have *junction* capacitances; however, the junction capacitances are usually of secondary significance, and the transistor is regarded as a resistive component.

GASEOUS COMPONENTS

Crystal diodes are essentially resistive components. A crystal diode has junction capacitance that is ordinarily neglected. However, you will find some applications in which the junction capacitance is of basic concern, and the diode resistance is neglected. That is, the junction capacitance is utilized as an electronic capacitor, inasmuch as the capacitance varies with the applied voltage. Such a semiconductor capacitor may be used as an FM modulator in a sweep-frequency generator. In this case, the crystal diode is not regarded as a resistive component, but as a capacitive component.

Gaseous components are classified as resistive because this parameter is usually of basic concern in applications and test procedures. A neon bulb has a practically infinite resistance or a low resistance of a few hundred ohms, depending upon the applied voltage. A voltage-regulator tube is a resistive component in the same general class as a neon bulb; however, the design of voltage-regulator tubes is elaborated for the purpose of maintaining as constant a voltage drop as possible across the anode resistance in the conducting state. Thyratrons are resistive components in which the anode resistance has two discrete values (extremely high and very low) which can be switched from high to low by the grid-driving voltage.

TRANSFORMERS

Beginners often challenge the classification of an audio output transformer, for example, as a resistive component. Because the conventional symbol shows two coil windings, the beginner assumes that the transformer has an inductive characteristic. This misconception, in the case of an audio output transformer, stems from a limited knowledge of electronic theory. In normal application, the transformer is loaded by a resistive utilization device, and its purpose is to match the source resistance (such as the plate resistance of a tube) to the load resistance. Now, unless the transformer is defective, the load resistance will be reflected back to the primary terminals as a much higher and almost pure AC resistance—the tube does *not* "see" an inductive load. Hence, in the nature of things, an audio output transformer must be logically classified as a resistive component.

AC AND DC RESISTANCE

The newcomer is certain to confuse AC resistance with DC resistance. As a matter of fact, their values are often widely different. Consider an ordinary tuning coil in a broadcast receiver—its DC resistance is very low, but at 1 mc its AC resistance will be much greater. This difference is due to skin effect in wires at higher frequencies, which forces the RF current out of the center of the wire and increases the apparent resistance. Furthermore, there are eddy-current losses in the wire, which imposes loss and increases the apparent resistance as the operating frequency is raised.

With this introduction to the subject of resistive components, the technical details of resistance must now be considered briefly, along with a breakdown into the chief forms of resistance and the way in which Ohm's law applies to each.

POSITIVE, NEGATIVE, AND ZERO RESISTANCE

Resistance occurs chiefly in three forms: *positive, negative,* and *zero.* An ordinary wirewound resistor exemplifies positive resistance. Negative resistance is found in oscillators, some types of amplifiers, and in all regenerative circuitry. The simplest negative-resistance component is the tunnel diode; but even an ordinary germanium diode, such as the 1N34, becomes a negative-resistance component when it is suitably biased. Zero resistance often is unrecognized; if you increase the back bias on a germanium diode, there is a critical voltage at which the diode has zero resistance—on one excursion from this point the diode has positive resistance, and on the other excursion, it has negative resistance.

Zero Resistance in the Laboratory

Sophisticated types of scientific equipment (including certain computer devices) utilize a type of zero resistance called *super conductivity.* Many metals which have positive resistance at room temperature suddenly develop zero resistance near absolute zero (−273° C). In other words, some ordinary conductors can become superconductors at very low temperatures.

Resistance and Ohm's Law

Ohm's law holds for all forms of resistance. This law states that $I = E/R$. In this expression, R is positive, and the formula says that the positive resistance opposes current flow. Again, if a component has negative resistance, Ohm's law is written $I = E/-R$. This formula states that the negative resistance enhances current flow. Otherwise stated, negative resistance increases current flow, whereas positive resistance decreases current flow. Finally, if a component has zero resistance, Ohm's law is written $I = E/0$. The component neither opposes current flow nor enhances current flow. For example, if a current is started in a zero-resistance component, the same current theoretically will be found flowing in the component years later. Zero resistance then, can be compared to the absence of friction in a mechanical device.

The Meaning of Resistance

Resistance, as defined by Ohm's law, is basically a voltage/current ratio. A graphical presentation of positive resistance is shown in Fig. 1-1. This relation shows that the current flow doubles when the voltage is doubled. Of course, this is an ideal, theoretical relation that is not strictly true in practice. However, if you make this test with an ordinary 100-ohm, wirewound resistor, the relation will *seem* to be true. For many practical purposes, it can be said that a wirewound resistor is an ideal positive resistance. Although when substantial current is passed through the resistor, the electrical picture presented in Fig. 1-1 will be incorrect.

Coefficient of Resistance

Getting down to the practical details, it will be observed that the current flow does not exactly double when the voltage is doubled. When the current is made large enough to heat the resistor appreciably, this fact becomes quite obvious. Metals have a positive *temperature coefficient of resistance.* This means that their resistance *rises* when the temperature is *increased.* Fig. 1-2 shows the electrical picture of a 7-watt, 117-volt lamp. The E/I characteristic is curved. It rises fast at low voltage, and rises less rapidly at higher voltages for which the resistance is higher.

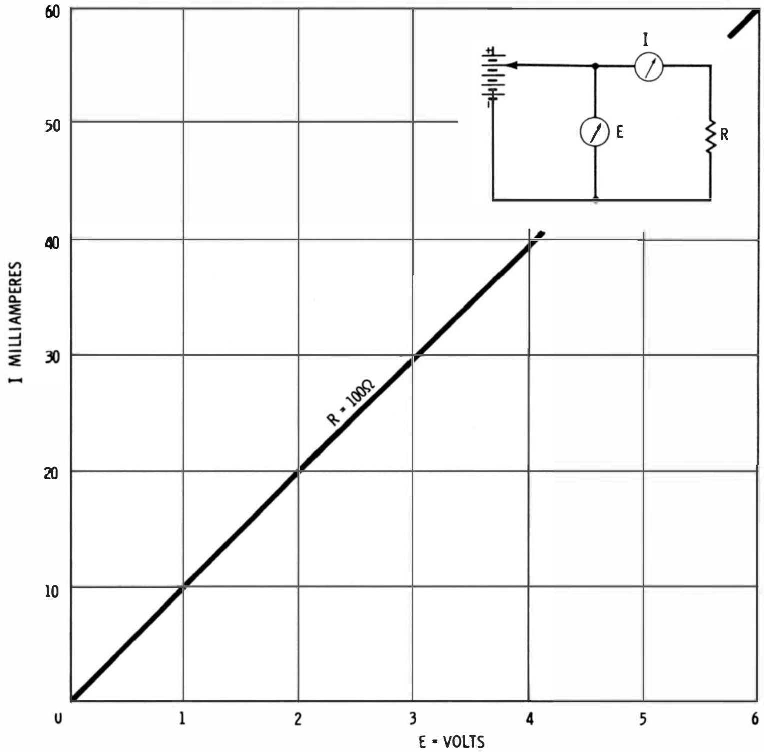


Fig. 1-1. An "electrical picture" of resistance.

Nonlinear Resistance

It follows that Fig. 1-2 depicts positive *nonlinear* resistance. You will find that a composition resistor is also nonlinear and that it has a positive temperature coefficient of resistance. If an ohmmeter is connected to a composition resistor as depicted in Fig. 1-3, and the pigtail is heated with a soldering gun, the pointer will creep up on the ohmmeter scale. But if the heat is removed and a chill spray is applied to the resistor, the pointer then creeps down the scale to its normal "cold" value. Of course, if the resistor is greatly overheated, it becomes damaged and does not return to its initial resistance value.

RESISTANCE TESTS

The temperature coefficient of composition resistors is controlled in production, and various types are rated, for example, for ¼, ½, or 1 watt of power dissipation. The power dissipated by a resistor is equal to I^2R, or E^2/R, watts. A composition resistor is customarily rated for a resistance change of less than 6% when operated at the full rated load. However, a thermally unstable resistor might change 30% in value from ambient to normal operating temperature. Moreover, its hot resistance can tend to drift up and down instead of stabilizing at an abnormally high value. In turn, associated trouble symptoms may be caused in TV receiver circuitry, such as rolling picture, fluctuating sound, loss of horizontal sync, variations in picture height, etc.

Testing For Thermal Stability

Hence, it can become necessary to check a suspected resistor for thermal stability, as well as its resistance value at an arbitrary, prevailing temperature. An out-of-circuit test can be made as depicted in Fig. 1-3. In addition to heating the resistor

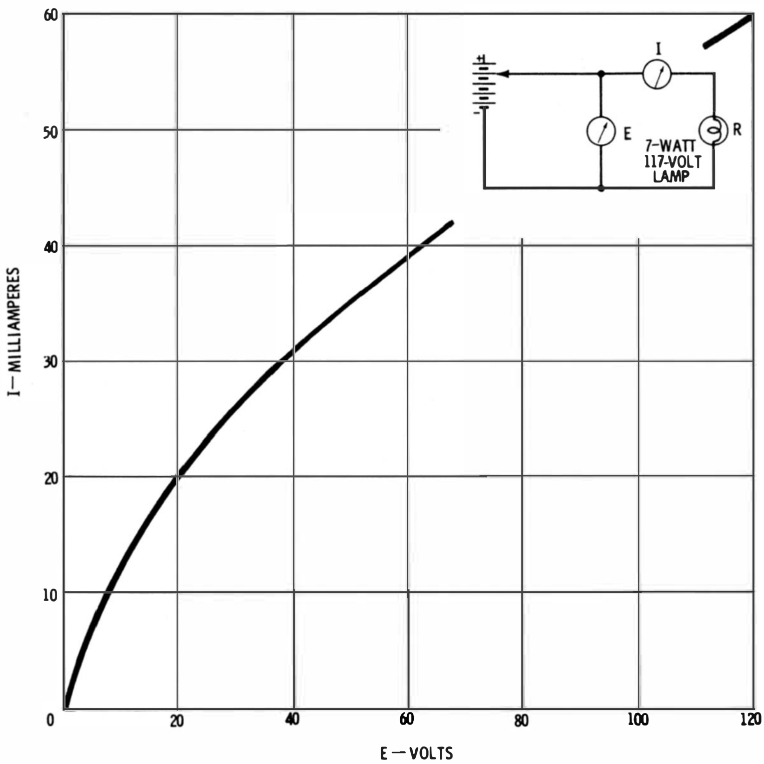


Fig. 1-2. An "electrical picture" of filament resistance.

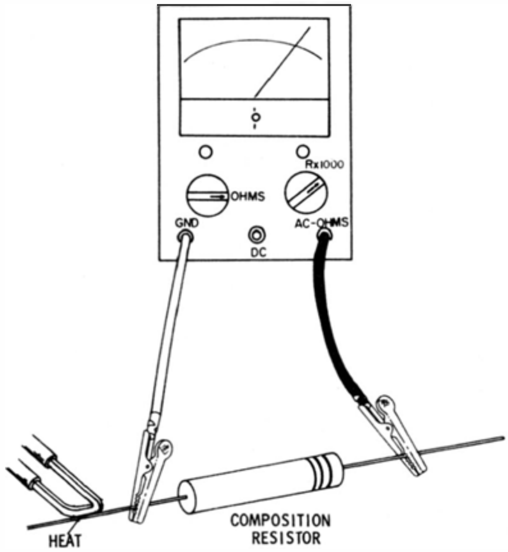


Fig. 1-3. Resistance increases with increase in temperature.

up to, or somewhat above, its normal operating temperature, it is also advisable to tap the resistor sharply while observing the ohmmeter reading as a mechanically unstable condition might be present.

Technicians commonly make in-circuit tests of resistors for thermal stability. In this case, the receiver or other device under test is used as an indicator, instead of an ohmmeter. For example, suppose that a picture-rolling symptom is to be localized. The grid resistors in the vertical-oscillator section are ready suspects. They can be heated with a soldering gun and then cooled with a chill spray, to see whether the rolling symptom is responsive. Potentiometers such as the vertical-hold control are equally suspected in such a case and can be tested similarly.

To summarize the foregoing, it is clear that because ohmmeter current does not overheat the resistor an ohmmeter is a practical instrument for measuring the nominal resistance values of wirewound and composition resistors. On the other hand, it is useless to use an ohmmeter to measure the resistance of a 1R5 tube filament because the ohmmeter current heats the filament substantially, and the current flow is unknown. Two different ohmmeters can be expected to read different values of filament resistance, and neither value is likely to agree with the rated resistance of the filament.

Resistance at a Point

It follows that the method depicted in Fig. 1-2 must be used to measure filament resistance. The rated voltage must be applied to the filament, and the current flow read for this applied voltage. To continue the previous example, a 1R5 tube has a rated filament-current flow of 0.05 ampere at 1.4 volts. Ohm's law states that the resistance is 28 ohms for this voltage and current:

$$R = E/I = 1.4/0.05 = 28 \text{ ohms.}$$

This is the resistance at the rated operating point and at some other operating point, the resistance value will be different. Far from being only an interesting theoretical fact, this has a very practical significance. In a series filament string, a tube that has higher than rated filament resistance will "rob" the other tubes. In the past, this has caused numerous "tough dog" service problems, and has resulted in the design of tube types which have closer tolerances on filament or heater resistance.

Operation of Series Heater String

Fig. 1-4 depicts a typical series heater string. Evidently, if all the tubes had comparatively high heater resistance, less than the rated 600-ma current flow would be measured in the circuit. However, if all tubes had comparatively low heater resistance, more than the rated 600-ma current flow would occur. Too little current produces a subnormal operating temperature —emission goes down, and the local oscillator might "drop out," for example. Again, too much current produces an excessive operating temperature that can shorten tube life.

If you suspect a bad tube in a series string, it can be easily localized with an AC voltmeter. For example, you would expect to measure 12 volts rms across V7 (Fig. 1-4), but if you measure a substantially higher voltage, the heater resistance is too high. In turn, you will find more or less subnormal voltages across the other heaters—provided that they are not far out of tolerance.

Tube testers of the mutual-conductance type often provide a filament-activity switch or equivalent to determine whether a tube will operate satisfactorily at reduced heater voltage. A G_m reading is made with the heater voltage reduced approximately 10%. If the pointer falls in the "bad" sector during the filament-activity test, many technicians reject the tube without question.

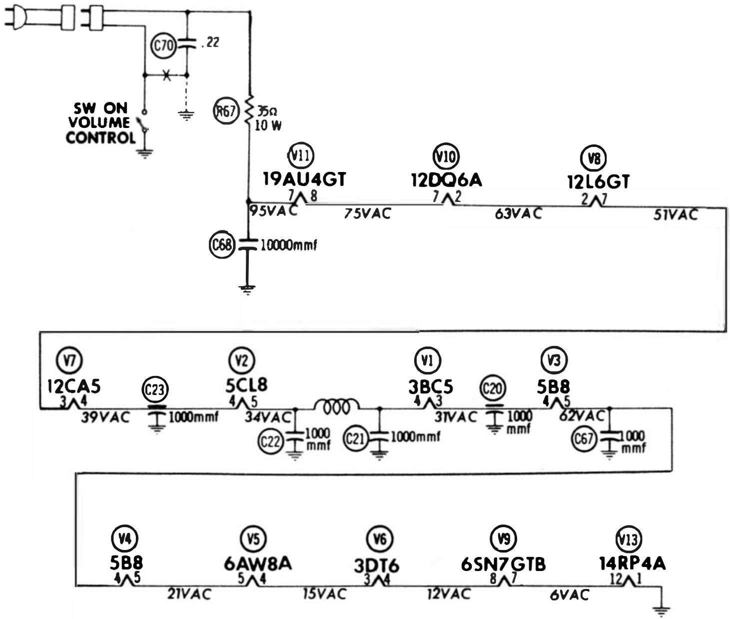
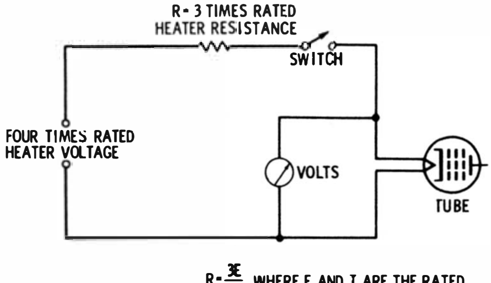


Fig. 1-4. A typical series heater string.

Heater Warm-Up Time

Since there is a thermal lag when the line voltage is suddenly applied across a series string, it is desirable that the tubes heat up at about the same speed. There is a heavy starting current surge, as implied by the curve in Fig. 1-2. Tube life is prolonged by controlled heater warm-up time. This is defined as the elapsed time for the voltage across the heater to reach 80% of rated value in the test circuit of Fig. 1-5. Note that the heater is energized through a series resistance having



$R = \frac{3E}{I}$ WHERE E AND I ARE THE RATED HEATER VOLTAGE AND CURRENT

Fig. 1-5. Test setup for checking heater warm-up time.

three times the rated heater resistance. The source voltage is four times the rated heater voltage.

The warm-up time can be measured with a watch having a sweep-second hand. It is the elapsed time from the instant the switch is closed to the moment that the voltmeter reads 80% of its final value. Note that the particular value of the warm-up time is not of significance in itself—the important consideration is whether all tubes in a certain heater string have approximately the *same* warm-up time. From previous discussion, it is clear that when one tube in a string has a comparatively slow warm-up time, it will cause abnormal voltages across other tubes in the string.

Although it is helpful to utilize tubes that have the same warm-up time, series strings are often protected also against the large starting-current surge (which still exists, although partially controlled) by use of tubes with controlled warm-up

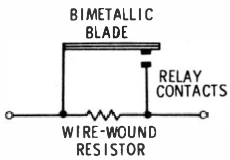


Fig. 1-6. Relay-type surge resistor.

time. This additional protection may be a series resistor having a negative temperature coefficient, as explained subsequently. Or, it may be a relay-type of surge resistor as depicted in Fig. 1-6. When connected in series with a heater string, the device provides a high initial resistance which is later reduced to a very low value as the bimetallic blade closes the relay contacts.

Test of Surge Resistor

To test this component, first measure the resistance of the wirewound resistor (Fig. 1-6) with an ohmmeter. When the device is cold, the contacts are normally open, and the reading should be about 100 ohms. If you observe a very high resistance reading, the wirewound resistor (or its terminal connections) is defective. Conversely, if the resistance is very low, look for welded contacts or foreign matter between the contacts.

It is more difficult to check out the bimetallic blade because its cold resistance is normally about 0.1 ohm. However, if you have an ohmmeter with an R × 0.1 range, you can easily check the resistance of the bimetallic blade. A high reading indicates a defective element—one of the blades might be fractured, or it could have a resistive connection to its fixed terminal. Finally, hold the relay contacts together, and measure the contact resistance; it should be zero as indicated on the R × 0.1 ohmmeter range. If the contact resistance is measurable, clean the contacts with fine emery cloth.

The question may be asked why the bimetallic blade has a normal cold resistance of 0.1 ohm. The reason for this value is that the relay contacts must be held closed by I^2R heating of the blade. Note that heat from the 100-ohm resistor closes the contacts initially. Then current flow is bypassed around the resistor by the bimetallic blade. Normal current flow dissipates sufficient heat in the 0.1-ohm resistance to warp the blade and keep the contacts closed.

NEGATIVE TEMPERATURE COEFFICIENT

Components with a negative temperature coefficient of resistance are widely used in electronic equipment. The difference between positive and negative characteristics is seen by comparing Fig. 1-7 with Fig. 1-8. A positive temperature coefficient means that the resistance increases as the temperature (voltage) is increased. On the other hand, a negative temperature coefficient means the resistance decreases as the temperature (voltage) is increased.

Depending on the point of view, the characteristic of a component having a negative temperature coefficient of resistance can be depicted in three different ways, as shown in Fig. 1-9. In other words, current may be plotted against voltage, resistance may be plotted against voltage, or resistance may be plotted against current. All three characteristics in Fig. 1-9 give the same information—they are simply tied together by Ohm's law.

Source of Negative Temperature Coefficient

Resistance is basically opposition to electron flow. If a substance has zero resistance, the moving electrons encounter no opposition. A metallic wire has many free electrons, which means that the electrons are comparatively unopposed while drifting from the negative end to the positive end of the wire. Nevertheless, the conduction electrons strike a metal atom occasionally, as well as the other electrons that are given a random motion by heat energy. These collisions establish the resistance of the wire. Now, if the temperature of the wire is increased, the random motions of the electrons are increased, causing more collisions and consequently a higher resistance. Hence, metals have a positive temperature coefficient of resistance.

However, semiconductors do not conduct by means of free electrons only. In addition to the electrons, holes are present. Both electrons and holes conduct current. Now, the number of free electrons and holes that are present in a semiconductor is *not* the same at different temperatures. Instead, an increased temperature causes the production of more holes and free electrons. Since more current carriers become available in the presence of heat, the resistance decreases. Hence, semiconductors have a negative temperature coefficient of resistance.

Ohmmeter Measurement

If you connect a thermistor to an ohmmeter as depicted in Fig. 1-10 and apply heat to the pigtail with a soldering gun, you will see the pointer falling on the scale. The more the thermistor is heated, the lower its resistance becomes. Note that the curves in Fig. 1-9 result from the generation of heat

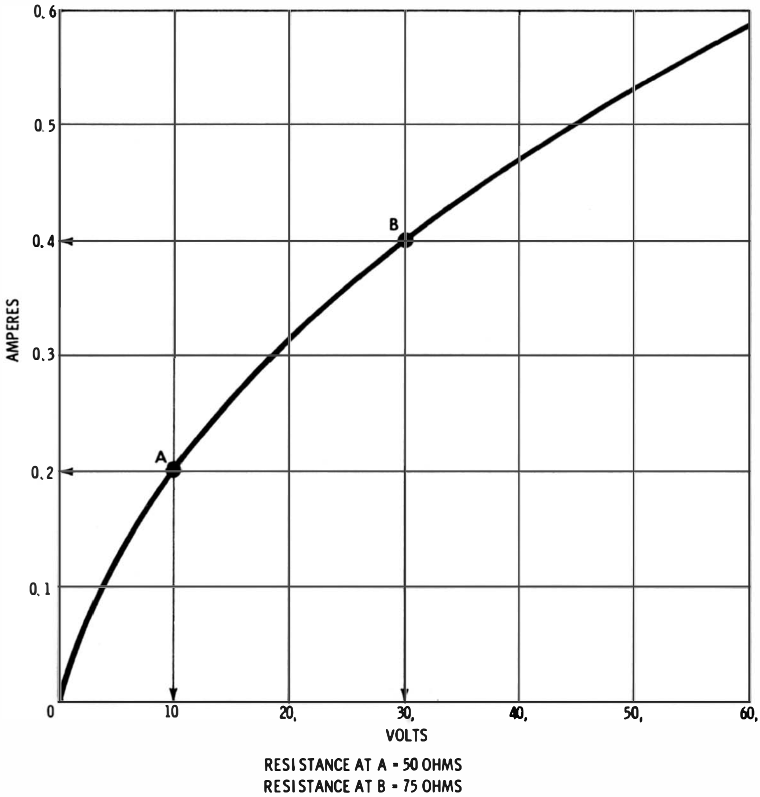


Fig. 1-7. Curve for positive temperature coefficient of resistance.

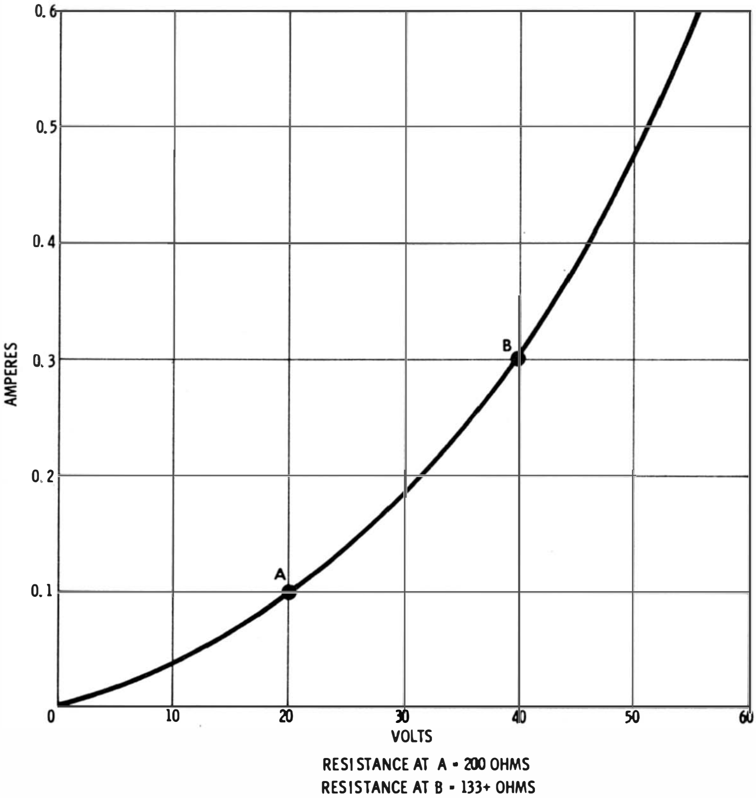


Fig. 1-8. Curve for negative temperature coefficient of resistance.

due to power dissipation in the semiconductor. Since power is equal to I^2R, a greater current flow generates more heat and reduces the resistance.

Sometimes a thermistor (also called a *GLOBAR* resistor), is connected in a series heater string, instead of a wirewound resistor. Thus, a thermistor might be used instead of R67 in Fig. 1-4. A typical unit has a cold resistance of 130 ohms and a hot resistance of 31 ohms. In any case, the normal hot and cold resistance values will be specified in the receiver service data. Two ohmmeter measurements are usually adequate to check a thermistor. The chief precaution is to measure the hot resistance immediately after the power is switched off, so that the thermistor does not have time to cool.

Thermistors usually increase in resistance when they become defective due to aging. This can cause a slow warm-up of the receiver, even if other trouble symptoms do not result from

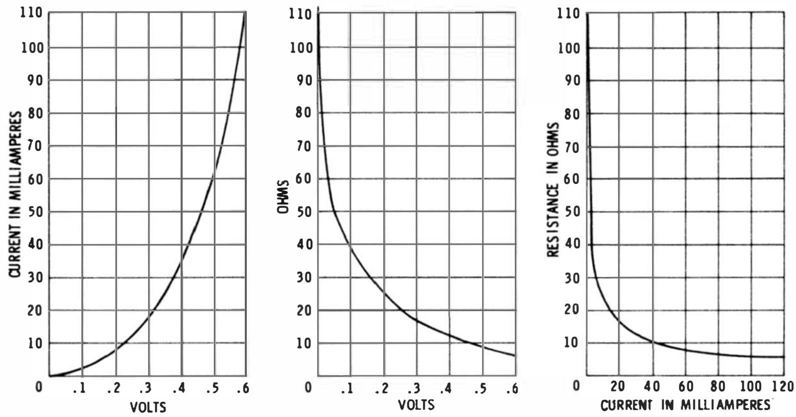


Fig. 1-9. Three methods of presenting negative temperature coefficient.

the low heater voltage. Substantial increase in hot resistance results in a wide range of trouble symptoms, in addition to slow warm-up. In a typical case history, a ten-minute warm-up was required to obtain a full raster and brightness. The culprit was a heater-string thermistor that had a hot resistance of 50 ohms instead of 19 ohms.

Testing Small Thermistors

Comparatively small thermistors are used in low-current circuits, such as the plate-supply lead of a vertical oscillator.

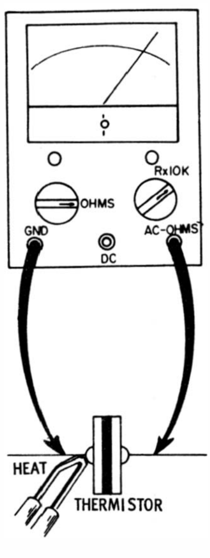


Fig. 1-10. Resistance decreases as the thermistor is heated.

Their cold resistance can be measured accurately with an ohmmeter. However, the hot resistance of a small thermistor does not lend itself to direct measurement. By the time the power has been switched off and the ohmmeter leads have been clipped to the thermistor, its temperature has usually dropped enough to result in a false reading.

Hence, accurate hot-resistance measurements require checking the thermistor with power on, in terms of voltage and current. Voltage drop across the component is readily measured with a VTVM, and the easiest way to calculate the current is to measure the voltage drop across a known resistor in series with the thermistor. Referring to Fig. 1-11, if 100 volts is

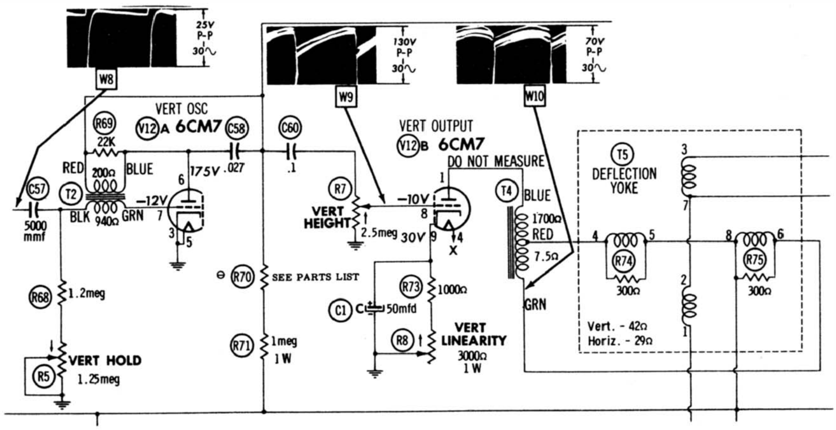


Fig. 1-11. Thermistor R70 stabilizes height and linearity.

measured across the 1-meg resistor R71, the current through it (according to Ohm's law) is 0.1 ma. Then, if the voltage across thermistor R70 measures 50 volts, the hot resistance is 500K.

SEMICONDUCTOR DIODES

If you measure the resistance of a thermistor, and then reverse the ohmmeter leads, the reading is the same. However, when this test is made on a semiconductor diode, widely different resistance values are normally obtained. The resistance readings shown in Fig. 1-12 are typical for the silicon junction diodes used in small power supplies. This ohmmeter test is only a rough indication of diode condition; however, it also provides a ready means of establishing the terminal polarity of an unmarked diode.

Temperature Coefficient

While making either of the tests depicted in Fig. 1-12, you will observe that the resistance decreases if the diode is heated. Even the heat transferred by holding the diode between your fingers will cause the pointer on the resistance scale to fall. In other words, a semiconductor diode has a negative temperature coefficient of resistance. This temperature dependence is illustrated for a typical diode in Fig. 1-13A.

In practice, the temperature characteristic of semiconductor diodes is put to use in various ways. For example, germanium diodes are used to stabilize the emitter-base bias in transistorized circuitry. Semiconductor diodes are also used as photocells, since light energy also decreases the resistance of a diode. The only difference between heat and light radiation is in their wavelength and frequency.

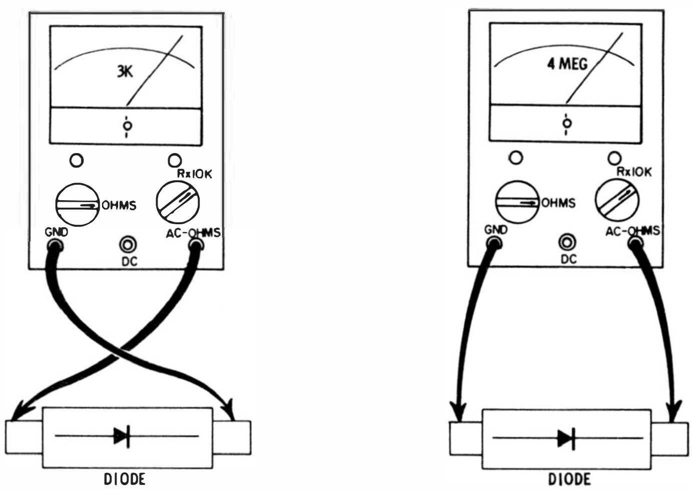
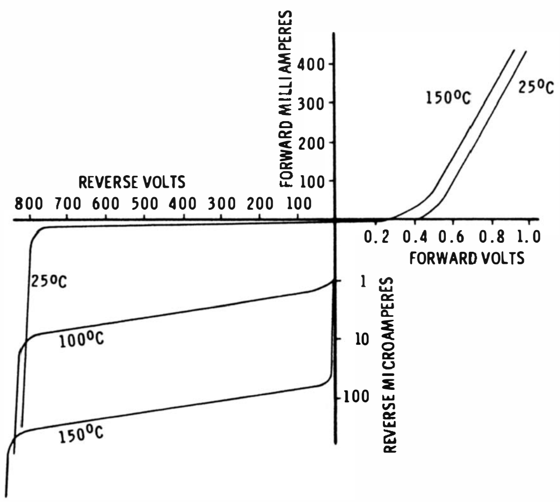


Fig. 1-12. Checking a semiconductor diode.

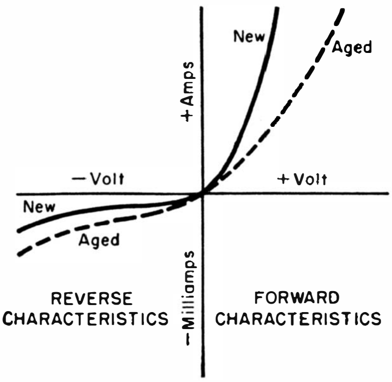
Resistance Change Due to Aging

Most resistive components eventually change in value and characteristics as a consequence of aging. In the case of selenium diodes, this is generally recognized as an increase in forward resistance (Fig. 1-13B), although aging can, and often does, cause a decrease in back resistance. Hence, aging reduces the front-to-back ratio of the diode. The change due to aging is irreversible but resistance changes due to temperature variations are reversible.



(A) Temperature effects on a typical silicon diode.

(B) Change in selenium diode characteristics by aging.



Courtesy General Electric Co.

Fig. 1-13. Changes in diode characteristics due to temperature and aging.

Bilateral and Unilateral Resistances

It is clear that resistive components can be categorized into *bilateral* and *unilateral* types. Fig. 1-14 illustrates this classification. A wirewound resistor can be regarded as a bilateral linear resistance (Fig. 1-14A), provided it is operated at low temperatures. The term bilateral simply means that the resistance remains the same when the applied voltage is reversed in polarity. The resistance is linear because the current flow is proportional to applied voltage.

Next, observe the bilateral nonlinear resistance characteristic shown in Fig. 1-14B. At any applied voltage the current flow remains the same when the polarity is reversed. Hence, this indicates a bilateral resistance. However, the current flow is not proportional to the voltage. Accordingly, it is termed a bilateral, nonlinear resistance. A thermistor or a lamp filament is in this class. Recall that the characteristic of a filament curves downward, whereas the characteristic of a thermistor curves upward; these curvatures are differences of detail and do not change the general classification of the component.

Note the unilateral, linear resistance characteristic depicted in Fig. 1-14C. It is unilateral because current flows only for one polarity of applied voltage. When the voltage is reversed in polarity, no current flows. In the conduction interval, the current is proportional to the voltage. Accordingly, the characteristic depicts unilateral, linear resistance. An ideal diode would have this characteristic. However, in the present state of the art, ideal diodes can only be approximated in practice.

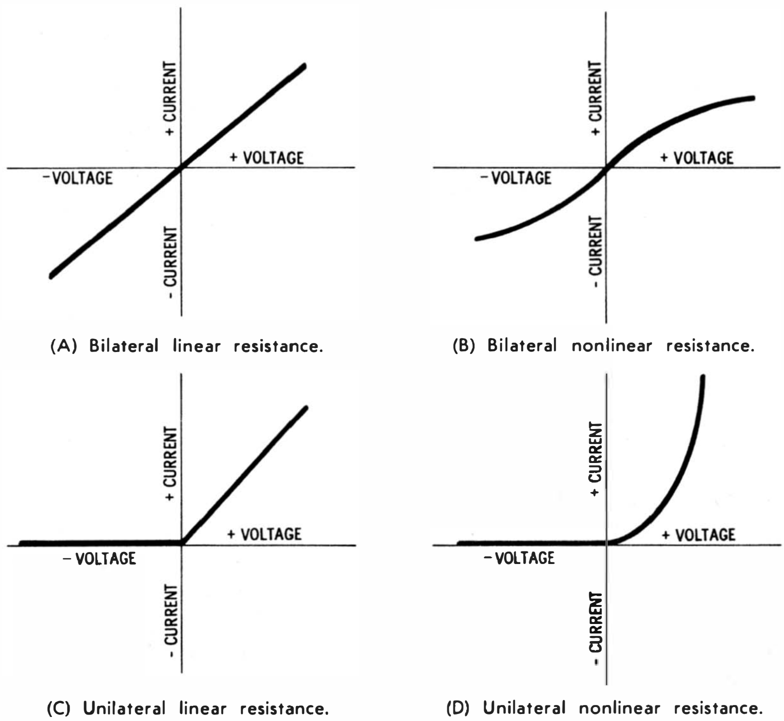


Fig. 1-14. Characteristic curves of bilateral and unilateral resistances.

Finally, observe the unilateral, nonlinear resistance characteristic shown in Fig. 1-14D. As before, this is a unilateral resistance because current flows for only one polarity of applied voltage. Inasmuch as current flow is not proportional to voltage over the conduction interval, the unilateral resistance is a nonlinear resistance. This characteristic approximates diode resistance more closely than the previous classification. Nevertheless, still other factors must be considered to characterize a diode with maximum accuracy.

Reverse Current

From Fig. 1-13, it is evident that a semiconductor diode is not strictly a unilateral, nonlinear resistance because a small, reverse current flows—the reverse current is not quite zero. Strict classification therefore requires that a semiconductor diode be termed an *unsymmetrical,* nonlinear resistance. The diode actually conducts for both polarities of applied voltage, but the reverse conduction is very small in comparison with forward conduction.

Beginners sometimes suppose that the reverse current is always very small, and might be neglected in practice. However, the reverse current is often put to practical use in electronic equipment. Fig. 1-13A shows that when the reverse voltage is increased to a certain critical value (800 volts in this example), the reverse current starts to increase with extreme rapidity. The reverse current now increases much faster than the forward current. If there is insufficient series resistance in the external circuit, the diode will be destroyed by reverse current flow.

Zener Resistance

The reverse-current interval past 800 volts in Fig. 1-13 is called the zener resistance region. This is a very low positive resistance. The 800-volt point on the reverse characteristic is called the zener point. All diodes do not have an 800-volt zener point. Fig. 1-15 shows three commercial zeners (HB-1, HB-2, and HB-3) that have comparatively low critical voltages. The zener point depends chiefly on how much doping concentration is used in the semiconductor materials.

Zener diodes are commonly used as clippers, voltage regulators, electronic switches, and for meter protection. In each of these applications, the zener point is of interest and may need to be measured. All diodes have manufacturing tolerances which are quite wide in some cases. A clipping application can require matched diodes that have practically the same

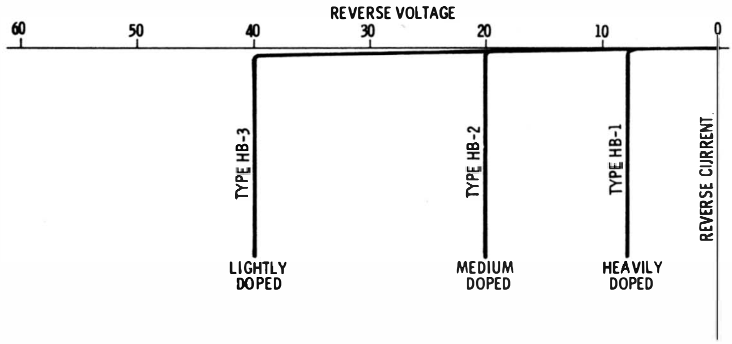


Fig. 1-15. The zener voltage point depends on the doping concentration used in the semiconductor materials.

zener voltage. Again, a zener diode that is used for meter protection must "break down" slightly past the full-scale indication.

Testing Zener Diodes

A test setup for checking the zener voltage point as well as zener resistance is depicted in Fig. 1-16. The power supply must provide sufficient voltage to reach the zener point. For example, if the zener diode is rated for 8 volts, a bench power-supply with 10 or 12 volts output is suitable. Be sure to set the 5K potentiometer to minimum before connecting the zener diode in the circuit. Also, check to see that you are connecting the diode so that reverse voltage is applied.

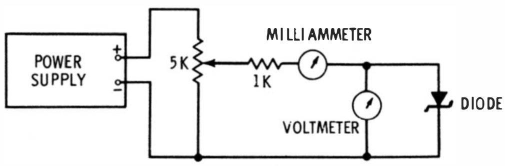


Fig. 1-16. Test setup for a zener diode.

Now, advance the potentiometer in small steps. The voltage across the diode may be increased at first in 2-volt steps, unless it has a very low voltage rating. Note the small current increase at each step. *Caution: Reduce the voltage steps as you approach the rated zener voltage.* When the milliammeter reading starts to rise rapidly, you are passing through the zener point. The voltmeter reading then checks the actual zener voltage against the rated value.

Next, the zener resistance can be determined to a rough approximation. It is difficult to measure accurately because the Zener resistance is small. Advance the potentiometer very carefully, to avoid damage to the meter and/or the diode. First, pass the zener point and enter the zener region. You might start with a current of 1 ma, for example. Note the voltmeter reading. Then, advance the potentiometer slightly for a current flow of, say, 11 ma. Again, note the voltmeter reading. In this example, the current change is 10 ma.

Suppose the voltmeter reading has changed 0.1 volt. Then, since $R = E/I$, the zener resistance is 0.1/0.01, or 10 ohms. The difficulty in reading 0.1 volt on the 10-volt scale of an ordinary voltmeter illustrates the source of the large experimental error that you can expect.

Power in a Zener Diode

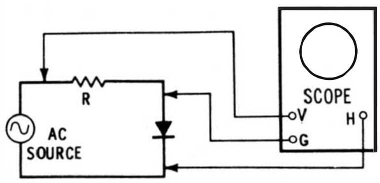
The power dissipated by a zener diode or other type of diode is calculated in the same manner as for an ordinary resistance. In other words, power is equal to voltage times current. If you apply 10 volts across the diode, and the current flow is 10 ma, the diode dissipates 0.1 watt. The power rating must not be exceeded in any test or application. A very small diode might be rated for a maximum power dissipation of 0.25 watt. A large diode could be rated for 10 watts of dissipation.

OSCILLOSCOPIC METHODS

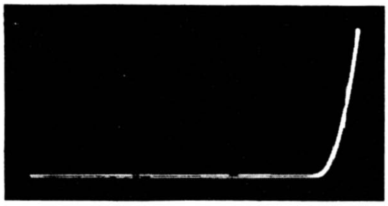
The simple ohmmeter test depicted in Fig. 1-12 provides preliminary data, but it is insufficient for many purposes. Incoming inspection, production testing, etc. require that the diode characteristic be checked in detail. Diode characteristics are generally available from semiconductor manufacturers. These are bogey (average or nominal) characteristics that depict design centers. In other words, manufacturing tolerances cause the actual characteristic of an individual diode to depart more or less from the bogey characteristic. Tolerance limits are often included in diode ratings.

From the previous discussion, it is evident that the voltage versus current values can be measured for a particular diode and the diode characteristic plotted from the meter readings. Point-by-point meter measurements are tedious and time-consuming. Hence, the automatic curve-tracing method is usually preferred. The oscilloscope test setup depicted in Fig. 1-17A continuously displays the complete characteristic on the cathode-ray tube screen. Horizontal deflection is proportional to voltage across the diode, and vertical deflection is proportional to current flow through the diode. Resistor R must be sufficiently great to prevent excessive current flow through the diode.

Voltage and current values can be read directly from the scope screen, if the scope has been previously calibrated. Calibration is accomplished by applying known voltages in turn to the vertical and horizontal channels of the scope, and adjusting the gain controls for convenient units of deflection. Current values are measured on the screen with reference to the resistance values across which the vertical-input terminals are connected. A typical diode characteristic is illustrated in Fig. 1-17B. Note that the display may appear right side up, or upside down, or reversed left-to-right. This simply depends on the deflection polarity of the particular oscilloscope and on the polarity with which the diode is connected into the test circuit.



(A) Oscilloscope test setup for diodes.



(B) Typical voltage-current waveform.

Fig. 1-17. Checking the voltage-current characteristic of a diode.

The source voltage in Fig. 1-17 is a sine wave. It makes no difference whether the voltage source is a true or distorted sine wave, sawtooth wave, or other shape; different wave-shapes will merely vary the brightness distribution in the pattern. A square wave is least desirable in displaying EI curves, because the source voltage then changes very rapidly over the leading and trailing edges; in turn, the ends of the pattern appear bright, and the characteristic is very dim.

Junction Capacitance

All diodes have junction capacitance, which is usually small enough so that the scope pattern is not noticeably distorted in a 60-cycle test. On the other hand, selenium diodes have a comparatively high junction capacitance which generally introduces distortion at 60 cycles. Some diodes have a very large junction capacitance compared with their back resistance. In such case, pattern distortion (looping) as seen in Fig. 1-18 makes the test impractical. Either the test frequency must be considerably reduced, or meter readings employed in a point-by-point test.

The looping in Fig. 1-18 results from the leading current drawn by the junction capacitance. In turn, the voltage drop across R in Fig. 1-17A is out of phase with the drop across the diode. If the test frequency is sufficiently low, the reactance of the junction capacitance becomes so high that negligible leading current is drawn. In case a DC test is made with meters, the reactance becomes infinite and introduces no error in determination of the resistance characteristic.

When it is desired to measure junction capacitance in a laboratory or factory, an oscilloscope method is used. The procedure and evaluation of test data are comparatively involved and cannot be covered here. Interested readers are referred to advanced texts for detailed derivations and discussion.

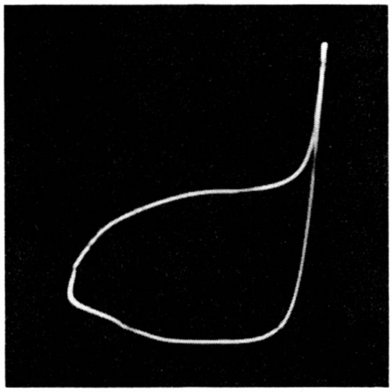


Fig. 1-18. Severe looping in the pattern.

NEGATIVE RESISTANCE

When the test depicted in Fig. 1-17 is made with a germanium diode, such as a 1N34A, and the source voltage is sufficient, the reverse interval of the diode characteristic is traced out to the turnover point and into the negative-resistance region. A typical pattern is seen in Fig. 1-19. Note that this pattern happens to be reversed from left to right, compared to the pattern shown in Fig. 1-17. When displaying negative resistance, be sure to make the series resistance R in Fig. 1-17 sufficiently large so that the diode is not damaged by the peak current flow.

Consider the pattern in Fig. 1-19. As the reverse voltage increases, the reverse current also increases and finally starts to rise very rapidly. The end of the reverse characteristic curves, and its maximum excursion at the right-hand end in

Fig. 1-19, is called the turnover point. At this point, the diode resistance is zero. Past the turnover point, the trace begins to curve back again—the voltage is decreasing, but the current is still increasing. This is the definition of negative resistance–less voltage causes more current to flow, and vice versa. The external series resistance sets a maximum limit to the current which passes through a maximum at the bottom of the pattern and then returns back to the origin.

Source of Negative Resistance

What is the source of the negative-resistance interval past the zero-resistance point in Fig. 1-19? In a point-contact germanium diode, the development of negative resistance is based on generation and radiation of heat at the contact point. As in all semiconductor diodes, junction resistance decreases with increasing heat. This decreasing resistance is first seen as a downward slope in the reverse characteristic until the zero-

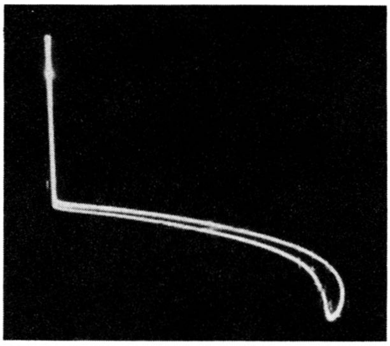


Fig. 1-19. Diode driven into negative-resistance region.

resistance point is passed. The slope of the curve is vertical (infinite) at the turnover point. Then, a negative resistance is entered because the diode can no longer radiate the heat as fast as it is generated by the I^2R power factor. Now, a runaway condition exists. The junction resistance decreases, and the current increases in an avalanche process.

Although the current is increasing, the voltage drop across the diode is decreasing because the heat build-up is decreasing the junction resistance out of proportion to the voltage. This is evidently an unstable condition, and the diode will be destroyed unless the current is limited by a sufficient amount of external positive resistance. After the current peak is passed, the characteristic reverses its slope (the diode resistance is now positive), and the retrace follows another path back to the origin. This looping is the result of heat radiation that is now decreasing instead of increasing.

Measurement of Negative Resistance

Negative resistance can be measured from the screen pattern, provided the scope has been previously calibrated. As shown in Fig. 1-20, a tangent is placed at a selected point on the negative-resistance characteristic. The slope of the tangent gives the value of the negative resistance. Any tangent line so considered defines at its ends a certain voltage interval corresponding to a certain current interval. The quotient of the voltage divided by the current gives the negative-resistance value.

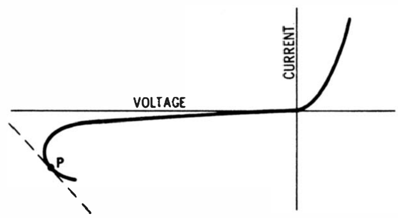


Fig. 1-20. The negative-resistance value curve.

Note that the negative-resistance interval passes through all possible values from zero to minus infinity. The negative resistance is very small just past the turnover point and approaches infinity just before the peak-current point. In suitable circuitry, you can bias the diode to a chosen value of negative resistance and use it as an amplifier or an oscillator. However, the life of a germanium diode is limited in such applications because of the large amount of heat that is generated. Hence, negative-resistance devices commonly use tunnel diodes that can be operated at low temperatures.

TUNNEL DIODES

Unlike a germanium diode, a tunnel diode has a negative-resistance interval on its forward-current characteristic. A typical EI curve is depicted in Fig. 1-21. The negative-resistance interval occurs from 55 mv to 350 mv. The value of the negative resistance at a chosen point is given by the slope of the tangent to the curve at that point. It is not as easy to check out a tunnel diode as an ordinary diode. First, unless the external circuit resistance is very low, the tunnel diode operates as an electronic switch, and it is impossible to plot or display the negative-resistance interval. Second, unless the test-circuit reactance is strictly minimized, the system will oscillate even though the circuit resistance is sufficiently low.

Testing Tunnel Diodes

An ohmmeter will show whether a tunnel diode is open or shorted, but it gives no further information. Hence, service-type testers such as depicted in Fig. 1-22 often provide a switching-circuit test. The tunnel diode is tested for the electronic switching action previously mentioned. This test

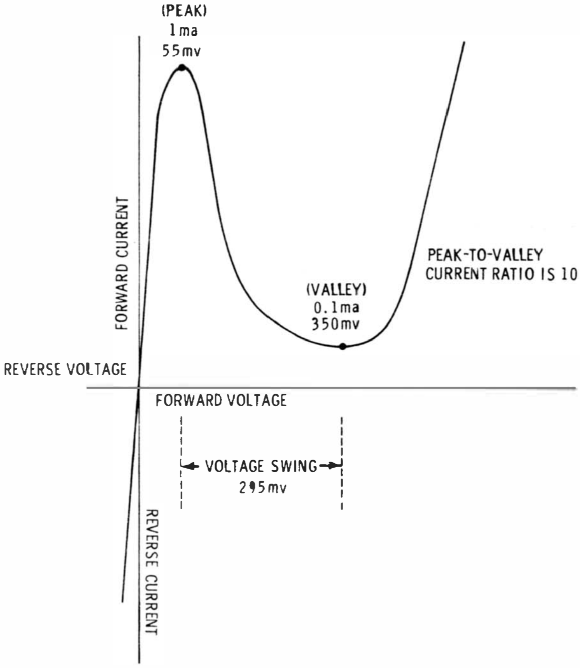


Fig. 1-21. Typical tunnel-diode voltage-current characteristic.

principle is seen in Fig. 1-23B. Here is how it works. When the potentiometer is set to minimum, no voltage is applied across the diode, and no current flows. This corresponds to point 1 on the characteristic in Fig. 1-23A.

Next, as the potentiometer is advanced, a load line is established, as shown by the dashed line on the characteristic. Voltage is now applied, and current flows, as indicated by the milliammeter. Further advance of the potentiometer raises the load line to the peak-current point, as shown by the solid line on the characteristic in Fig. 1-23A. The peak-current flow occurs at point 2 and is indicated by the milliammeter. This is

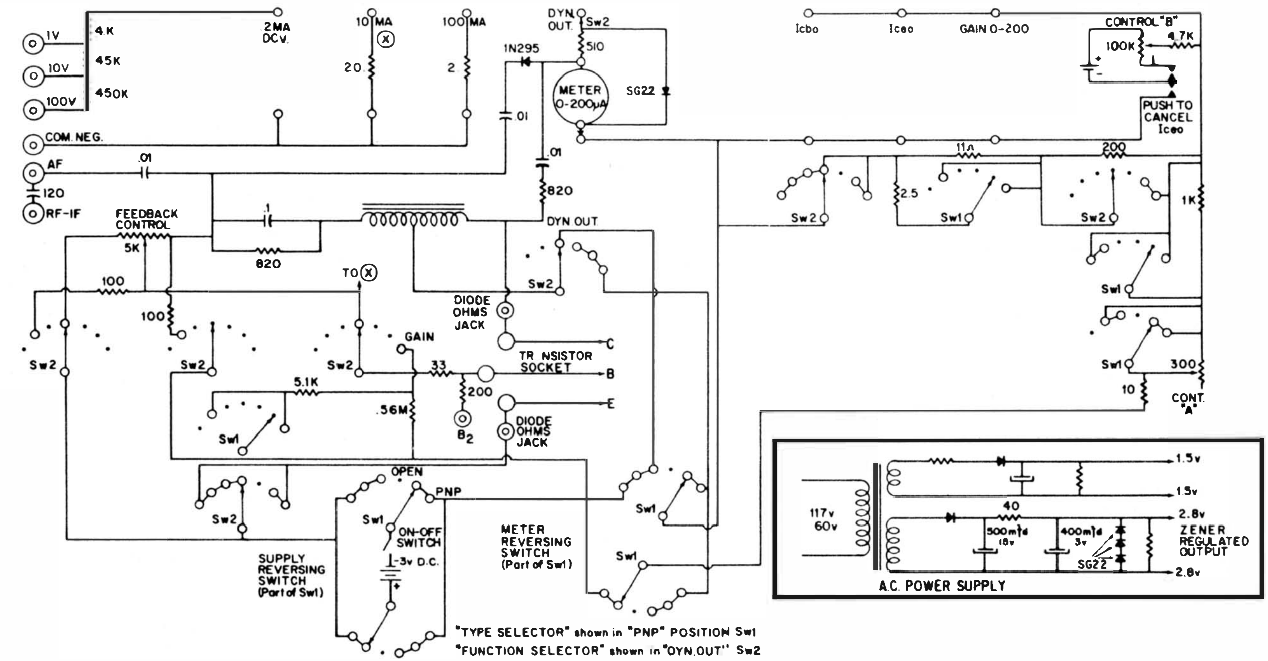
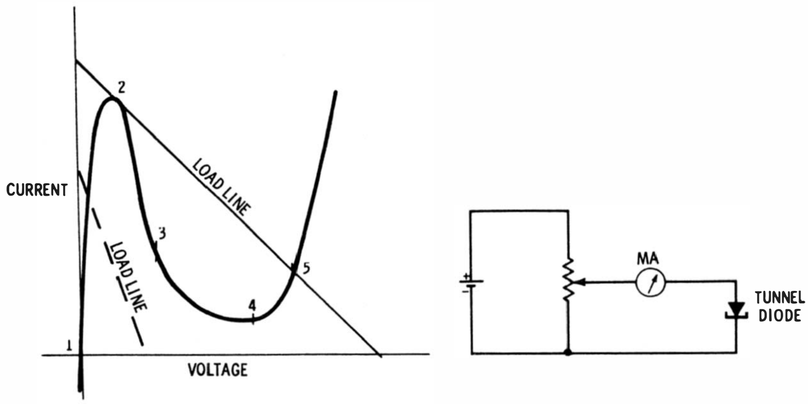


Fig. 1-22. A tunnel-diode and transistor tester.

the first part of the test, inasmuch as tunnel diodes are rated for peak-current value.

Now, a slight increase of voltage results in switching action that occurs as follows: The path of operation is *not* along the negative-resistance interval; in all configurations of this type, the path of operation is along the load line. Hence, the current flow is *not* indicated at points 3 and 4, for example. Instead, the meter reading suddenly drops and indicates the current at point 5 in Fig. 1-23A. Now, if you back off on the potentiometer, the current flow will reduce still further until the load line passes through point 4. This is the minimum or valley current and is the second part of the test, inasmuch as tunnel diodes are rated for valley current.



(A) Voltage-current characteristic.

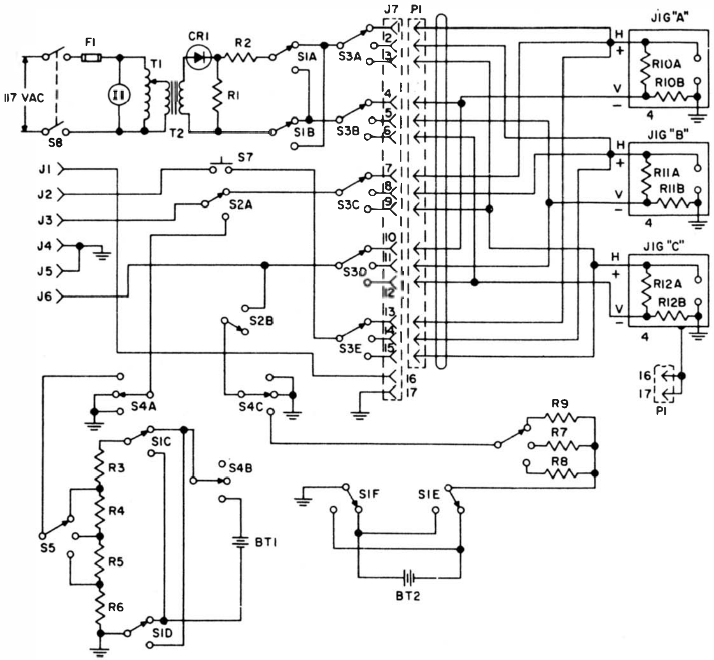
(B) Switching-circuit test setup.

Fig. 1-23. Switching test for a tunnel diode.

To summarize, this type of tester checks tunnel diodes by measuring the peak and valley current values. It gives no detailed information concerning the negative-resistance interval because it provides electronic-switching action only. More elaborate types of testers are used by laboratories and factories. These are critically designed using the basic principle shown in Fig. 1-17 to trace out the complete diode characteristic while avoiding switching action and/or oscillation. This requires a low-resistance series sweep circuit and low-inductance test leads.

Lab-Type Tester

A lab-type, tunnel-diode tester is diagrammed in Fig. 1-24. Jig A is used to test 1- and 2.2-ma diodes. Jig B is for 4.7- and 10-ma diodes. Jig C is for 22-ma units. Vertical and horizontal



PART NO.	NAME	DESCRIPTION
BT1	BATTERY	1.34 VDC MALLORY # RM-12R *
BT2	BATTERY	1.34 VDC MALLORY # RM-12R *
CR1	DIODE	1N1695
F1	FUSE	1 AMP
I1	LAMP	NE-51
J1	BINDING POST	SUPERIOR ELECTRIC TYPE DF30BC *
J2	BINDING POST	SUPERIOR ELECTRIC TYPE DF30RC *
J3	BINDING POST	SUPERIOR ELECTRIC TYPE DF30RC *
J4	BINDING POST	SUPERIOR ELECTRIC TYPE DF30BC *
J5	BINDING POST	SUPERIOR ELECTRIC TYPE DF30BC *
J6	BINDING POST	SUPERIOR ELECTRIC TYPE DF30RC *
J7	SOCKET	AMPHENOL # 77-MIP-20, 20 PINS *
P1	PLUG	AMPHENOL # 70-20, 20 PINS *
R1	RESISTOR	47Ω, 2W
R2	RESISTOR	20Ω, 10W
R3	RESISTOR	340Ω, 1/2 W, 1/4%
R4	RESISTOR	500Ω, 1/2 W, 1/4%
R5	RESISTOR	400Ω, 1/2 W, 1%
R6	RESISTOR	100Ω, 1/2W, 1%
R7	RESISTOR	264.6Ω, .5%
R8	RESISTOR	1353Ω, .5%
R9	RESISTOR	131.4Ω, .5%
S1	SWITCH	6 POLE, 2 POSITION
S2	SWITCH	2 POLE, 2 POSITION
S3	SWITCH	5 POLE, 3 POSITION
S4	SWITCH	3 POLE, 3 POSITION, MOMENTARY CONTACT
S5	SWITCH	1 POLE, 3 POSITION
S6	SWITCH	1 POLE, 3 POSITION
S7	SWITCH	N.O., MOMENTARY CONTACT, PUSH BUTTON
S8	SWITCH	DPST, TOGGLE
T1	TRANSFORMER	POWERSTAT TYPE 10B *
T2	TRANSFORMER	STANCOR # P-6134 *
XF1	FUSE HOLDER	FUSETRON TYPE HJM *
XI1	LAMP HOLDER	DIALCO # 95408-931 *
1	ASSEMBLY	
2	CABINET	PREMIER # SFC-502 - 8"X14"X8" *
3	CHASSIS	PREMIER # ACH-426-5"X7"X2" ALUMINUM *
4	CURVE TRACING JIG	FOR DETAILED DRAWING SEE FIG. # 7.5
R10A & B	RESISTORS	10Ω PYROFILM RESISTOR CO # D375 CARBON FILM MICROWAVE RES.
R11A & B	RESISTORS	4Ω PYROFILM RESISTOR CO # D375 CARBON FILM MICROWAVE RES.
R12A & B	RESISTORS	2Ω PYROFILM RESISTOR CO # D375 CARBON FILM MICROWAVE RES

* OR EQUIVALENT

Fig. 1-24. A laboratory-type tunnel-diode tester.

Courtesy General Electric Co.

scope inputs are taken from the V and H points in the jig that is in use. The AC output from T2 then sweeps out the characteristic on the scope screen. Details of control settings for various diodes are not covered here, but interested readers may refer to advanced texts such as the Tunnel Diode Manual published by the General Electric Co.

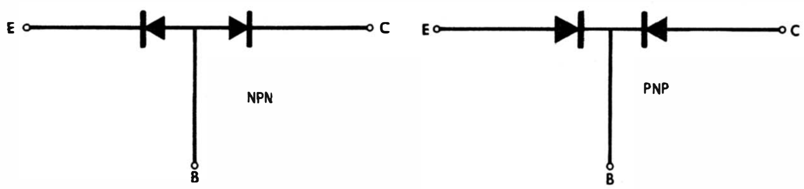


Fig. 1-25. Equivalent circuits for transistors.

TRANSISTORS

Some transistor tests are essentially the same as diode tests. For example, ohmmeter tests can be made to weed out definitely defective transistors. Preliminary equivalent circuits for transistors can be considered in such tests as are depicted in Fig. 1-25. The transistor is regarded as two diodes connected back-to-back. Although only a rough approximation, an equivalent circuit of this sort is a guide in making simple resistance tests. For example, a reasonably high front-to-back ratio is anticipated between emitter and base terminals, as well as between collector and base terminals. If forward current flow (low resistance) is found when the negative ohmmeter lead is connected to the emitter and the positive lead to the base, the transistor is identified as an NPN type. The opposite finding indicates a PNP type.

You might or might not measure a substantial front-to-back ratio from emitter to collector, even if the transistor is in good condition. A few transistors are symmetrical, meaning that the emitter and collector junctions have identical characteristics. In this case, the front-to-back ratio from emitter to collector is unity. On the other hand, most transistors are unsymmetrical, which means that you will measure a definite front-to-back ratio from emitter to collector although this ratio is usually lower than the other two ratios. Ohmmeter measurements on a "good" transistor selected at random are noted in Fig. 1-26.

Junction Resistances

Simple transistor testers, which may have certain supplementary tests, are basically ohmmeters. A common follow-up

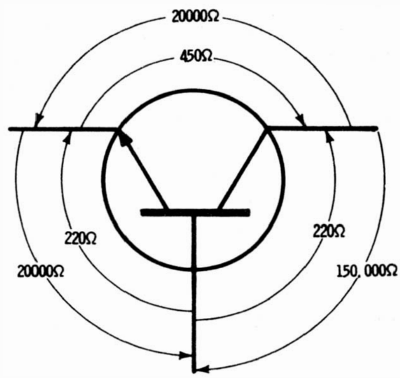
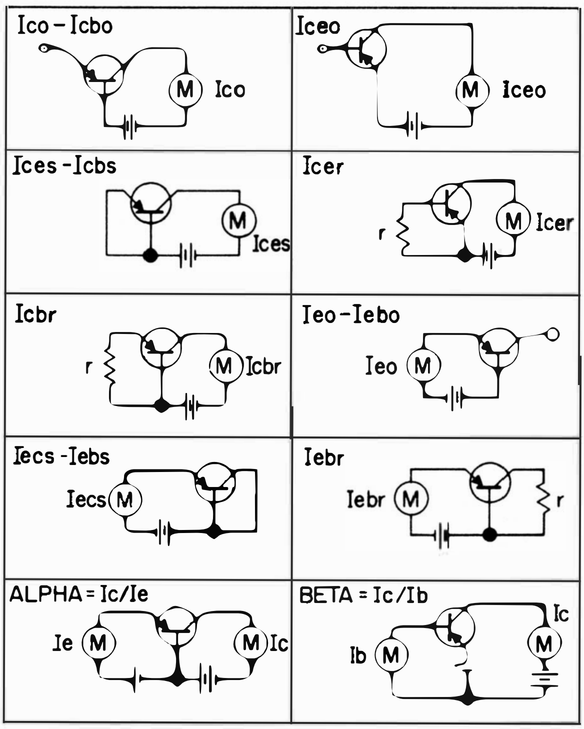


Fig. 1-26. Ohmmeter test for forward and reverse junction resistances.



Courtesy Hickok Electric Instrument Co.

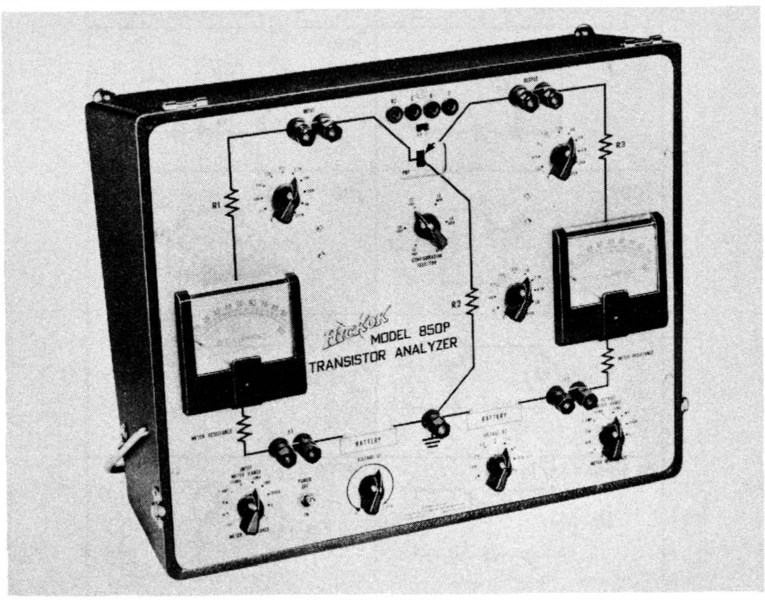
Fig. 1-27. Basic transistor test circuits.

test is measurement of junction back resistances in terms of current flow. Nearly all testers provide for a test of I_{co} (also called I_{cbo}), which is a measurement of leakage current. An I_{co} test applies a moderate reverse voltage between collector and base with the emitter open, as seen in Fig. 1-27. A micro-ammeter in the collector circuit indicates whether the back resistance of the collector junction is acceptably high. Transistor manufacturers rate their various types for I_{co} values.

An I_{ces} (also called I_{cbs}) test is made in the same manner as an I_{co} test, except that the emitter is shorted to the base, as depicted in Fig. 1-27. The I_{cbs} current flow is normally somewhat greater than the I_{co} current flow. Transistors are customarily rated for I_{ces} as well as I_{co}. Simple transistor testers seldom provide an I_{ces} function.

The I_{cbr} test shown in Fig. 1-27 is intermediate to the I_{co} and I_{ces} tests. A resistance (commonly 10K) is connected between emitter and base during measurement of reverse collector current. The meter will normally indicate a value greater than I_{co}, but less than I_{ces}. The more elaborate types of transistor testers provide for measurement of both I_{ces} and I_{cbr}.

Observe that an I_{ecs} (also called I_{ebs}) test is basically the same as an I_{ces} test, except that emitter and collector terminals



Courtesy Hickok Electric Instrument Co.

Fig. 1-28. A transistor tester providing a wide choice of test configurations.

are reversed. That is, the reverse emitter-junction current is measured with collector shorted to base. In a truly symmetrical transistor, the I_{ecs} and I_{ces} readings are normally the same. Of course, most transistors are unsymmetrical, and the I_{ces} rating is different from the I_{ecs} rating.

Many transistor testers provide an I_{ceo} test, as shown in Fig. 1-27. An I_{ceo} reading is normally greater than an I_{co} reading because the reverse current is increased by emitter-base junction

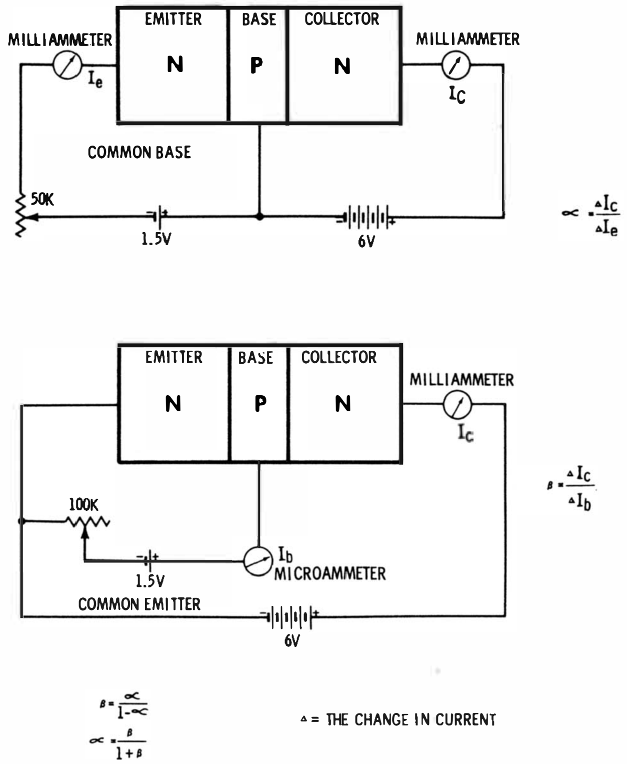


Fig. 1-29. Alpha and beta relationships.

action. This test, as well as the foregoing tests, are provided by instruments which feature maximum flexibility for DC tests (Fig. 1-28).

Observe that an I_{cer} test compares with an I_{cbr} test in the way that an I_{ceo} measurement compares with an I_{co} measurement. The base-emitter resistor has a typical value of 10K. As would be anticipated, an I_{cer} reading is normally higher than an I_{cbr} reading.

The I_{eo} (also called I_{ebo}) and I_{ebr} tests depicted in Fig. 1-27 are emitter-junction tests which are the counterpart of the I_{co} and I_{cbr} collector-junction tests. The resistor used in the I_{ebr} test has a value of approximately 10K. Note that the test voltage employed in each of the foregoing tests is not critical—a comparatively low voltage will provide a test point on the flat portion of the reverse-resistance characteristic. Of course, an excessively high test voltage must not be used, because the transistor will be irreparably damaged if the rated voltage is exceeded.

Measurement of Alpha and Beta

A more critical test of a transistor is made by measuring its alpha or beta. Basically, this is the measurement of transfer resistance. As shown in Fig. 1-27, the emitter is forward-biased, and the collector is reverse-biased. A forward emitter-bias lowers the emitter junction resistance, which is transferred by lattice action as a lowering of the collector junction

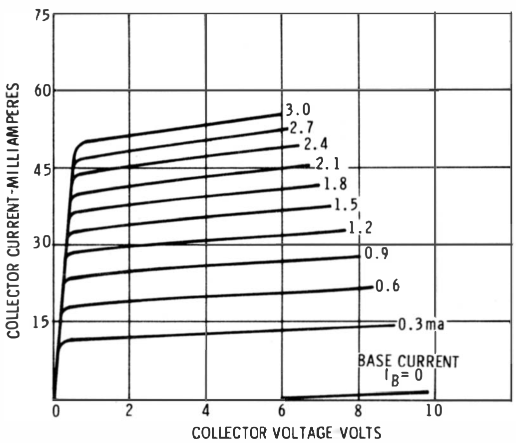


Fig. 1-30. Example of alpha crowding.

resistance. Alpha is defined as the ratio of emitter-to-collector current. Beta is defined as the ratio of base-to-collector current.

The simple ratio of input to output currents gives the DC alpha or beta of a transistor. This is a test that simulates large-signal operation of a transistor, in which the input signal drives the transistor over a large excursion of its characteristics. On the other hand, transistors are commonly rated for small-signal operation, and published values of alpha and beta must be checked by a slightly elaborated procedure.

Incremental Test

To check small-signal alpha and beta, the input current is set to an operating value specified by the transistor manufacturer. This establishes an operating point at a median in the characteristics, as would be used for Class-A amplification. Then, the input current is increased by a small amount. The corresponding change in collector current is noted. The small-signal alpha or beta is then given by the ratio of input-current change to output-current change. Alpha and beta are simply related to each other, as shown in Fig. 1-29.

The DC alpha or beta will have a different value from the small-signal alpha or beta because the transfer resistance of many transistors is nonlinear as seen in Fig. 1-30. Note that a base-current change from 0 to 0.3 ma produces a much larger collector-current change than a base-current change from 0.9 to 1.2 ma. Hence, this transistor will measure a larger DC beta than its small-signal beta.

SECTION 2

Capacitive Components

All electronic components are capacitive; however, a capacitive component is defined as one in which *capacitive reactance* is its dominant parameter. Beginners are often confused by the term capacitive reactance. However, the principle of capacitive reactance is basically very simple. Consider a long, small-diameter pipe that is bent in a circle and connected in series with a water pump. The water pump in hydraulic theory is analogous to a battery in electronic theory. Pressure must be applied to force water around the pipe "circuit," because the small bore of the pipe imposes *hydraulic friction*; in an electronic circuit, a small wire similarly imposes *resistance* to electron flow.

CAPACITIVE REACTANCE

Proceeding to the concept of capacitive reactance, suppose that a rubber diaphragm is now inserted in the pipe to oppose water flow. Now, the water which is urged forward by pump pressure encounters an additional type of resistance. The diaphragm stretches and exerts a backward pressure against the pump. When the diaphragm is stretched to the point where the back pressure equals the pump pressure, the water flow stops. In electronics, we would say that the capacitor is charged—its back electric force equals the battery voltage.

Evidently, if the pump is valved out of the pipe line and the two ends of the pipe are connected with a bypass pipe (short circuited), the diaphragm relaxes and causes water to flow through the pipe in a reverse direction to establish equilibrium. In an equivalent electronic circuit, the charged capacitor has been short-circuited and thereby discharged.

The important point here is that capacitive reactance (the stretched diaphragm) opposes current flow (water flow) by *storing energy* (back force of the stretched diaphragm). Conversely, resistance dissipates energy and when water is forced to flow through a small pipe, the losses due to friction are converted to heat. Likewise, when electrons are forced to flow through a small wire, the wire becomes hot.

When a diaphragm is stretched, or a capacitor is charged, no energy is dissipated—the energy is simply stored, and it can be recovered when the circuit conditions are appropriate. It should be remembered that reactance stores energy, and resistance dissipates energy. However, since reactance opposes current flow, this opposition like resistance is also measured in ohms. Ohm's law states that $I = E/X_c$, where X_c is the capacitive reactance in ohms. The reactance of a capacitor is equal to $1/2\pi fC$ ohms, which shows that capacitive reactance varies inversely with frequency. It is meaningless to state the reactance in ohms of a capacitor, unless the frequency of measurement is given.

VOLTAGE-CURRENT RELATIONSHIP

This writer has spent many hours with various apprentices, explaining how and why the current leads the voltage in a capacitive circuit. The best way to clarify this fact seems to be a continuation of the water analogy discussed above. In other words, consider a water-pipe circuit containing a pump and a rubber diaphragm. When the pump is first started, the diaphragm offers no opposition because it is not stretched. The stretch is zero, or, the "voltage" across the diaphragm is zero. Yet water is rushing rapidly against the diaphragm, and it could be said that the "current" is large when the pump is first started.

The water flow then begins to slow, because the diaphragm is being stretched and is opposing the water flow. Plainly, the diaphragm "voltage" is increasing, while the "current" is decreasing. Finally, the diaphragm becomes so stretched that the water flow stops. The current is then zero, but the "voltage" of the stretched diaphragm has increased to a maximum. To summarize briefly, current maximum corresponds to voltage zero; current medium corresponds to voltage medium; current zero corresponds to voltage maximum. This is simply another way of saying that current and voltage are 90° out of phase.

Is the current leading the voltage in the pipe circuit? Of course it is—the water current has its maximum speed of flow *before* the diaphragm voltage rises to its maximum value. This hydraulic analogy shows how current leads the voltage in a capacitive circuit. On the other hand, current is always in step with the voltage in a resistive circuit. Now, the fact that current in a capacitive circuit is 90° out of phase with current in a resistive circuit illustrates another vital principle: resistive ohms and capacitive ohms must be added at 90°, or, they must be added at right angles.

IMPEDANCE

Imagine a circuit consisting of a 100-ohm resistor in series with a capacitor that has a reactance of 100 ohms at the operating or test frequency. A right triangle must be drawn, with the base equal to the altitude. The base represents the 100-ohm resistance, and the altitude equals the 100-ohm reactance. The hypotenuse of the triangle then represents the *impedance* of the RC circuit. The hypotenuse has a length which represents the impedance of the circuit, and this impedance is evidently 141 ohms (approximately). Ohm's law states that $I = E/Z$, where Z is the impedance of the circuit.

With this basic understanding of the electrical action in a capacitive circuit, it is simple to understand how capacitance values are measured and how capacitive components are tested. Different methods are employed to test various types of capacitive components, but all are based fundamentally on the principle of capacitive reactance.

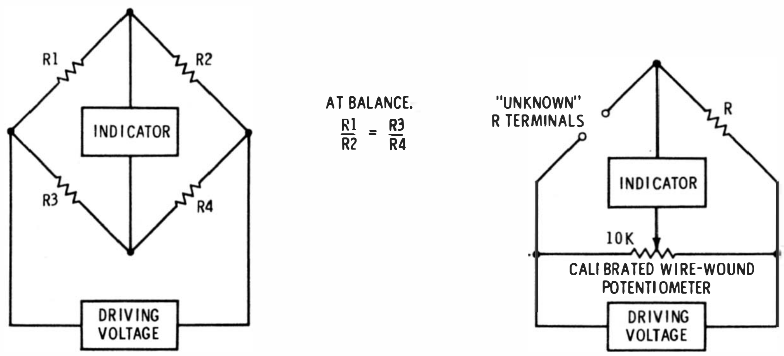
OUT-OF-CIRCUIT CAPACITOR TESTS

A good capacitor has a rated value of capacitance, within a specified tolerance. When it is suspected that a capacitor is off-value, technicians often replace it without testing. However, some technicians prefer to test capacitors. Testing is sometimes mandatory when a suitable replacement is not available for substitution. Several instruments are useful for measuring capacitance values. Your choice will depend on shop instrumentation as well as personal preference.

Capacitance Measurement With RC Bridge

The most common instrument employed to measure capacitance in both service shops and labs is the RC bridge. This is basically a Wheatstone bridge, the operating principle of which, is shown in Fig. 2-1A. In service-type instruments, an eye tube is generally used as a null indicator; lab-type bridges employ a galvanometer, which is more sensitive. In either case, the indicator reads zero when the bridge is adjusted for balance. As depicted in Fig. 2-1B, a potentiometer with a calibrated dial is generally used to directly indicate the value of the unknown capacitor.

The Wheatstone bridge circuit shown in Fig. 2-1B is used to measure unknown resistance values. The better bridges can indicate resistance values more accurately than an ohmmeter. The general principle of the Wheatstone bridge is also used to measure capacitance values when the instrument is switched



(A) Basic circuit. (B) Practical circuit.

Fig. 2-1. A Wheatstone bridge.

to its capacitance ranges. As depicted in Fig. 2-2A, two of the bridge arms now consist of capacitors. One is a *standard* or reference capacitor inside the instrument. The other is the unknown capacitor connected to the external terminals of the bridge. A potentiometer with a calibrated dial is customarily used to directly indicate the capacitance value at balance (Fig. 2-2B).

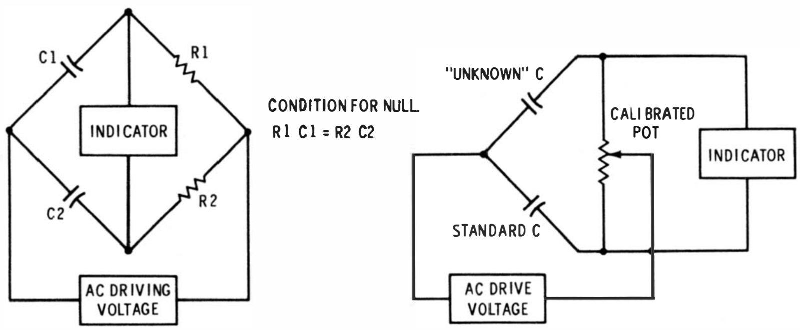
Test Voltage in the Bridge

An AC driving voltage is necessarily used to drive a capacitor bridge, since capacitance values are measured on the basis of capacitive reactance. On the other hand, a Wheatstone bridge might be driven by either AC or DC voltage. In general, it is desirable to drive a Wheatstone bridge with DC, because a resistance measurement can then be made in the presence of reactance.

Service-type capacitor bridges are usually driven by 60-cycle AC. However, lab-type bridges are generally driven by 1,000-cycle AC. A typical service-type bridge applies up to

50 volts across the capacitor under test. This value is well within the working-voltage range of paper, mica, and ceramic capacitors. On high-capacitance ranges used for testing electrolytic capacitors, the bridge ordinarily applies less voltage across the "unknown" capacitor—a value of three volts rms is typical. Inasmuch as the peak voltage could exceed the rating of some electrolytic capacitors used in transistor circuitry, it is evident that this danger must be kept in mind.

It is easy to check the voltage applied across an unknown capacitor. Simply connect a VTVM across the capacitor under test—if the applied voltage is excessive, turn off the bridge immediately to avoid damage to the capacitor. With the advent



(A) Basic circuitry of an RF bridge. (B) Typical instrument configuration.

Fig. 2-2. RC bridge used to measure capacitor values.

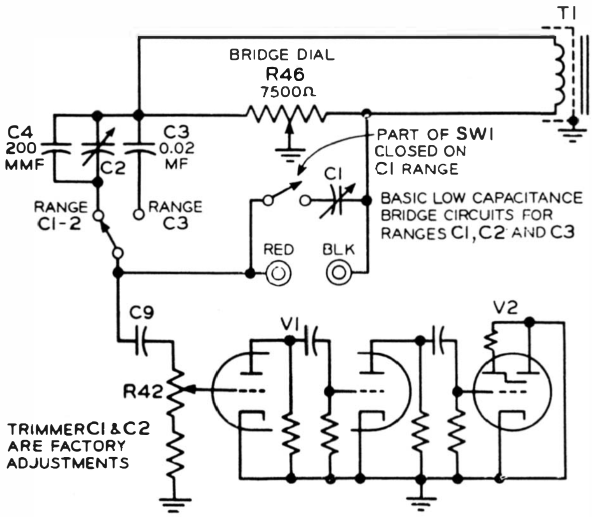
of electrolytic capacitors rated at low working voltages, service-type bridges have become available which apply a maximum of 0.5 volt to the capacitor under test.

Measuring Small Capacitance Values

Service-type bridges commonly have a lower limit of 10 mmf, although some instruments measure capacitance values as small as 1 mmf. Obviously, if it were attempted to use test leads when measuring small capacitances, the stray capacitance of the leads would introduce a large error. Therefore, small capacitors should be connected directly to the instrument terminals. Test leads also tend to pick up stray hum which can mask the null indication.

Sensitivity of Null Indication

The bridge dial can be set accurately only if the null indication is sensitive, to give a sharp indication of balance. Sensitivity is increased if higher driving voltage is applied to the bridge. On the other hand, high test voltages must not be applied to low-rated capacitors. Therefore, other means are employed when it is necessary, to obtain adequate sensitivity. For example, one manufacturer utilizes an amplifier for the eye tube, as seen in Fig. 2-3. The amplifier provides a sensitive null indication, although the test voltage applied is less than 0.5 volt rms. R42 provides adjustment of sensitivity.



Courtesy Sprague Electric Co.

Fig. 2-3. An amplifier increases the null-indicator sensitivity.

It is interesting to note that if you wish to rework an older-type capacitor bridge, this can easily be accomplished. It is only necessary to reduce the test voltage by means of a voltage divider and to increase the indication sensitivity. The easiest way to increase the sensitivity is to remove the eye tube, and insert a pair of scope leads into the input (grid and cathode) terminals of the socket. A scope has comparatively high vertical sensitivity, and gives a sharp null indication although the test voltage is quite low.

Test of Leakage Resistance

A defective paper, mica, or ceramic capacitor might be open, or it may have lost a substantial portion of its rated capacitance. This defect shows up as a subnormal reading on the capacitance dial. Also, a defective capacitor can have the correct capacitance but exhibit objectionable leakage. When the leakage is substantial, a complete null cannot be obtained.

Or, if the capacitor is practically shorted, even a partial null will not occur.

Moderate leakage does not affect the capacitance test, and a defective capacitor would be passed as good unless a supplementary leakage test is made. The simpler types of capacitor bridges test for leakage by applying an adjustable DC voltage to the capacitor. The test voltage is typically adjustable from 0 to 500 volts. In any event, the rated working voltage of the capacitor should not be exceeded. If the capacitor has excessive leakage, the eye tube closes somewhat. A shorted capacitor closes the eye completely. Of course, this type of test does not tell you the value of the leakage resistance. If you want to determine its value, note the extent to which the eye is closed in the leakage test. Then remove the capacitor, and connect various high-value resistors in its stead. When you match the original eye opening, the value of the resistor is equal to the leakage resistance of the capacitor.

A few service-type capacitor bridges have an ohmmeter indication in addition to an eye tube. The ohmmeter operates typically at 25 volts DC. Leakage resistances up to 20,000 megohms are indicated on the calibrated ohmmeter scale. This test can be used on all fixed capacitors that have a rated working voltage of 25 volts, or higher. But you might run into a ceramic capacitor rated at 3 volts. In this case, the test voltage is set to rated value, and the leakage current measured on the meter. The leakage resistance is then calculated from Ohm's law: $R = E/I$.

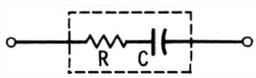


Fig. 2-4. Series resistance increases power-factor value.

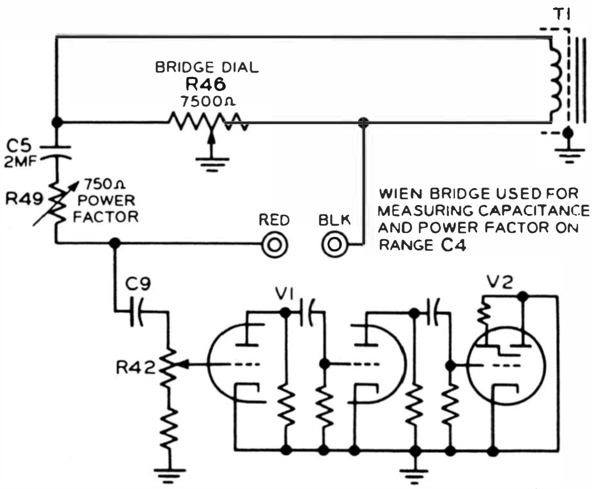
Power Factor

Service-type bridges do not provide measurement of power factor for paper, film, paper-film, mica, and ceramic capacitors. The reason for this omission is that small fixed capacitors rarely become defective due to high power factor. The only exception might be found when there is a poor internal contact to the capacitor electrodes. This effectively places resistance in series with the capacitance, as depicted in Fig. 2-4, and raises the power-factor value.

On the rare off-chance that this defect might exist in a small fixed capacitor, the capacitor bridge would probably pass the capacitor as being good. For example, the contact resistance must exceed 50K before the defect is apparent on a typical service bridge. Then, it will show up as an incomplete null—the eye tube does not open up as wide as for a normal capacitor. However, lab-type bridges that operate at 1 kc can weed out the rare cases in which a small fixed capacitor has an appreciable power factor.

Electrolytic Capacitors

Although conventional electrolytic capacitors are used in pulsating-DC circuits only (DC with an AC component), it is common practice to measure electrolytic capacitance with an AC bridge at comparatively low voltage. Unlike paper capacitors, electrolytic capacitors generally have an appreciable



Courtesy Sprague Electric Co.

Fig. 2-5. Circuitry of an electrolytic-capacitor bridge.

power factor. Hence, bridges provide for its measurement. A typical configuration is depicted in Fig. 2-5. Rheostat R49 is connected in series with the standard capacitor C5. A calibrated dial for R49 provides direct reading of power-factor values.

Recall that a power factor greater than zero occurs when there is effective resistance in series with the capacitor under test (Fig. 2-4). A complete null in the Fig. 2-5 configuration can be obtained only when R49 is adjusted to have the same resistance as the effective series resistance in the capacitor under test. Thus, both R46 and R49 must be adjusted for final balance. Then, the R46 dial reads the capacitance value, and the R49 dial reads the power factor.

Meaning of Power Factor

Just what is a power factor? Consider a 25-mfd electrolytic capacitor that has an excessively high power factor. It has an effective series resistance, say, of 60 ohms. At 60 cycles, a capacitance of 25 mfd has a reactance of 100 ohms, approximately. The reactance, X_c is equal to $1/2\pi fC$, where π is 3.14, and C is the capacitance in farads. Now, the power factor is defined as resistance divided by impedance. Resistance and reactance combine at right angles, as shown in Fig. 2-6. In this example, the impedance will be 116.6 ohms. Accordingly, the power factor is equal to 60/116.6, or about 50%. A power factor might have any value from zero to 100%.

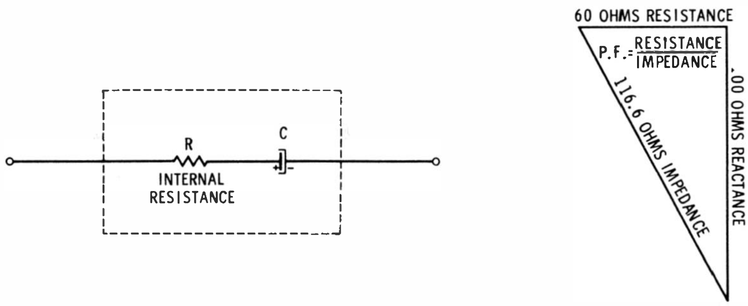


Fig. 2-6. Power factor defined as resistance divided by impedance.

Of course, the power factor would be different at some other frequency than 60 cycles. The reactance of the capacitor will be less at a higher frequency, such as 1 kc. In turn, the impedance will also be less, and the power factor will be greater. Evidently, it is meaningless to state the power factor of an electrolytic capacitor by itself; you must also note the frequency at which the power factor was measured. The only exception is when the capacitor has zero effective series resistance. Then, its power factor is zero at any frequency.

Leakage in Electrolytic Capacitors

A defective electrolytic capacitor often has leakage resistance. Unlike the situation depicted in Fig. 2-6, the leakage resistance is in shunt to the capacitor. Or, the leakage resistance acts as shown in Fig. 2-7. The leakage resistance is measured on a DC test as previously explained for small fixed capacitors. However, you must be careful to polarize the electrolytic capacitor correctly, because the leakage is commonly checked at the full rated working voltage.

Appreciable leakage resistance will result in incorrect readings of both capacitance and power factor. Hence, it is advisable to check an electrolytic capacitor for leakage first. If leakage is excessive, reject the capacitor without making further tests. If the leakage is satisfactorily low, proceed to

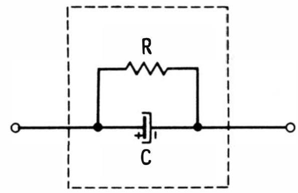


Fig. 2-7. Resistor R represents leakage resistance of capacitor C.

check out the electrolytic capacitor for its capacitance value and power factor.

Ohmmeter Test of Leakage

A limited test for leakage in an electrolytic capacitor can be made with an ohmmeter. Since as the leakage is usually greater at rated working voltage than at a low voltage, the resistance reading of the ohmmeter is not conclusive. Of course, if an electrolytic capacitor should show substantial leakage on an ohmmeter test, it should be rejected. An ohmmeter test is time consuming because it takes a long time for a large electrolytic capacitor to reach full charge through an ohmmeter circuit.

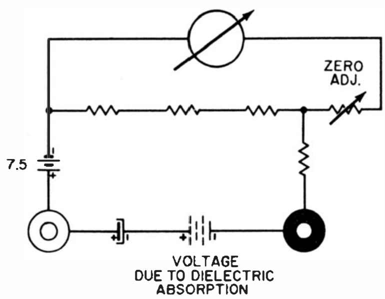


Fig. 2-8. Nature of dielectric-absorption voltage.

Dielectric absorption imposes another difficulty. Fig. 2-8 illustrates the nature of dielectric absorption. If an electrolytic capacitor is charged, and its terminals are then short-circuited, it might be supposed that all the charge is drained out of the capacitor. On the contrary, if the capacitor is allowed to stand open-circuited for a short time after the short-circuit is removed, a DC-voltage measurement will show that due to dielectric absorption a charge has built up.

In an ohmmeter test situation, any dielectric-absorption voltage adds to or subtracts from the ohmmeter battery voltage, thereby giving a false resistance reading. The reading will "crawl" as the dielectric absorption voltage gradually diminishes via the ohmmeter load. This annoyance occurs when an electrolytic capacitor is disconnected from a receiver for test; it also occurs when the capacitor has no residual absorption (has been short-circuited for a long time) if you switch ranges on the ohmmeter.

Temperature Coefficient of Electrolytic Capacitors

Capacitance and power factor of electrolytic capacitors varies with temperature, as illustrated for a typical capacitor in Fig. 2-9. Capacitance increases with temperature, and the power factor improves. On the other hand, leakage ordinarily

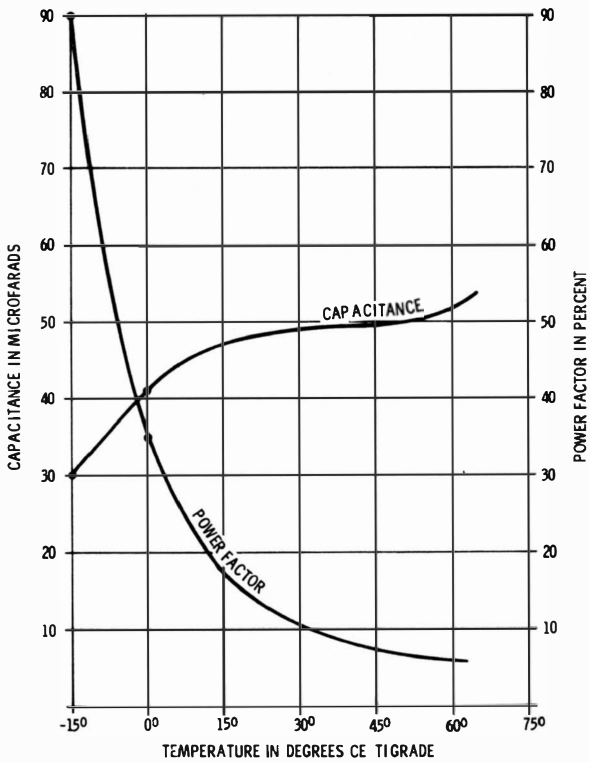


Fig. 2-9. Temperature coefficient of an electrolytic capacitor.

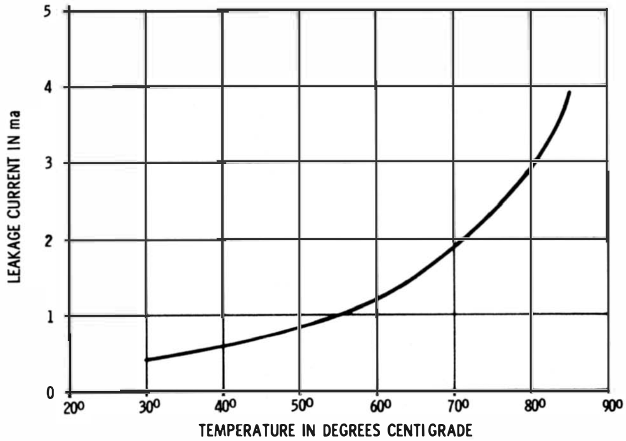


Fig. 2-10. Leakage current at rated working voltage for a typical electrolytic capacitor.

becomes greater as the temperature rises (Fig. 2-10). Clearly, you should test electrolytic capacitors at their ambient operating temperature in the receiver.

Temperature Effects

A small fixed capacitor might have a positive, negative, or zero temperature coefficient. If the temperature coefficient is positive, the capacitance increases with temperature. A negative temperature coefficient causes its capacitance to decrease with increasing temperature. Again, the capacitance change may be cyclic or noncyclic. A negative temperature-coefficient capacitor is carefully designed to have a cyclic coefficient, meaning that it will return to its original value when the temperature returns to its initial value. Capacitors with almost zero temperature coefficient are commonly called temperature-stable capacitors.

Defective capacitors which are thermally unstable change value objectionably, and often erratically, when subjected to heating and cooling cycles. If they are tested on a capacitor bridge, the null-point drifts when the pigtail is heated with a soldering gun. Such capacitors are definitely defective and should be rejected. If moderate heat does not cause a change in the capacitance value, a capacitor can still be mechanically faulty; it is good practice to tap the capacitor sharply while observing the null indication. Also, a chill spray can be used for further tests of thermal instability.

Leakage resistance commonly becomes lower when a capacitor is heated. If you raise the temperature of a moderately leaky capacitor on a bridge test, it will often become excessively leaky until it cools off again to room temperature. Sometimes the change is noncyclic, and the capacitor remains at its low value of leakage resistance. A capacitor which appears to be normal at room temperature can give a "bad" indication on the leakage test when its temperature is increased by 50 or 75 degrees.

CAPACITANCE METERS

Capacitance meters are easier to use than bridges because no null adjustment is required. A capacitance meter such as illustrated in Fig. 2-11 operates in the same manner as an ohmmeter. You will find a few VTVM's which also have capacitance

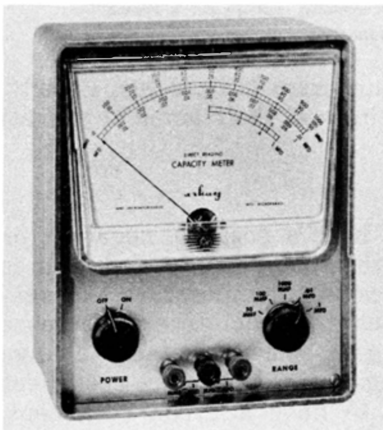
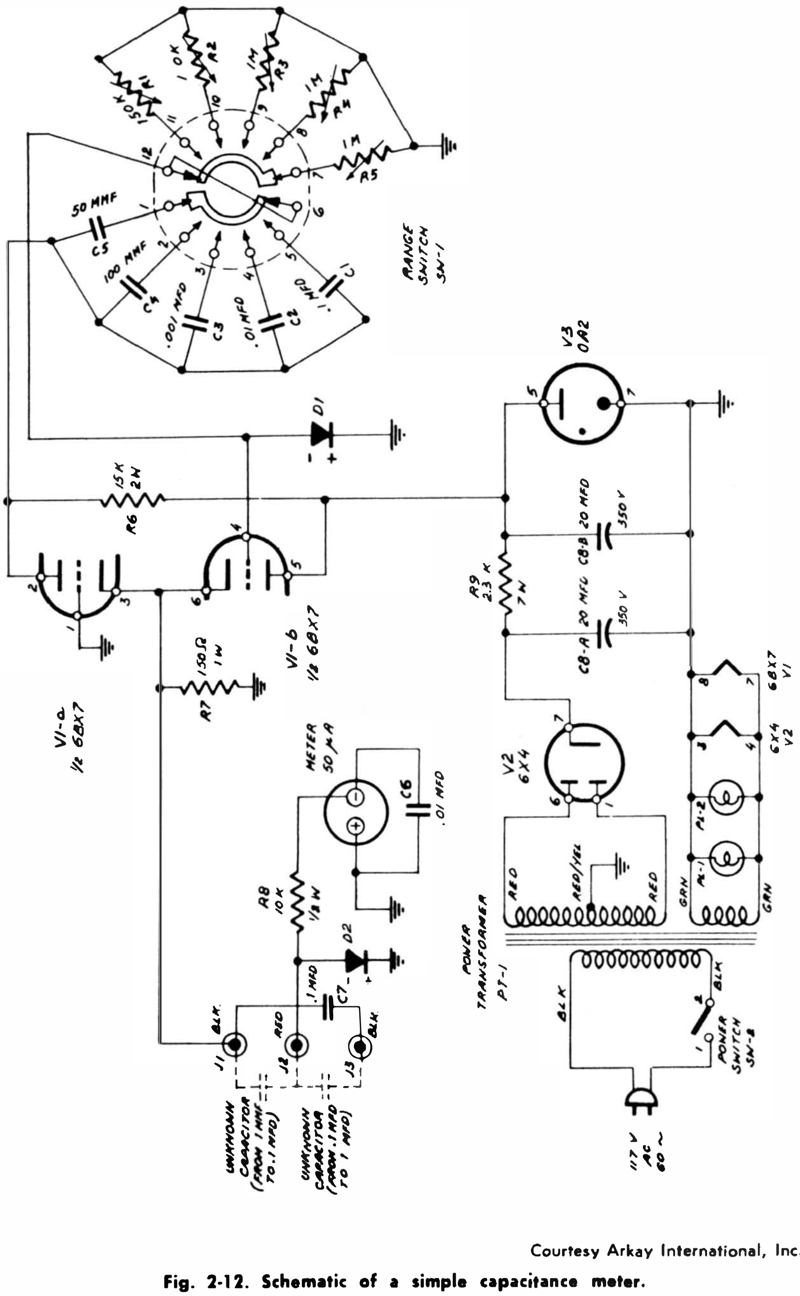


Fig. 2-11. A typical capacitance meter.

Courtesy Arkay International, Inc.

scales. There are two chief types of capacitance meters. One type operates from the 60-cycle line frequency while the other type operates from a wide range of frequencies generated by a built-in oscillator. A high test frequency permits measurement of small capacitance values, typically as small as 1 mmf.

Regardless of the test frequency employed, capacitance meters measure the AC that flows through the capacitor. Ohm's law for AC states that $I = E/X_c$, where X_c is the reactance of the capacitor. Since $X_c = 1/2\pi fC$, current flow $I = 2\pi fCE$, which means that if the capacitance is doubled the current also doubles. The circuit diagram for a simple capacitance meter



Courtesy Arkay International, Inc.

Fig. 2-12. Schematic of a simple capacitance meter.

is seen in Fig. 2-12. Its principle of operation is evident from the functional schematic shown in Fig. 2-13. The oscillator is a cathode-coupled multivibrator. Its operating frequency depends on the values of C and R. Output is taken from the cathode circuit and applied across the capacitor under test in series with the meter rectifier. The amount of current flowing through the meter circuit is proportional to the value of the capacitor under test.

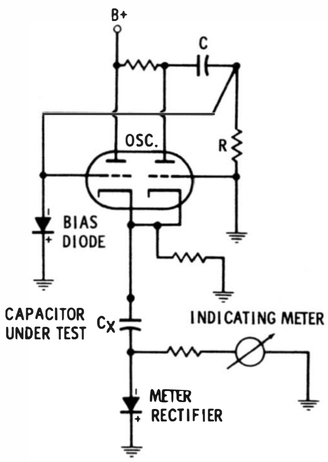


Fig. 2-13. Basic capacitance-meter circuit.

This type of capacitance meter does not check for leakage. However, more elaborate capacitance meters have a DC megohmmeter function for measuring leakage. A typical instrument tests all capacitors for leakage at 200 volts, and measures up to 1,000 megohms. Since the test voltage applied across the capacitor is not adjustable in this instance, the capacitor must have a rating of at least 200 working volts. Otherwise, it would be subject to damage in the leakage test.

VOM as Capacitance Meter

A rough test of the comparative capacitance of paper capacitors can be made with a VOM by means of the test method depicted in Fig. 2-14. In this example, the VOM has a sensitivity of 1,000 ohms per volt on its AC voltage ranges. Pointer deflection is proportional to current flow through the capacitor, or, larger capacitance values produce a greater pointer deflection. Before making a capacitance measurement the capacitor should first be tested for leakage. If it is leaky, it should be immediately rejected. In any case the VOM range switch should first be set to read line voltage (117 volts). If, for example, the capacitor is shorted, the meter reads the line voltage.

In case a small pointer deflection is observed, it is then safe to switch the VOM to a lower range. Capacitance measurements are made on the 10-volt range for the Fig. 2-14 configuration. Table 2-1 shows the approximate readings that will be obtained in testing capacitance values from 0.001 to 1 mfd. (This test method must not be attempted on any electrolytic capacitor.)

If no pointer deflection is observed, the capacitor is open. Note that open capacitors can often be found on an ohmmeter test. The ohmmeter must have a polarity-reversing switch. Set the ohmmeter to its highest range, such as R × 10,000. Connect the capacitor to the test leads. If any steady pointer deflection

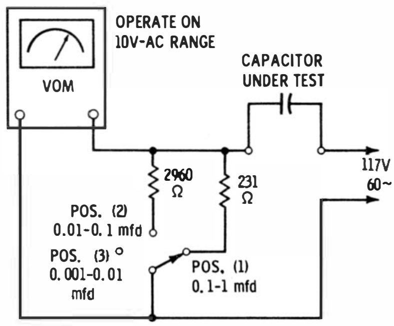


Fig. 2-14. VOM utilized as a capacitance meter.

takes place, the capacitor is leaky and should be rejected. If the pointer rests at infinity, you can proceed to an open test. Flip the polarity-reversing switch. If there is no pointer deflection, the capacitor is open. A ballistic deflection occurs if the capacitor has appreciable capacitance. A ballistic test can be made down to 0.01 mfd on a typical VOM.

VTVM's seldom provide for reversal of ohmmeter polarity. However, an external DPDT switch can be used for this purpose. It might be installed as a test jig on the service bench. Since a VTVM is much more sensitive than a VOM, you can make ballistic tests of comparatively small capacitance values. The VTVM is also a much more sensitive indicator of leakage.

QUICK TEST OF CAPACITOR LEAKAGE

It is often handy to make quick tests for leaky capacitors. One method is to charge the suspected capacitor from the B+ line. Wait a few seconds and short-circuit the capacitor. If

Table 2-1. Readings Obtained in VOM Capacitance Test

Unknown Capacitor Mfd	Meter Range	Approximate Reading AC Volts
	Pos. 1 in Fig. 2-14	
0.001	10 VAC	.6
0.002	10 VAC	1.1
0.003	10 VAC	1.5
0.004	10 VAC	1.9
0.005	10 VAC	2.5
0.006	10 VAC	3.0
0.007	10 VAC	3.6
0.008	10 VAC	4.0
0.009	10 VAC	4.4
0.01	10 VAC	4.8
	Pos. 2 in Fig. 2-14	
0.01	10 VAC	1
0.02	10 VAC	2
0.03	10 VAC	3
0.04	10 VAC	4
0.05	10 VAC	5
0.06	10 VAC	6
0.07	10 VAC	7
0.08	10 VAC	8
0.09	10 VAC	9
0.1	10 VAC	10
	Pos. 3 in Fig. 2-14	
0.1	10 VAC	1
0.2	10 VAC	2
0.3	10 VAC	3
0.4	10 VAC	4
0.5	10 VAC	5
0.6	10 VAC	6
0.7	10 VAC	7
0.8	10 VAC	8
0.9	10 VAC	9
1.0	10 VAC	10

there is no spark, the capacitor is very leaky or shorted and should be rejected. To test for high values of leakage resistance, observe how long the capacitor will hold a charge. The way in which a charged capacitor discharges through its leakage resistance is seen in Fig. 2-15. This is an exponential discharge—the discharge is fast at first and then slows down as the charge diminishes. The *time constant* of a leaky capacitor is equal to its capacitance in farads times its leakage resistance in ohms. For example, a 0.25-mfd capacitor with a leakage resistance of 10 megohms has a time-constant of 2.5 seconds. This means, in practical terms, that the voltage of the capacitor will decay to 37% of its original value in 2.5 seconds. To put it another way, if you charge this capacitor to 100 volts and then allow it to stand open-circuited, its voltage will fall to 37 volts in 2.5 seconds. This test is not useful on small-value capacitors.

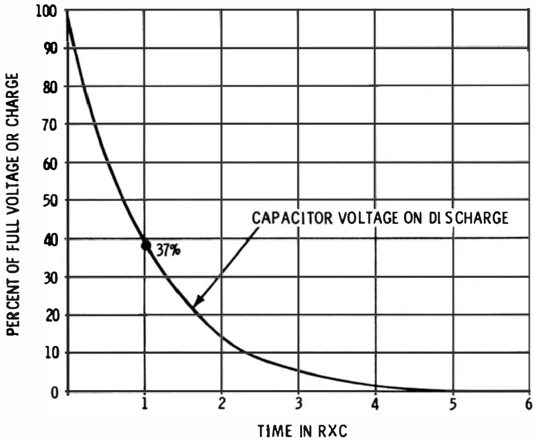


Fig. 2-15. Exponential curve of a capacitor discharging.

Another type of quick test is depicted in Fig. 2-16. The speaker in the radio or TV receiver being repaired serves as an indicator. It permits quick tests of comparatively small values of capacitors. When the capacitor under test is connected between the B+ line and the input to the audio amplifier, no click will be heard from the speaker if the capacitor is open. But if you hear a click, the capacitor is not open. As you

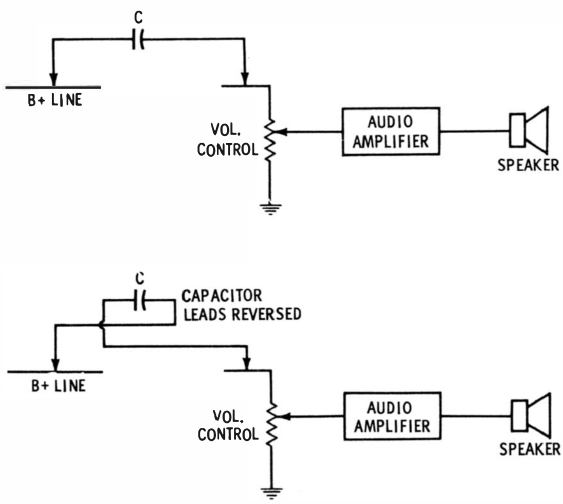


Fig. 2-16. If C is open, there is no click from the speaker in either the first or the second test.

make and break the circuit, a click might be heard every time; in this case the capacitor is leaky. But if no click is heard on successive contacts, even after several seconds of waiting between contacts, the capacitor is holding its charge. To cross-check, reverse the capacitor leads, as shown in Fig. 2-16. With a good capacitor, you should hear a click each time a reversal test is made.

IN-CIRCUIT CAPACITOR TESTS

When it is practical to do so, an in-circuit capacitor test is desirable because the capacitor does not have to be disconnected from its associated circuitry. There are various types of in-circuit capacitor testers available. One of these is simply

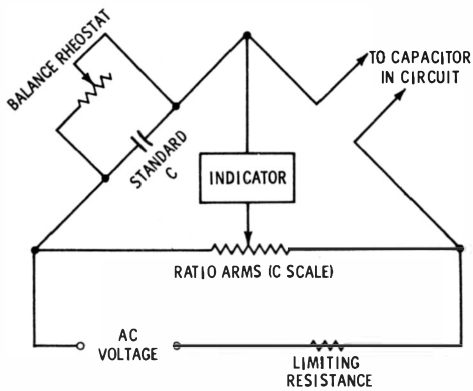


Fig. 2-17. Bridge for measuring capacitance shunted by resistance.

designed to measure the value of a capacitor, although shunted by some arbitrary amount of circuit resistance. The principle of the test is depicted in Fig. 2-17. This is a parallel RC bridge. It differs from an ordinary capacitance bridge in that a balance rheostat is provided across the standard capacitor in the bridge. When the test leads are connected across a capacitor shunted by circuit resistance, the balance rheostat permits a null-adjustment in conjunction with the ratio-arm adjustment.

The ratio arms are comprised of a precision wirewound potentiometer, with a scale calibrated in capacitance values. The indicator is commonly an eye tube. A complete null is obtained only when the balance rheostat is correctly adjusted and the potentiometer also correctly adjusted. An accurate reading of the capacitance value is then obtained. The chief limitation occurs when the capacitor under test is shunted by a low value of circuit resistance. Then, most of the test current flows through the shunt resistance and it is difficult to find a null on the potentiometer. This limitation can be minimized by operating the bridge at higher frequency.

In-Circuit Open and Short Quick Tests

Technicians often work against the clock and prefer to make preliminary quick tests of suspected open or shorted capacitors in operating circuits when it is possible. A coupling, decoupling, or bypass capacitor can be tested for an open simply by bridging it with a good capacitor. Then if circuit operation returns to normal, the conclusion is clear. The bridging test is useful to localize leaky filter capacitors in power supplies, as well as loss of capacitance. For example, when ripple voltage is excessive, it might be due either to loss of filter capacitance or a reduced time constant due to leakage. In either situation the defective filter capacitor can often be localized by bridging with a good electrolytic capacitor. The greatest reduction in ripple voltage is expected when the defective capacitor is bridged. Heat may also be a useful clue—a leaky electrolytic capacitor often runs hot. Likewise, a screen resistor runs too hot if the screen-bypass capacitor is leaking badly.

Suspected shorted capacitors can sometimes be localized by a short-circuit test. For example, consider an overload symptom which you think may be caused by a shorted cathode-bypass capacitor. Simply short out the suspected capacitor, and observe the change in receiver response, if any. A change in picture or sound reproduction shows that the capacitor is not shorted. If there is no change in response it could be due to a short in the capacitor.

VTVM In-Circuit Tests

To check for leaky in-circuit capacitors, various test methods have been devised. A VTVM may often serve as an in-circuit leakage tester for coupling capacitors. The basis of the VTVM test is seen in Fig. 2-18. With the receiver operating, B+ voltage is usually present on one side of a coupling capacitor, and normally there is very little or no voltage present on the other side. Hence, if C (Fig. 2-18), has appreciable leakage resistance R_L, a small (or sometimes large) current will flow through grid resistor R. This current flow produces across the grid resistor a voltage drop which is indicated by the VTVM.

An objection to this simple method is that small grid currents in tubes sometimes suggest a false conclusion concerning capacitor condition. This objection can be overcome in a parallel-heater system by unplugging the tube; in a series-heater system it is also possible to unplug the tube, provided semiconductor rectifiers are used in the power supply. But if the power supply employs a rectifier tube in the heater string, heater continuity must be maintained by some means. Either a dummy tube must be used (grid pin cut-off), or possibly the heater terminals in the socket could be jumpered.

When the tube cannot be simply unplugged, less time may be consumed by disconnecting one end of the capacitor and making a conventional leakage test as shown in Fig. 2-19. A VTVM ohmmeter is not an ideal function for a coupling-capacitor leakage test because the operating voltage is usually only 1.5 volts, whereas the plate voltage in the receiver might be 150 volts or more. Thus, the test depicted in Fig. 2-19 is approximately 100 times more sensitive than a VTVM ohmmeter test.

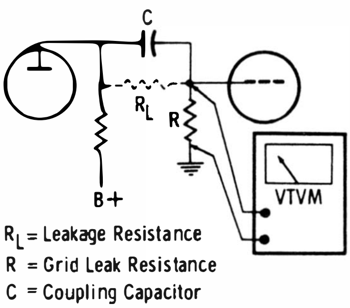


Fig. 2-18. Test for leakage current.

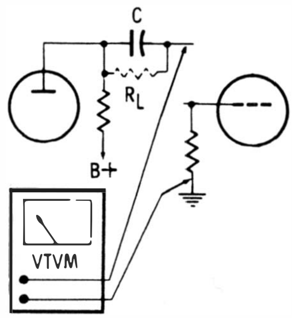


Fig. 2-19. Sensitive leakage test.

Three-Lead In-Circuit Tests

To facilitate in-circuit test for leakage of coupling capacitors, manufacturers have developed an instrument that operates on the principle depicted in Fig. 2-20. Three test leads are used. One lead applies approximately 100 volts DC to the plate side of the coupling capacitor C; the second lead connects to ground or B– in the receiver, and the third lead is connected across the grid-leak resistance R. The test is made with the receiver "dead." Hence, no grid-current problem can be encountered. An eye tube is used as the indicator and leakage current through R_L causes the eye to open. With average values of grid-leak resistances this type of test will indicate leakage resistance as high as 50 megohms.

Sometimes this form of test is provided as a function of a more complex capacitor tester, as illustrated in Fig. 2-21. In this case, a meter is used as an indicator of leakage, instead of an eye tube, and comparatively high values of leakage resistance can be detected. However, it is evident that the meter

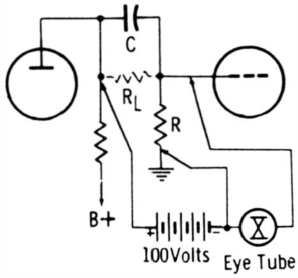


Fig. 2-20. Basic three-lead in-circuit leakage test.

Courtesy Simpson Electric Co.

must indicate on the basis of a Good-Bad scale, since the value of the grid-leak resistance is arbitrary. This makes it impossible to calibrate the meter scale accurately in resistance values for in-circuit tests.

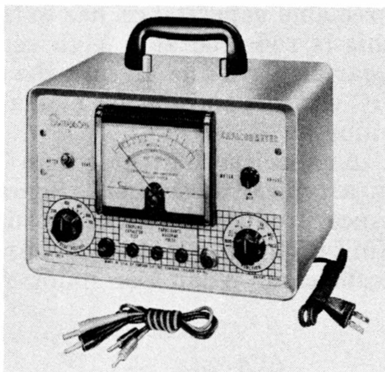


Fig. 2-21. Capacitor tester using a three-lead test.

Open-and-Short In-Circuit Tests

A much more difficult test problem is presented by capacitors that are shunted by resistance in-circuit. This is the situation encountered with plate-bypass, screen-decoupling, and AGC-delay capacitors for example. The leakage resistance R_L of the capacitor (Fig. 2-22) is directly shunted by the circuit resistance so that a three-lead test cannot be made. In-circuit tests are usually restricted to detection of dead-shorted and open-circuited capacitors. Most of the two-lead, in-circuit capacitor testers in present use operate with this restriction.

This type of instrument operates at RF and provides separate tests for open-circuited and short-circuited capacitors. The principle of the open-circuit test is seen in Fig. 2-23. A 6C4 oscillator which operates at approximately 20 mc is used. The test cable with the loading coil (L) represents a quarter-wave line at the operating frequency. Hence, a short at the output end of the cable will be reflected back as an open circuit at the input end (and vice versa).

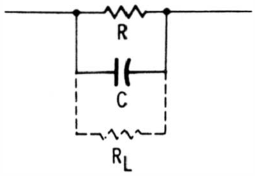


Fig. 2-22. The value of R_L when C is shunted by R is a difficult test.

The RF voltage at the input end of the cable is rectified by the crystal diode and applied to the eye tube which is normally open. When the test leads are applied across an open capacitor, the terminal conditions for the cable are essentially unchanged, and the eye remains open. However, a capacitor with appreciable capacitance has extremely low reactance at 20 mc; this is reflected as a high reactance to the input end of the quarter-wave line. In turn the eye tube is driven by appreciable DC voltage, and the eye closes in proportion to the capacitance value.

A capacitance greater than 20 mmf closes the eye completely in a typical instrument. Somewhat smaller values of capacitance produce a partial closure of the eye. Again, the chief limitation in this test is imposed by small values of shunt resistance. When the shunt resistance is less than 50 ohms

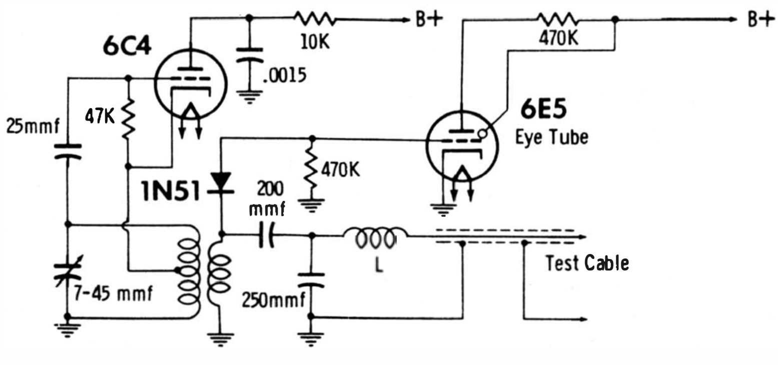


Fig. 2-23. Basic circuit for the "opens" test in the RF-type checker.

an open capacitor will seem to test good. Inasmuch as higher values of shunt resistance tend to produce partial closure of the eye, the instrument cannot be used to measure or estimate capacitance values.

The principle of the short-circuit test is depicted in Fig. 2-24. The 6.3-volt 60-cycle, AC source voltage serves to keep the eye normally closed. Note that if the test leads are shorted together, the bias on the 6E5 grid is "killed," which causes the eye to open. Leaky capacitors cannot be detected by this test, inasmuch as practically a dead short is necessary to open the eye. Moreover, shunt resistance of 20 ohms or less will open the eye and mask the test. Likewise, very large electrolytic capaci-

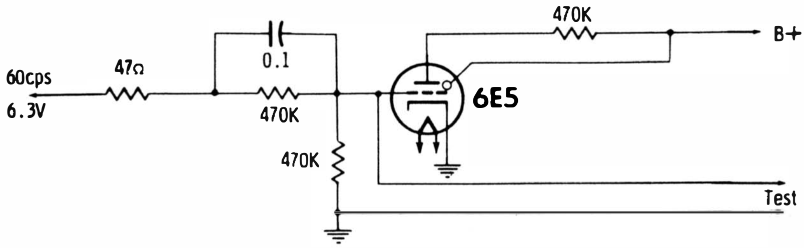


Fig. 2-24. A shorted capacitor kills the bias on the 6E5 and opens the eye.

tors (2,000 mfd or greater) cannot be tested because their normal reactance is practically a short circuit. Intermittent capacitors can sometimes be picked up on the permissible tests by tapping which may cause the eye tube to flicker.

Borderline Test

In-circuit tests of borderline capacitors that have a poor life expectancy are made by a pulsing technique. This function is provided by the instrument illustrated in Fig. 2-21. The pulsing test will detect capacitors which are sufficiently leaky that they would be "caught" by a VOM ohmmeter if an out-of-circuit leakage test were made. The principle of the test is shown in Fig. 2-25. A 1,000-volt DC source is used to charge up a 1-mfd capacitor that periodically discharges through a thyratron tube, thereby generating a sharp pulse voltage.

The test voltage applied by the pulse is determined by adjusting the grid bias on the thyratron, as required. The pulse waveform is developed across a 600-ohm resistor. It is effectively an AC pulse with an average value of zero. The pulse current flows through a 50 μa DC meter to the hot test lead. The meter is practically completely bypassed for AC. It will not deflect unless a DC component is generated during the in-circuit test. Note that when the test leads are connected across a resistor no pointer deflection occurs in most cases; however, if the resistance has a very low value the pointer will tend to oscillate the scale.

In application, a DC component flows in the meter circuit when the test leads are connected across a borderline capacitor. In this instance, the comparatively low leakage resistance between the capacitor electrodes tends to break down at the peak voltage of the pulse. Disproportional current, which indicates partial rectification, flows on the peaks. In turn, the pointer deflects on the meter scale. A good capacitor will withstand at least 50% overload on a pulse test, without developing a detectable DC component. The question is sometimes asked why a pulse waveform is best adapted to this test; the reason is that comparatively little power is dissipated by the shunting resistance at the peak voltage of a narrow pulse. In turn, circuit resistors are not heated appreciably, even though the test might employ several hundred peak volts.

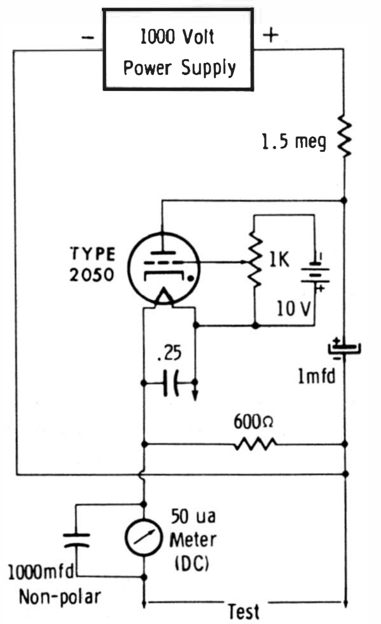


Fig. 2-25. Working-voltage pulse-test circuit.

Just as pulse tests cannot advantageously be made across low values of shunt resistance, neither can capacitors which are shunted by inductance be tested. One end of the capacitor must be disconnected and an out-of-circuit test made. Pulse tests are unsuitable for electrolytic capacitors because there is an inherent rectifying action that falsifies the test indication. You will find that if you apply an AC voltage to an electrolytic capacitor, such as 3 volts in a capacitor-bridge test, a DC voltmeter connected across the capacitor will show that partial rectification is occurring.

Input Capacitance of Scope

Measuring the input capacitance of a scope is easily accomplished by means of the test shown in Fig. 2-26. An audio oscillator and a trimmer capacitor are utilized. The trimmer is connected in series between the vertical-input terminal of the scope and audio oscillator. The audio oscillator is set to a fairly high frequency, such as 100 kc. The trimmer capacitor is short-circuited in the first part of the test, and the vertical deflection is noted on the scope screen.

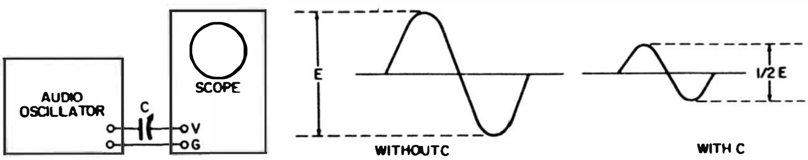


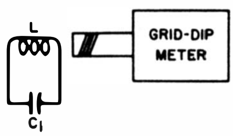
Fig. 2-26. Measuring input capacitance of an oscilloscope.

Next, the short circuit is removed from the trimmer capacitor, and the trimmer is adjusted to obtain one-half of the original deflection. Finally, the trimmer is disconnected, and its capacitance is measured on a capacitor bridge or meter. The value thus measured is the input capacitance of the scope. This test is based on the fact that a scope input resistance is very high and can be neglected with respect to the reactance of the input capacitance at 100 kc. For example, a capacitance of 25 mmf has a reactance of about 60K at 100 kc, whereas the input resistance of the scope will be 1 megohm or even higher. Thus, the input resistance introduces negligible error into the measurement.

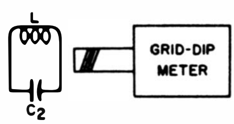
The input capacitor (blocking capacitor) of an AC scope can be easily quick-checked for leakage. A source of 300 or 400 volts DC is desirable, such as from the low-voltage power supply in the scope or from a radio or TV receiver. Apply the DC voltage to the vertical-input terminal of the scope with the vertical-gain control advanced to maximum. The trace will flick off-screen and then return. Remove the DC voltage from the vertical-input terminal, and wait a few seconds. Reapply the voltage, and observe the trace. Little or no deflection should be observed. If the trace flicks off-screen, the blocking capacitor is leaky and has not held its charge.

Distributed Capacitance

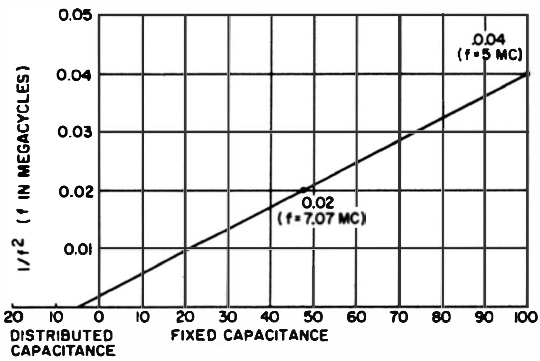
When you wish to test a capacitor that is connected across a coil, an in-circuit test is not advised because it is fairly involved. Under ordinary circumstances you will clip one lead of the capacitor from the coil and make an out-of-circuit test. However, occasions arise in which we need to know the value of distributed capacitance in a coil. The coil winding cannot be disconnected from its distributed capacitance, of course, hence, there is no choice but to make an in-circuit test of the capacitance value.



(A) First test where C_1 equals 47 mmf.



(B) Second test where C_2 equals 100 mmf.



(C) Plot of readings obtained in tests.

Fig. 2-27. Measurement of distributed capacitance.

The test can be conveniently made with a grid-dip meter and two, small, fixed capacitors rated for $\pm 1\%$ tolerance. The equipment is connected as depicted in Fig. 2-27A. In this example a 47-mmf capacitor is placed in parallel with the coil for Test 1. The resonant frequency measured with this combination is 7.07 mc. Therefore, the value for $1/f^2$ when the 47-mmf capacitor is used is 0.02. When a 100-mmf capacitor is used for C_2, in Test 2 (Fig. 2-27B), the resonant frequency measured for the combination is 5 mc; or, $1/f^2$ is now 0.04.

Mark off the vertical and horizontal axes of the graph linearly as shown in Fig. 2-27C. (Values assigned to each division will depend on the range of the two readings which in turn depend on the particular L and C values). Plot the $1/f^2$ values against the capacitance values, as shown. Then draw a straight line connecting the two plotted points, and extend the line until it intersects the capacitance axis, as shown. The distributed capacitance of the coil (5 mmf in this example) is found at the point where the drawn line intersects the capacitance axis.

This test method is algebraically derived from the resonant-frequency formula $f = 1/2\pi\sqrt{LC}$, and the derivation is left as an exercise for the reader who may be mathematically inclined.

CAPACITANCE OF COAXIAL CABLE AND TWIN LEAD

The input cable to a scope, as an example, has a certain capacitance. It also has some inductance and resistance. However, the inductance is comparatively small, and the resistance is very low. Therefore, this is a form of in-circuit capacitance measurement that is easy to make.

Twin lead has less capacitance per unit length than coaxial cable. However, its capacitance is the most prominent parameter at low frequencies. The capacitance of either coaxial cable or twin lead can be measured on an ordinary 60-cycle capacitor bridge, with the far end of the cable or lead left open. The measurement can also be made on a 1-kc capacitor bridge for any reasonable length of cable. It is impossible to measure cable capacitance directly on an RF bridge, however, because the distributed inductance then resonates with the distributed capacitance. We say that a section of coax cable acts as a tuned stub when tested at RF. This makes it necessary to use a comparatively low test frequency when measuring cable capacitance.

Measurements of cable capacitance are also used to quickly find the length of a cable. For example, if you measure the capacitance of a 1-foot sample of cable you might read a capacitance of 10 mmf. Then if the capacitance of an unknown length of cable is measured at 1,000 mmf, its length is 100 feet.

TESTS OF HIGH-VOLTAGE FILTER CAPACITORS

High-voltage filter capacitors can be checked for capacitance value with a capacitor bridge or capacitance meter; leakage tests must be made at rated working voltage to be valid. The flyback power supply of a TV receiver is a suitable source of this test voltage. Select a receiver that provides an accelerating voltage equal to, or slightly greater than, the rated working voltage of the capacitor under test. The voltage can be conveniently measured with a VTVM and high-voltage probe. Note that the value of the accelerating voltage can be varied within a moderate range by adjustment of the horizontal-drive control and the brightness control. To test for leakage, connect the capacitor in series with the high-voltage supply and the high-voltage probe of the VTVM. Any pointer deflection is objectionable and should be regarded as sufficient reason for rejecting the capacitor.

The aquadag coating used on many glass picture tubes is one electrode of a high-voltage capacitor. The other terminal of the capacitor is the receptacle for the high-voltage lead. To measure the capacitance, a pair of clip leads may be used with a capacitor bridge or capacitance meter. Clip one lead to the high-voltage receptacle of the picture tube and the other lead to the aquadag coating; light pressure will make a satisfactory contact. A typical reading of 900 mmf will be obtained if the coating is in good condition. Scratched-up coatings may give various subnormal readings when tested at different points. The coating can be repaired in such case by means of aquadag paint.

WAVEFORM TESTS OF CAPACITORS

A scope is useful for checking suspected open capacitors. Consider C41 in Fig. 2-28. If it is open, little or no image appears on the picture-tube screen. To find out if C41 is open,

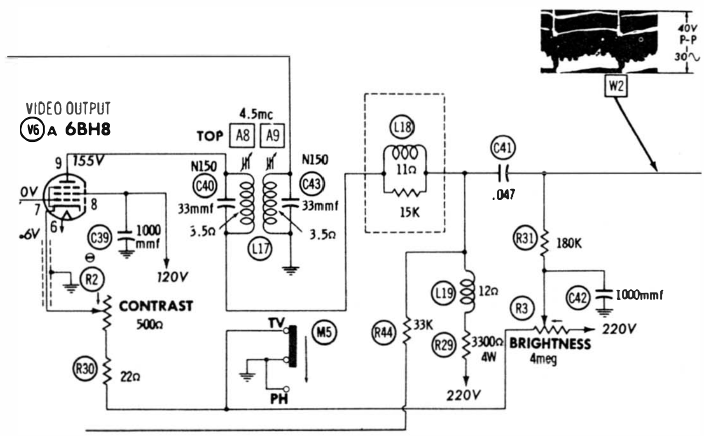


Fig. 2-28. Waveform W2 normally found on both sides of C41.

simply check the waveform on both ends of the capacitor. In case it is open you will find W2 at the input end of the capacitor but absent at the output end. Again, consider the situation in which C41 might have lost a considerable portion of its normal capacitance. In this case you will measure 40 volts peak-to-peak at the input end of the capacitor but substantially less peak-to-peak voltage at the output end. This condition corresponds to low contrast in the picture.

Always use a low-capacitance probe for waveform tests, unless otherwise specified in the receiver service data. A low-capacitance probe minimizes circuit loading. For example, if a direct cable is used to check the waveform in Fig. 2-28, sub-

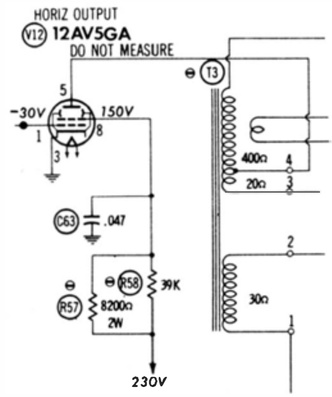


Fig. 2-29. Bypass capacitor C63 normally holds screen at AC ground.

stantial capacitance is shunted across the comparatively high-impedance circuitry. Consequently, the displayed waveform becomes distorted and reduced in amplitude.

Bypass Capacitors

A bypass capacitor is basically a short circuit for AC. For example, C63 in Fig 2-29 has the purpose of holding the screen grid effectively at AC ground potential. If you check with a scope across C63 you will normally find very little waveform amplitude. But suppose C63 were open; then a very large waveform amplitude would be displayed on the scope screen. Note that the screen grid is not "dead-shorted" to AC ground by C63, because the reactance of an 0.047-mfd capacitor at 15,750 cycles is about 200 ohms. The screen resistors have a value of about 8K. Hence, a small residual waveform is normally found across C63. The important point is this—in normal operation the screen grid is at AC ground potential, from a practical viewpoint.

Filter Capacitors

Waveform tests are also useful to determine defective filter capacitors (Fig. 2-30). For example, the output ripple voltage from the power supply is normally about 0.5 volt and has the waveform illustrated. Now if C1, C2, or C3 should lose substantial capacitance or develop a high power factor, the waveform amplitude will increase considerably, and its waveshape will change. In this case, bridge each of the filter capacitors in turn with a good electrolytic capacitor while watching the ripple waveform on the scope screen. When the defective capacitor is bridged, the waveform will return to normal.

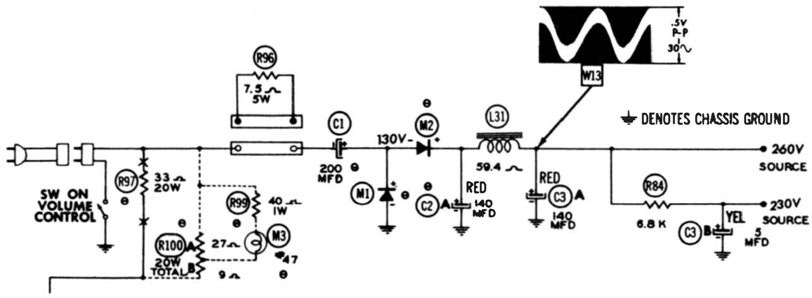


Fig. 2-30. Waveforms indicate condition of filters.

Signal-Circuit Capacitors

Waveform tests are also useful to localize open capacitors in signal circuits. IF circuitry such as depicted in Fig. 2-31 is checked with a demodulator probe. Consider a situation in which there is little or no output from the IF amplifier. Then C39 or C43 might be open. To test these coupling capacitors,

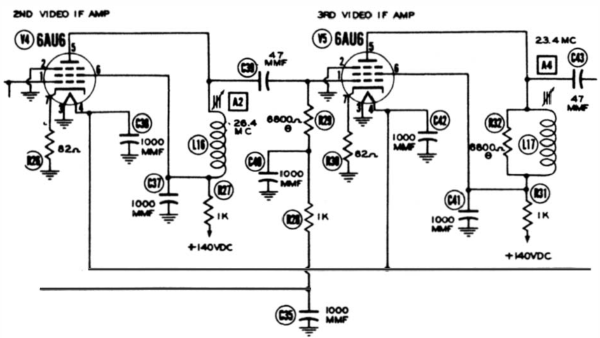


Fig. 2-31. C39 and C43 are checked for an open condition with a demodulator probe and scope.

simply use a demodulator probe and scope to check the progress of the video signal. If you find the video waveform present at the input end of coupling capacitor but absent at the output end, the capacitor is open.

A demodulator probe is also useful to check for open bypass and decoupling capacitors. Practically no video signal will normally be found across C37, C40, or C41 in Fig. 2-31. However, if one of the capacitors is open, there is substantial video signal across the defective capacitor in a demodulator-probe test since there is no bypassing action present.

OUT-OF-CIRCUIT SCOPE TEST

If you do not have a capacitance bridge available, you can use a scope to test an electrolytic capacitor for power factor, as depicted in Fig. 2-32. The voltage drop across the 150-ohm

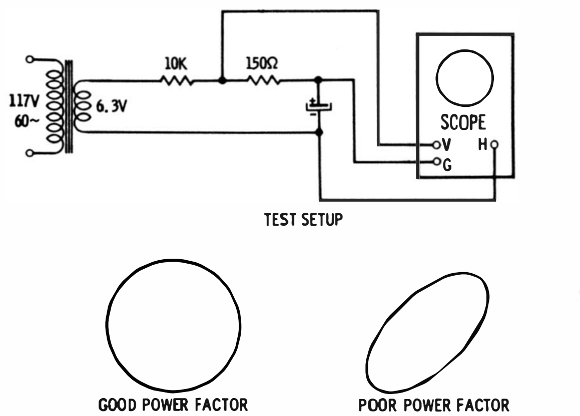


Fig. 2-32. Oscilloscope test of the power factor of an electrolytic.

resistor is proportional to current and is applied to the vertical-input terminals of the scope. The voltage drop across the electrolytic capacitor is applied to the horizontal-input terminals of the scope. Now if the power factor of the capacitor is zero (or very small) you can adjust the gain controls of the scope to obtain a perfect circle on the screen. However, if the power factor is poor, the pattern is an ellipse and cannot be displayed as a circle no matter how the gain controls are adjusted. In case the power factor is extremely poor (equal to 1), you will see a straight, diagonal line on the scope screen. Note that you can calculate the value of the power factor from the scope pattern. Evaluate the pattern as follows:

Center the pattern carefully on the screen. Now note the two points A and B along the vertical axis, as shown in Fig. 2-33. Count the number of vertical intervals to A and to B and divide A by B. This will give you a fraction which is related to the power factor. The power factor is calculated as:

$$\text{Power Factor} = \sqrt{1 - (A/B)^2}$$

The power factor thus calculated is the same as the power factor that you would read on a capacitance bridge. Note that for a perfect circle, A and B have the same values in Fig. 2-33.

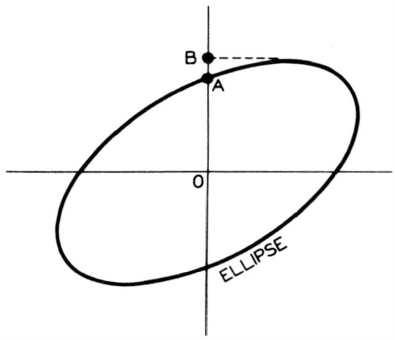


Fig. 2-33. Phase angle is given by A and B.

It follows that in this case A/B is equal to 1, and the power factor is equal to zero. Now suppose a straight, diagonal line is displayed on the scope screen. Then A is equal to zero and A/B is equal to zero. Here the power factor is equal to 1.

Accuracy of the measurement depends on use of a good sine waveform in the test of Fig. 2-32. If the power line has a poor waveform, it is advisable to use an audio oscillator as a source of 60-cycle test voltage.

SECTION 3

Inductive Components

Although all electronic components are inductive, an inductive component is defined as one in which inductive reactance is the dominant parameter. Inductive reactance is similar to capacitive reactance in that it stores energy. Inductive reactance is measured in ohms—it opposes current flow but does not dissipate energy. The inductor stores energy in its magnetic field. The principle of inductive reactance is basically very simple; inductance in electronics resembles weight or mass in mechanics.

INDUCTANCE ANALOGY

Consider a water pipe that is bent in a circle and connected to a pump. As explained in the previous section, the pipe can be compared to an electric circuit, and the pump can be compared to a battery. Now, let "inductance" be placed in the pipe; this can take the form of a metal ball or piston that is free to move inside the pipe. The piston has weight, or mass. The heavier is the piston, the greater is its "inductance." When the pump is started, water presses against the piston. However, because the piston has mass, it does not respond instantly; it starts to move slowly and gradually gains velocity.

Although the pump initially applies maximum force (voltage) across the piston, the motion (current) is zero at first. Then, as the piston begins moving, the applied force is relieved (voltage is reduced) while the velocity of the piston (current) starts to rise. As the action continues, the piston moves even faster (current increases), and the rapid movement decreases the pressure across the piston still more (voltage decreases). It is clear that the current maximum occurs latest, at the time of zero voltage. Conversely, the voltage maximum occurs first, at the time of zero current. This is simply another way of saying that current and voltage are 90° out of phase.

CURRENT LAG

The current lags the voltage because the current maximum occurs later than the voltage maximum. The piston, once accelerated into motion, has stored energy. In other words, it tries to continue its forward motion when the pressure (voltage) is absent. Now, although voltage is zero, current is maximum. If the pipe valve is opened, the energy of the moving piston will cause water to spurt out of the pipe. In an electric circuit containing inductance the energy of the magnetic field in the coil will cause a spark when the circuit is opened, analogous to the spurt of water from the pipe.

When a coil is connected in series with a circuit, its inductive reactance opposes current flow. This is a different kind of opposition from that imposed by resistance, because inductance stores energy instead of dissipating it. Inasmuch as the current in an inductive circuit is 90° out of phase with the current in a resistive circuit, inductive ohms must be added at right angles to resistive ohms. Inductive reactance is expressed as $X_L = 2\pi fL$. Hence, inductive reactance increases with frequency. It is meaningless to state that an inductor has such-and-such ohms of reactance, unless the test frequency is given. Ohm's law states that $I = E/X_L$.

Consider an inductor that has 100 ohms of inductive reactance at the frequency of test. If this inductor is connected in series with a 100-ohm resistor, the resistive ohms are drawn as the base of a right triangle, and the inductive ohms are drawn as the altitude of the triangle. Then, the hypotenuse, which is equal to 141 ohms (approximately), is the impedance of this RL circuit. Ohm's law states that $I = E/Z$, where Z is the impedance of the circuit.

Inasmuch as the current lags the voltage in an inductive circuit, but leads the voltage in a capacitive circuit, inductive reactance is opposite to capacitive reactance. Suppose a hypothetical series circuit with a 100-ohm capacitive reactance and a 100-ohm inductive reactance. The two reactances cancel, and the result is a circuit reactance of 0. Again, suppose a circuit with a 100-ohm capacitive reactance is in series with a 50-ohm inductive reactance. Then only 50 ohms of capacitive reactance are cancelled, and the circuit acts simply as a capacitive reactance of 50 ohms.

SERIES AND PARALLEL RESONANCE

Now assume that we have a series circuit comprising a 100-ohm resistance, a 100-ohm inductive reactance, and a 100-ohm capacitive reactance. The reactances cancel out, leaving a circuit resistance of 100 ohms. However, this resistance is seen only at the frequency at which the inductor and capacitor each have 100 ohms of reactance. For example, a ohmmeter test of this series LCR circuit would indicate an infinite resistance. This is because the ohmmeter makes a zero-frequency test. Now suppose the LCR circuit is tested on an AC Wheatstone bridge, driven at the frequency at which the inductor and capacitor each have 100 ohms of reactance. Then, the bridge indicates a resistance of 100 ohms—the bridge sees only the 100-ohm resistor at this resonant frequency.

Next, suppose that the 100-ohm inductive reactance is connected in parallel with the 100-ohm capacitive reactance. This time, the reactances do not cancel each other. Instead, the total reactance must be found just as the total resistance of two resistors connected in parallel is found: $X_T = X_L X_C / X_L + X_C$, and if this is calculated for the foregoing values, the value is $X_T = 10{,}000/0$, a number which for practical purposes is considered to be infinite, meaning that the total reactance X_T of the parallel combination is infinite. This is simply the distinction between parallel resonance and series resonance.

All inductors have distributed capacitance, which makes the tuning coil in a broadcast receiver self-resonant (parallel resonant) at some upper frequency. All inductors have some winding resistance, which means that their effective reactance is less than infinite at their self-resonant frequency. The AC resistance of a coil in a parallel-resonant circuit makes the coil appear to be a resistor at its resonant frequency. The value of this apparent resistance at resonance has a value of approximately L/RC ohms.

With this basic understanding of the electrical action in an inductive circuit, one is in a good position to consider how inductance values are measured, and how inductive components are tested. Different methods are employed to test various types of inductive components. All these methods are based on the principle of inductive reactance.

DC RESISTANCE TESTS OF COIL WINDINGS

Inductors are generally more complex components than capacitors in that they have substantial series resistance. This resistance makes it more difficult to measure inductance values than to measure capacitance values—the winding resistance usually cannot be neglected in practical test procedures. When AC voltage is applied to a paper or mica capacitor, the current flow is determined by the reactance of the capacitor. On the other hand, when AC voltage is applied to typical inductors, the current flow is determined by the impedance of the inductor. In turn, the impedance must be separated by the test into its resistance and reactance components before the inductance can be determined. These requirements are subsequently explained in greater detail.

Since most coils and transformers have appreciable series (winding) resistance, this parameter is often selected as the basis of preliminary tests. Thus, an ohmmeter measurement is made of the winding resistance, and the ohmmeter reading is compared with the value specified in the receiver service data. Examples of specified winding resistances are given in Fig. 3-1. An infinite reading means that the winding is open. A zero reading indicates a completely shorted coil. These test results show that a coil or transformer is definitely defective. There is a serious limitation encountered in this test when there are a few shorted turns in the winding. The DC resistance decreases so slightly that the fault is not noticeable on the ohmmeter. However, a few shorted turns cause a large change in the AC characteristics of the component and impair receiver operation. Hence, supplementary tests are required to localize such defective inductors.

WAVEFORM TESTS

Waveform tests are in-circuit checks. Note the waveforms illustrated in Fig. 3-1. The waveforms are characterized by waveshape and amplitude. When an inductor is defective, the associated circuit waveform is changed. This is a much more definitive test than a DC resistance measurement. This is a vital point as the amplitude (peak-to-peak voltage) of the waveform is as significant in trouble analysis as is the waveshape.

In other words, a defective winding might cause a change in waveshape only; or, it might cause a change in amplitude only; again, it might cause a change in both waveshape and amplitude. These effects have their causes, and the astute technician trains himself to reason backward from effect to cause. If his reasoning is correct, he can then pinpoint a defective inductor that is causing a trouble symptom. Waveform

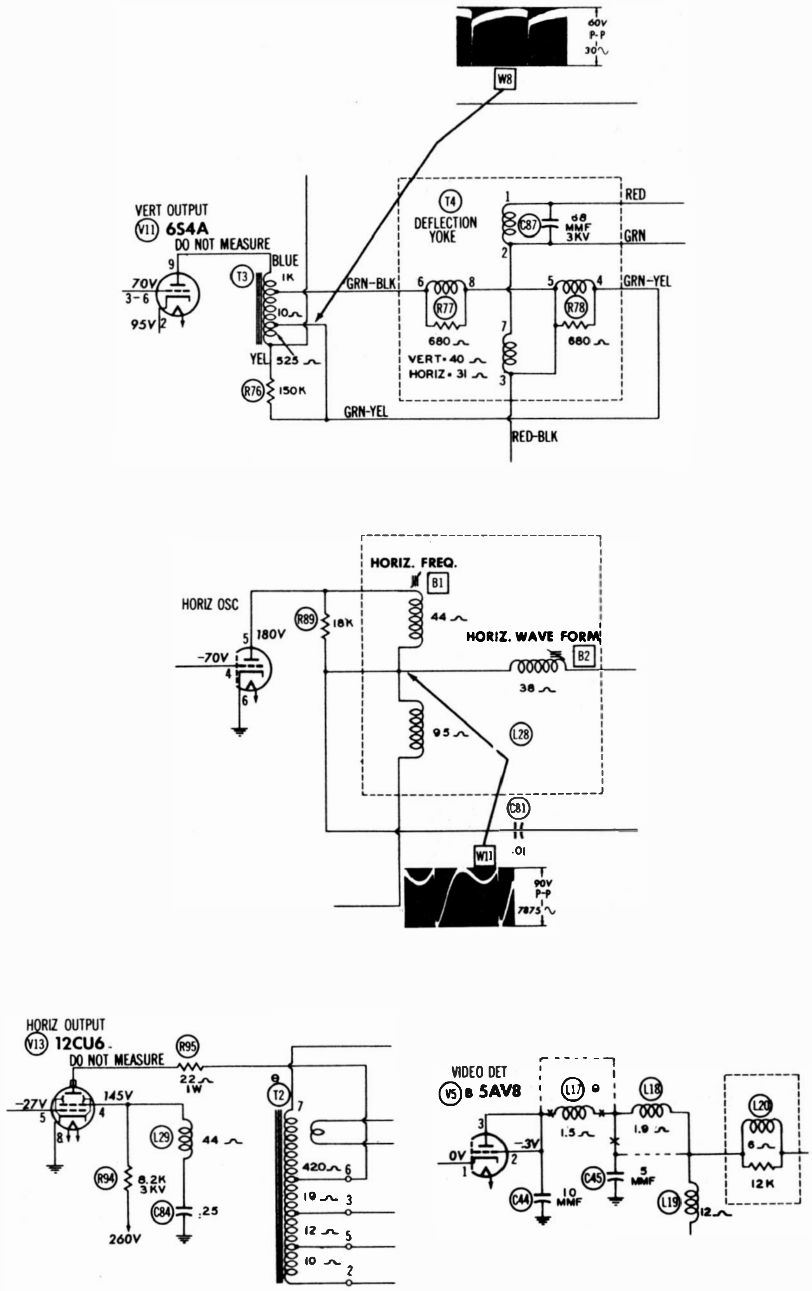


Fig. 3-1. Typical winding-resistance specifications.

analysis is seldom easy, and requires considerable study, plus experience, before proficiency is acquired.

Waveform tests are generally made with a low-capacitance probe. The probe minimizes circuit loading. The waveforms specified in receiver service data are always taken with a low-capacitance probe, unless otherwise noted. The chief exception to the use of a low-capacitance probe is found in the

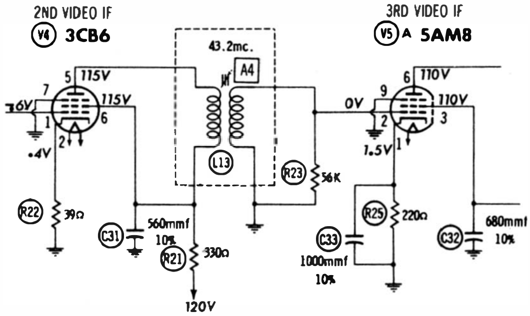


Fig. 3-2. Signal-circuit coil tested with demodulator probe.

high-frequency signal sections. For example, waveforms tests of the IF coils (Fig. 3-2) are made with a demodulator probe. If a waveform is present at the plate of V4, but little or none at the grid of V5, strong suspicion is cast on the secondary winding of L13.

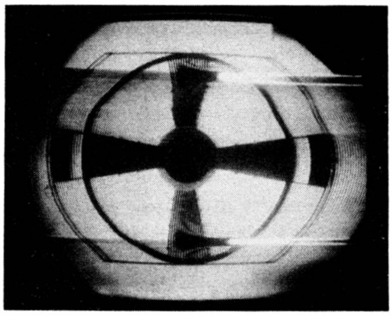


Fig. 3-3. Pattern showing regenerative IF amplifier.

Transformer coils in IF amplifiers are tuned. For example, L13 in Fig. 3-2 is normally peaked to 43.2 mc. Suppose a picture symptom such as the one illustrated in Fig. 3-3 is observed. This is a typical IF-regeneration symptom. The first test to make in this case is to check the *resonant frequency* of each transformer. When the grid and plate coils of an IF stage are peaked near the same frequency, a TPTG oscillator action often results. In other words, the troublesome coil is not defective—it is merely tuned to an incorrect frequency.

PEAKING-FREQUENCY TESTS

To check the resonant frequencies of IF coils, an IF sweep and marker generator is used with a scope. The test signals are applied to a floating tube shield over the mixer tube. The scope is connected through a 50K isolating resistor to the video-detector output. An override bias of −3 volts is applied to the AGC bus. It is often advisable to disable the local-oscillator tube in the front end, to avoid the possibility of confusing spurious markers.

Set the marker generator to the peaking frequency specified in the receiver service notes. A marker appears on the IF response curve, as illustrated in Fig. 3-4. Turn the slug in the coil until the marker rises to a maximum height above the base line, and starts to fall. Leave the coil slug set for maximum marker height. The coil or transformer is now peak-aligned. Repeat the procedure for each IF stage. Of course, an IF coil that cannot be tuned through the specified peaking frequency is probably defective—but first be sure that the associated circuit capacitors and resistors are not defective.

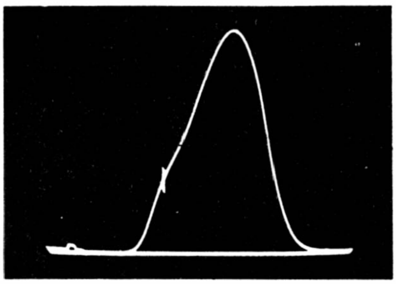


Fig. 3-4. Waveform at video detector.

Coil Leakage

A defective coil may develop shorted turns, or an open circuit. The powdered-iron core might be broken or otherwise defective. In addition to these defects, you will occasionally discover leakage between primary and secondary—particularly in the case of bifilar coils. In the configuration of Fig. 3-2, leakage will affect the tuning of the transformer and reduce the stage gain. Moreover, in the circuit of Fig. 3-5, leakage between primary and secondary of L8 bleeds positive voltage into the AGC line and causes picture overloading.

If this defect is suspected, clip the lead from the secondary of the transformer to the AGC bus, and check for positive DC voltage at the secondary. It is advisable to remove V4 when testing L8 (Fig. 3-5), to avoid possible confusion due to grid-current flow and clamping action. If a voltage reading occurs on the VTVM, the presence of leakage between primary and secondary is confirmed, and the IF transformer must be replaced.

Leakage in Iron-Core Coils

In iron-core coils such as the one depicted in Fig. 3-1, leakage to the core imposes excessive DC current drain, that can burn out the winding in a flyback transformer. The flyback pulse sometimes arcs through the leakage resistance, causing fluctuation of width or height in the picture. In other cases, the coil winding is damped excessively, causing a stubborn

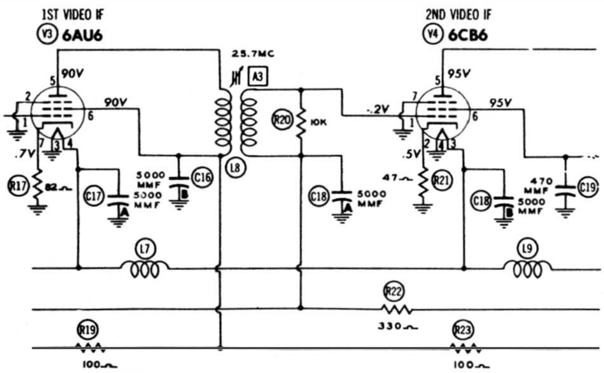


Fig. 3-5. Leakage in L8 upsets AGC action.

lack of picture height or width. All yokes have cores (not shown in Fig. 3-1), and leakage to the core may cause keystoning of the picture, in addition to loss of normal height or width.

Tests of output transformers and yokes for leakage can be made on the leakage function of a capacitor tester. However, since only a few hundred volts can be applied, the leakage resistance does not always show up. If there is any doubt, a substitution test is advised.

WINDING-TO-CORE CAPACITANCE

Sometimes we need to know the winding-to-core capacitance of a transformer. For example, when selecting a replacement power transformer for critical damper circuitry, the damper heater winding must not exceed a specified maximum capacitance to core. Otherwise, the picture will lack sufficient width. The winding-to-core capacitance can be easily measured on a service-type capacitance bridge, as shown in Fig. 3-6.

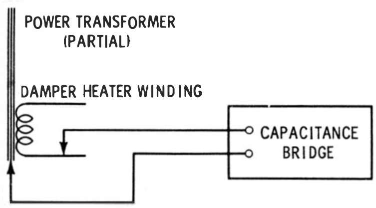
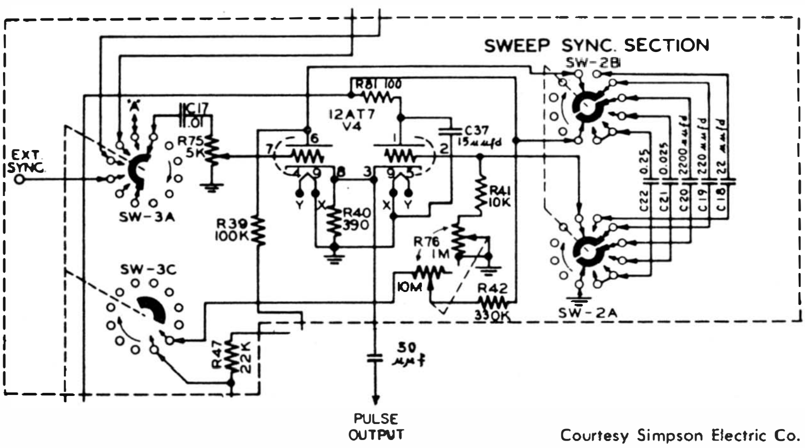


Fig. 3-6. Measurement of winding-to-core capacitance in a transformer.

RINGING TESTS

Ringing tests of inductive components have become increasingly popular in the past year or two. Much of their appeal is doubtlessly due to the simplicity of the tests. When a suitable standard of reference is available, a ringing test is definitive. Ringing tests are made with a scope and a source of pulse voltage. In service applications, the pulse voltage is obtained from the horizontal-deflection section of the scope itself. Some of the more recent service-type scopes are provided with a pulse-output terminal on the front panel. In any case, it is easy to bring out a pulse voltage on any scope.

If a scope utilizes a cathode-coupled multivibrator, as in Fig. 3-7, the common cathode resistor (R40) is a convenient



Courtesy Simpson Electric Co.

Fig. 3-7. Typical pulse take-off circuit.

pulse source. The pulse voltage is brought out in series with a small coupling capacitor—50 mmf is typical. When the scope does not have a cathode-coupled multivibrator, you can use the plate of the sawtooth amplifier tube as a pulse source. In this instance a coupling capacitance of 10 mmf is usually ample, because of the comparatively high amplitude of the sawtooth voltage.

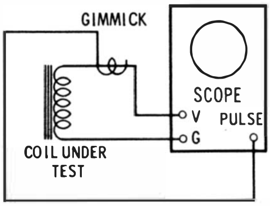


Fig. 3-8. Setup for ringing test.

Test Procedure

The test procedure is very simple. Connect the coil under test to the vertical-input terminals of the scope, as shown in Fig. 3-8. There are two common methods of injecting the pulse voltage. A "gimmick" is preferred by some technicians, because the coupling is very loose and imposes the least loading on the coil. However, in case the amplitude of the pattern is too low, you can connect the pulse lead directly to the vertical-input terminal.

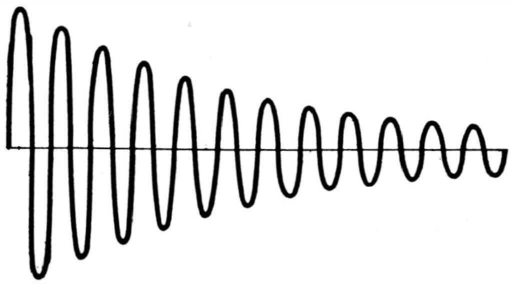


Fig. 3-9. Exponentially damped sine wave.

Advance the vertical-gain controls of the scope as required, and the ringing pattern will appear on the screen. The pattern is automatically in sync, because the pulse is initiated during the retrace interval. To display a suitable number of ringing cycles, adjust the horizontal deflection rate so that the pattern shows the major portion of the decay interval in the damped sine waveform (Fig. 3-9). The waveform has an exponential envelope, just as the discharge of a capacitor through a resistance has an exponential waveform. This is the type of waveform displayed when a ringing test is made on a width coil, for example.

This is a *comparative* test. This means that the decay rate is observed on the scope screen and compared with the decay rate of a similar coil that is known to be good. Whereas it is possible to evaluate the waveform for various electrical data, most technicians do not wish to take the time required to make the incidental calculations. Note in Fig. 3-9 that the ringing waveform has decayed to 1/6 of its initial amplitude after 11 cycles. Now, if a test coil decays the same amount after 6 cycles for example, it is concluded that shorted turns or an equivalent defect is present.

Transformer Waveforms

Next, consider a ringing test of a flyback transformer. The pattern is more complex than for a simple coil. A low-amplitude

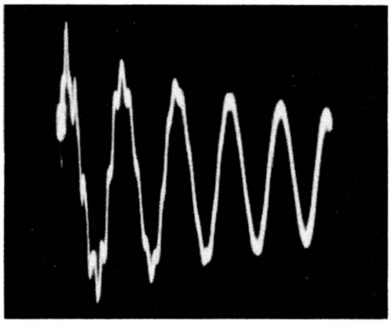


Fig. 3-10. Ringing waveform of transformer winding.

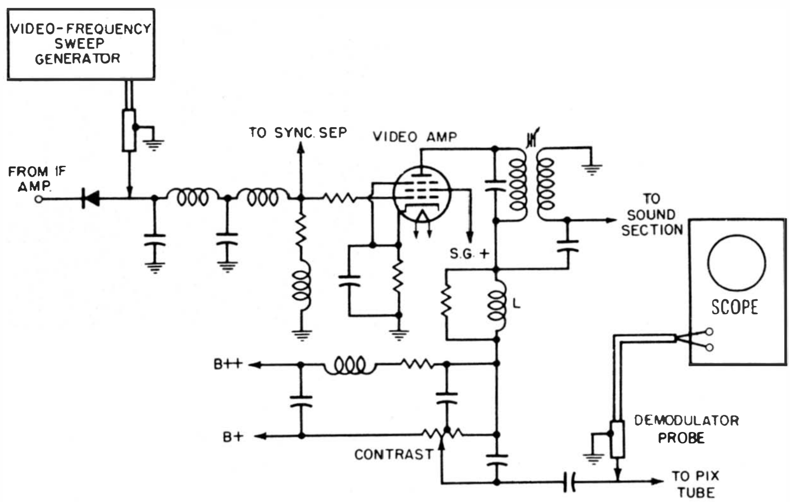
wave at higher frequency is superimposed on the main decay wave. This modified waveform results from transformer action. Since there is more than one winding on the transformer, and the windings are coupled to each other, when the tests pulse is applied, the pulse is coupled into all of the windings on the core, and a multiple ringing pattern occurs (Fig. 3-10). However, the principle of the ringing test is the same as before—two transformers of the same type display the same ringing waveform, if they are both good.

It will be found that some transformers will not ring. Such transformers may be overdamped (have a low Q), as exemplified by many audio types, while others may not respond to a ringing test because their natural resonant frequency is too high to pass through the scope. Thus, you might or might not observe a ringing waveform in a test of an intercarrier-sound coil or transformer, whereas, any service scope will display the ringing waveform produced by the IF transformer from a broadcast radio receiver.

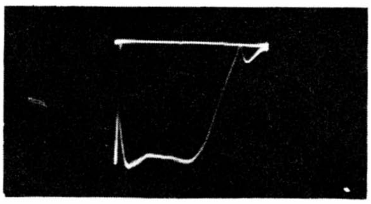
VIDEO-FREQUENCY SWEEP TEST

Peaking coils are used in video amplifiers and scope amplifiers to maintain a uniform high-frequency response. Some peaking coils are shunted by damping resistors; for example, L in Fig. 3-11A is damped. If the coil should open, the circuit continuity is maintained by the damping resistor. However, the high-frequency response of the amplifier then is impaired. This defect is readily detected in a sweep-frequency test. The normal frequency response appears in Fig. 3-11B, and the effect of an open circuit in L is seen in Fig. 3-11C.

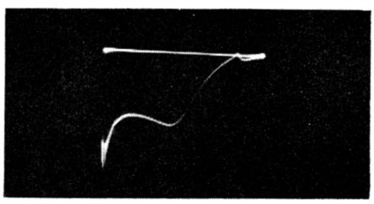
Open coils are usually the result of mechanical damage, although corrosion occasionally eats through the small wire.



(A) Test setup.



(B) Normal curve.

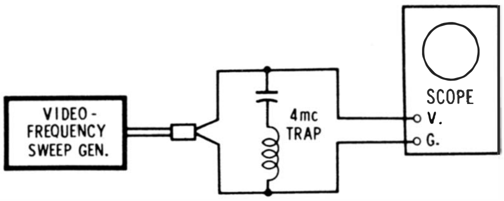


(C) Peaking coil open.

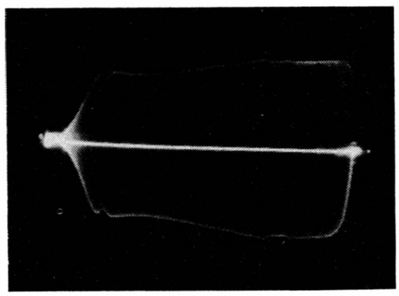
Fig. 3-11. Sweep-frequency test of video amplifier.

Poor solder joints are sometimes offenders. Damaged or corroded peaking coils may also have shorted turns, which reduces the inductance and increases the coil losses. This type of defect is also discovered in a video-frequency sweep test; the high-frequency response is attenuated, and the response curve may also show excessive mid-band dip.

It is easier to check out the peaking coils in a scope than in a TV receiver. The advantage here is that the scope serves as its own indicator. The output from a video-frequency sweep generator is applied to the vertical-input terminals of the scope. If a 4-mc trap is connected as shown in Fig. 3-12, an absorption marker appears at the 4-mc point on the pattern envelope. If one or more of the peaking coils in the scope vertical amplifier are defective, the pattern will be attenuated and distorted over the high-frequency region.



(A) Test setup.



(B) Scope display.

Fig. 3-12. Frequency response of scope vertical amplifier.

COIL TESTS WITH AN INDUCTANCE BRIDGE

An inductance bridge is usually one function of an impedance bridge; the other functions typically comprise a capacitance bridge and a Wheatstone bridge. Kit-type impedance bridges are reasonably priced, and are a valuable addition to shop instrumentation. The most common type of inductance bridge balances inductance in one arm of the bridge against capacitance in the opposing arm, as illustrated in Fig. 3-13.

Note that the inductor under test (L) is connected into the arm opposite the standard capacitor. This configuration is necessary because the inductor draws a lagging current, whereas the capacitor draws a leading current.

High-Q Coils

If the inductor under test should have a very high Q, an adequate null indication can be obtained with the simple bridge shown in Fig. 3-13. The rheostat opposite the standard resistance is provided with a scale that is calibrated in henrys or millihenrys. This type of bridge must be driven at the frequency at which it is calibrated (usually 1 kc), and the

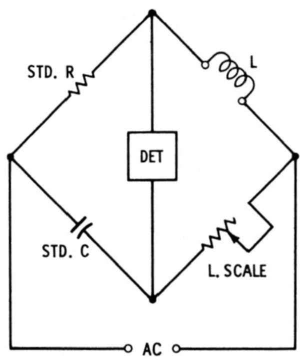


Fig. 3-13. Simplified schematic of inductance bridge.

AC source must have a good sine waveform. Otherwise, the inductance dial calibration will not read accurately.

Since the majority of inductors tested in service shops have appreciable resistance, the coil under test consists effectively of inductance in series with resistance. The effective series resistance lowers the Q of the coil and prevents obtaining a complete null on a simple bridge such as the one shown in Fig. 3-13. Moreover, the inductance scale reads incorrectly on a partial null. A practical inductance bridge makes provision for balancing the effective series resistance of a coil which, incidentally, gives a measure of the Q.

Testing a Coil for L and Q Values

A complete, basic bridge circuit for measuring L and Q values is shown in Fig. 3-14. A rheostat with a scale calibrated in Q values is connected in series with the standard inductor inside the bridge. Now, a complete null can be obtained for coils having moderate or low Q values. Beginners are sometimes confused because they do not understand that it is often necessary to "chase the null" at some length. That is, a partial null is obtained in many tests while the L and Q controls are still far from the complete balance settings. To obtain a better null-indication, the inductance control must be turned a small step in the suitable direction; then when the Q control is reset, the bridge becomes more nearly balanced. The complete null (zero indication) is obtained only after a number of back-and-forth adjustments of the L and Q controls.

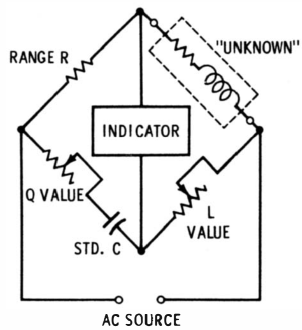


Fig. 3-14. Complete bridge for measuring L and Q.

Coils Which Provide a Minimum Null Only

Beginners are also sometimes puzzled by the fact that only a minimum null-indication can be found when some types of iron-core coils are tested. No adjustment of the L and Q controls suffices to obtain a complete null, and the readings of the minimum null must be accepted. This characteristic results from the fact that some iron cores produce an appreciable *iron third-harmonic* distortion of the bridge current in the unknown arm. In other words, the magnetic flux produced in the coil has a nonlinear relation to the coil current. The resulting distortion of the bridge-voltage waveform prevents the determination of a complete null. In the first analysis the dial readings at the minimum null indication are accepted.

The essential point is to understand bridge operation and to know inductor theory. Technicians often condemn a good inductance bridge simply because they do not understand the properties of practical iron-core coils and have not become sufficiently familiar with inductance-bridge operation. The configuration shown in Fig. 3-14 is called a *Hay* bridge. It is well suited to measurement of inductance values that are associated with Q values from 10 to 1,000. However, some coils encountered in service work have a Q value less than 10. In this case, the *Maxwell* bridge shown in Fig. 3-15 is more suited to accurate measurement. Note that the Q rheostat is connected across the standard capacitor, instead of in series. A separate dial scale is used.

Why a Standard Capacitor Is Used

Most bridges measure inductance values with reference to standard capacitances. A standard capacitor is preferred to a standard inductor, for two reasons. First, its cost is comparatively small. Second, a standard capacitor has a negligible external field; it neither induces spurious voltages in nearby circuits nor picks up spurious stray fields. In addition, a standard capacitor makes a more compact bridge possible. Finally, in an impedance bridge the standard capacitors do double duty in the capacitance-bridge function.

Meaning of a Q Value

A Q value is termed a quality factor. It is the ratio of inductive reactance to resistance, or, $Q = X_L/R$. Consider a 100-millihenry coil that has a resistance of 60 ohms. Since $X_L = 2\pi fL$, the inductive reactance of the 100-mh coil at 1 kc is

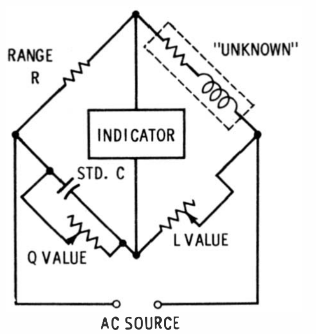


Fig. 3-15. Bridge for measuring low Q.

approximately 600 ohms, and its Q at 1 kc is equal to 600/60, or 10. It is important to note that inductive reactance is a function of frequency; therefore, a Q value is meaningless unless you state the frequency at which the Q was measured.

Since inductive reactance is directly proportional to frequency, a coil that measures a Q of 10 at 1 kc is expected to have a Q of 20 at 2 kc, and a Q of 5 at 0.5 kc. Therefore the Q of a coil at any frequency can easily be calculated after its Q has been measured at a certain frequency. This simple relation of Q values at various frequencies becomes less accurate as you depart widely from the frequency of measurement. It is less accurate in the case of iron-cored coils than air-core coils. In summary, unless you are considering operating frequencies fairly close to the frequency of the Q measurement, the bridge should be powered from an external oscillator and the test made at the actual operating frequency.

INDUCTANCE SHIFT OF IRON-CORE COILS

Beginners sometimes assume that if a coil has a certain inductance at 1 kc, it will have the same inductance at 60 cycles. This assumption is approximately correct for air-core coils, but is often in serious error for iron-core coils. The reason is that iron cores often have a very different magnetic characteristic at different frequencies. This effect is minimized in hi-fi audio transformers, but it is still present to some extent. In the case of low-quality, iron-core coils, an inductance value might be very misleading unless the test frequency is noted.

Some iron-cored inductors also shift their inductance value when the test current is varied in the bridge. Most inductance bridges have a level control that can be set to pass small or large AC currents through the coil under test. In many cases the inductance reading shifts to a lower value when the bridge current is increased. If the shift is substantial, a valid measurement must state the current flow that is present at the measured value of inductance. An AC current meter can be connected in series with the coil under test to measure the current flow.

Obtaining Maximum Accuracy

Recall that an iron-core inductor may generate an iron third-harmonic, due to the lack of ideal characteristics in the magnetic core. This impairs the accuracy of indication in a simple inductance bridge. Nevertheless, suitable methods permit accurate measurement of inductance values at the bridge driving frequency, such as 1 kc. One method employs a tuned transformer between the bridge arms and the indicator. Thus, if the bridge operates at 1 kc, the transformer is also tuned to 1 kc. The passband of the tuned transformer is made sufficiently narrow so that any harmonics of 1 kc are rejected. This permits a true and complete 1-kc null to be obtained.

A simpler method is to use a pair of earphones as the null indicator. After a little practice, you can easily distinguish between the 1-kc tone and the higher-pitched harmonic tones. Then the bridge is nulled on the 1-kc tone, and the higher tones are neglected. While the residual harmonics tend to mask the 1-kc null, a trained operator can make an accurate null determination.

COIL TESTS WITH A RATIO BRIDGE

Some capacitance bridges, such as the one illustrated in Fig. 3-16, have a ratio or comparator function with a ratio scale calibrated from 0.05 to 20, corresponding to ratio values over a range of 400 to 1. The basic plan of all such ratio bridges is shown in Fig. 3-17. This function of a capacitance bridge makes possible the measurement of impedance and inductance values of coils. When a ratio bridge is employed, it

Courtesy Paco Electronics Co., Inc.

Fig. 3-16. Capacitance bridge with ratio scale.

operates as a 60-cycle Wheatstone bridge, with two pairs of test terminals XX and YY, as depicted in Fig. 3-17. The calibrations on the ratio scale correspond to potentiometer settings.

If two identical coils are connected at XX and YY respectively, the ratio bridge will balance at 1 on the scale. This simply means that the two have the same impedance value. Also, if one coil has twice the impedance of the other coil, the ratio bridge will balance at 2 on the scale. The scale, of course, might read 0.5 instead of 2; this depends on which coil you connect to the YY terminals. With the large coil at YY and the small coil at XX, the scale reading will be 2. With the large coil at XX, and the small coil at YY, the reading will be 0.5 at balance. Either reading, of course, is correct—the ratio bridge is indicating that one coil has twice the impedance of the other coil.

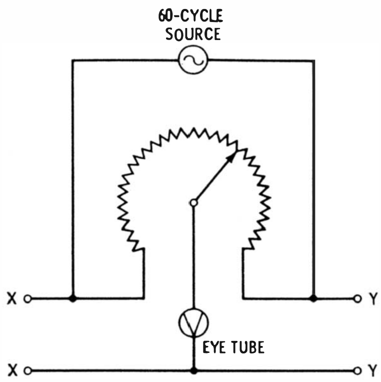


Fig. 3-17. Plan of a ratio bridge.

STANDARD INDUCTANCE

Instead of merely comparing the impedance of two coils, one is usually interested in specific values. Two basic questions will be asked:

1. What is the impedance of a certain coil, in ohms?
2. What is the inductance of the coil, in henrys or millihenrys?

To measure these values, a suitable standard of inductance is needed. Lab standards are available and are ideal for this—they are also quite expensive. For shop applications, commercial inductors for replacement purposes are adequate, provided they have a reasonably accurate inductance rating. Thus, you might choose a good-quality width coil rated at 100 mh or a choke that is rated at 1 henry.

Any coil has winding resistance as well as inductance. The winding resistance can be measured with an ohmmeter. Together, inductance and winding resistance form the impedance of the coil, as shown in Fig. 3-18. Resistance combines

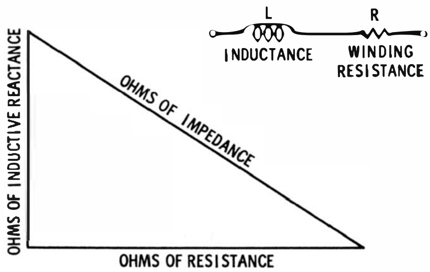


Fig. 3-18. Inductance and resistance form impedance.

with inductive reactance at right angles to form the impedance of the coil. Recall that inductive reactance is equal to $2\pi fL$, or in 60-cycle tests, the inductive reactance is equal to 377L ohms, where L is given in henrys.

For example, if a coil has 40 ohms resistance and 30 ohms reactance at 60 cycles, it has 50 ohms of impedance at 60 cycles. This is just another way of saying that if a right triangle is drawn with a base 4 inches long and an altitude 3 inches high, the hypotenuse will measure 5 inches in length.

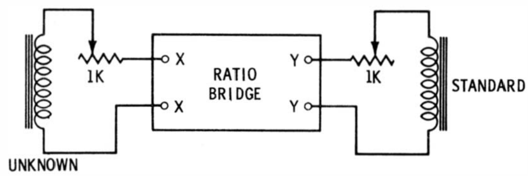


Fig. 3-19. Potentiometers used to equalize Q values.

Measurement of Coil Inductance

To measure the inductance of a coil, using a ratio bridge and a standard inductor, connections are made as depicted in Fig. 3-19. Note that a pair of 1K resistors have been included. These are utilized to balance the winding resistances of the two coils, so that the ratio bridge can be completely balanced. At the outset, it is unknown which coil will require additional series resistance to obtain a complete null. So start with both 1K potentiometers set to zero resistance, and adjust the bridge for a partial null. Then, advance one of the potentiometers to see if the null is improved; if not, return it to zero, and advance the other potentiometer. At balance, suppose the ratio scale reads 3, with a 100-mh coil connected in the standard position (to terminals YY in Fig. 3-19). It follows that the inductance of the coil under test is 300 mh.

Q Value at 60 Cycles

After measuring the inductance of a coil on the ratio bridge, the question may be asked what the Q value at 60-cycles might be. Continuing with the previous example in which the coil under test measures an inductance of 300 mh, an ohmmeter might indicate a winding resistance of 37.7 ohms. In this case, its 60-cycle Q is equal to 3. In other words, $Q = X_L/R = 113.1/37.7 = 3$. At some other frequency, of course, the coil will have some other value of Q. The change of magnetic core characteristics with frequency has been noted previously.

Changing resistance must also be taken into consideration at higher frequencies, even if the coil has an air core; at low frequencies, the AC resistance of the coil approaches the DC resistance, but at high frequencies the AC resistance is much greater than the DC resistance. The Q factor is based on AC resistance. At 60 cycles, the AC resistance of a coil is practically the same as its DC resistance.

DISTRIBUTED CAPACITANCE OF AUDIO-FREQUENCY COILS

Any coil has some value of distributed capacitance and this capacitance operates effectively as a capacitor shunted across an ideal inductance. Hence, all coils are self-resonant at a frequency given by the familiar resonant-frequency formula: $f = 1/(2\pi f \sqrt{LC})$. This is a parallel-resonant situation, so that the coil has a very high terminal impedance at its self-resonant frequency. Obviously, if a coil should be self-resonant at 1 kc, an inductance bridge would not respond on the basis of inductive reactance, but would read a much higher value—the value of the coil impedance at resonance.

It follows that an inductance bridge must be driven at a frequency considerably away from the self-resonant frequency of the coil under test; otherwise, the inductance reading will be false. This source of error is encountered in the shop chiefly when measuring the inductance of audio-frequency coils. For example, if you measure the primary inductance of an audio-output transformer on a 1-kc bridge, you will obtain an absurd inductance reading. Hence, it is standard practice to measure the inductance of audio-frequency coils at 60 cycles which is usually readily available.

MEASUREMENT OF SELF-RESONANT FREQUENCY

It is clearly helpful to know the self-resonant frequency of an unknown coil before proceeding with bridge measurements of inductance. If the self-resonant frequency is known, you can choose a bridge-driving frequency that is sufficiently low so that the distributed capacitance of the coil can be disregarded. The easiest way to measure the self-resonant frequency of a coil is to make a ringing test (Figs. 3-8, 3-9). Count the number of cycles displayed in the ringing pattern and, then, without changing the scope controls, disconnect the coil and apply the output from an audio oscillator. Tune the audio oscillator to display the same number of cycles observed in the ringing pattern. The dial of the audio oscillator then indicates the self-resonant frequency of the coil.

FREQUENCY-CORRECTION FACTOR

When the self-resonant frequency of a coil is near 1 kc, the internal oscillator in a 1-kc inductance bridge cannot be used. Instead, the bridge must be driven from an external source such as an audio oscillator. A 500-cycle test frequency would be suitable, for example. Use of the lower test frequency will not affect the reading of the dial on the inductance bridge. In addition, the Q dial must be corrected for the new test frequency. In this example, the measurement is being made at half the frequency for which the Q dial was calibrated; therefore, the reading of the Q dial must be divided by 2. If the Q dial should read 12, the actual Q value is 6 when the bridge is driven at 500 cycles. Furthermore, if the bridge were driven at 250 cycles, the Q dial reading of 12 must be divided by 4—the actual Q value will be 3.

BRIDGE TESTS OF TRANSFORMERS

Many iron-core transformers, such as those used in audio circuitry and power supplies, are designed to have the maximum coupling possible between primary and secondary. That is, the mutual inductance between primary and secondary is maximized. All other things being equal, an audio-output transformer is considered better than another comparable transformer if it has a greater mutual inductance. It is comparatively difficult to obtain full mutual inductance in such transformers, because of the large winding ratio.

If a transformer primary has an inductance L1 when measured by itself, and the secondary has an inductance L2 when measured by itself, the maximum mutual inductance attainable in theory is equal to $\sqrt{L1L2}$. Two tests are necessary to measure mutual inductance (Fig. 3-20). In the case of an audio-output transformer, which is likely to be self-resonant in the vicinity of 1 kc, the measurements must be made at a reduced bridge frequency. The primary and secondary are connected in series, and their total inductance L_{t1} is measured. Then, the secondary connections are reversed, and the total inductance L_{t2} is measured. The mutual inductance of the transformer is then given by $(L_{t1} - L_{t2})/4$.

The same method is applicable to measurement of mutual inductance in air-core transformers, which have comparatively loose coupling. As an example, an IF transformer from a hi-fidelity AM receiver has a primary inductance which measures 29 mh. The secondary inductance measures 124 mh. The theoretical maximum mutual inductance should be 60 mh. When series-aiding and series-opposing inductance measurements are made next, the measured values are 188.6 mh and 117.4 mh. By calculation, the mutual inductance of this IF transformer is 17.8 mh.

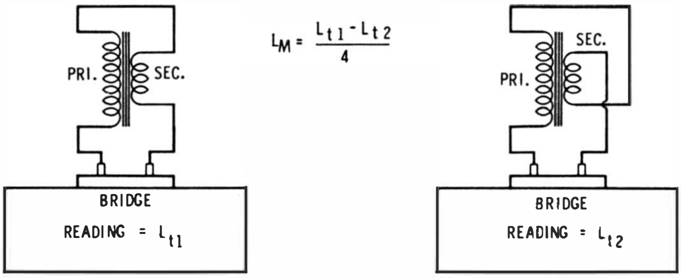


Fig. 3-20. Measurement of mutual inductance.

COIL TESTS WITH VTVM AND AUDIO OSCILLATOR

You can also measure the inductance of iron-core or large air-core coils with a VTVM and an audio oscillator. The basic test circuit is shown in Fig. 3-21. A low test frequency (such as 60 cycles) is employed so that AC and DC coil resistance will be essentially the same. An audio oscillator is used to

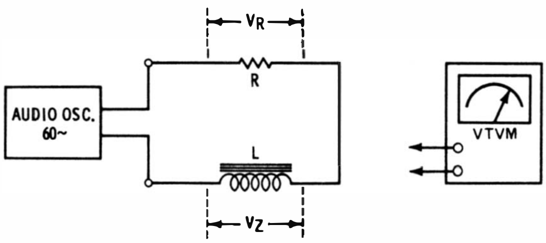


Fig. 3-21. Inductance test circuit.

ensure a good waveform, thereby providing maximum accuracy of AC voltage measurements. The winding resistance of the inductor is measured with an ohmmeter or on a resistance bridge. In a typical example, the winding resistance of the coil under test measured 77.1 ohms.

In the test circuit detailed in Fig. 3-22, the winding resistance is shown separate from the inductance. Together, inductance L and the 77.1-ohm winding resistance form an impedance. The series resistor R that was utilized had a measured value of 191 ohms. A measurement of V_R gave a reading of 4.6 volts. Since I = E/R, the current flow in the circuit is evidently 24 ma.

A measurement of V_Z gave a reading of 2.2 volts. Since Z = E/I, the corresponding impedance was calculated to be

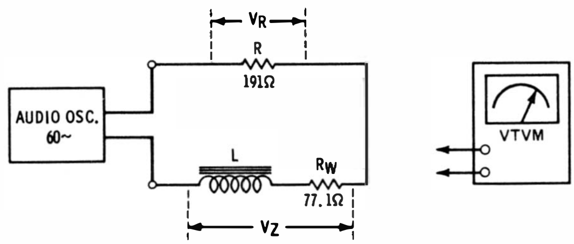


Fig. 3-22. Separation of inductance and winding resistance.

91.7 ohms. Now, the impedance and winding resistance must be scaled off and combined in a right triangle, as shown in Fig. 3-23. The triangle has an altitude that scales off as 49 ohms. From this fact, the inductance L can be calculated. Since $X_L = 2\pi fL$, it is clear that L = 49/377, or 130 mh, in this example. To check the apparent error, a cross-check was made with an inductance bridge, which gave a reading of 114 mh.

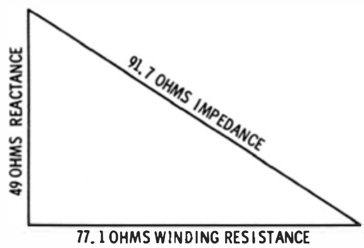


Fig. 3-23. The impedance triangle.

The apparent error is about 14%, which could be roughly charged to the VTVM method of test (the actual accuracy of the bridge measurement was of course unknown). However the bridge test is assumed to be more accurate.

Inasmuch as the preceding method requires calculations, it is more time-consuming than an inductance-bridge test. However, when a bridge is not available, the alternate method is highly desirable.

REFLECTED RESISTANCE OF A TRANSFORMER

Audio technicians, in particular, are often concerned with the reflected resistance of a transformer. This knowledge is required to match impedances and obtain maximum power transfer. A transformer steps-up or steps-down impedance as well as voltage and current. Consider the simple configuration shown in Fig. 3-24. The generator has an emf of 80 volts and an internal resistance of 400 ohms. It is desired to transfer maximum power to a 25-ohm load. A 4 to 1 stepdown transformer is required.

The transformer steps 40 volts at the primary down to 10 volts at the secondary. The secondary current is given by Ohm's law, I = E/R, or I = 400 ma. The primary current is

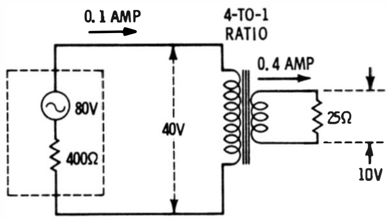


Fig. 3-24. Maximum power transfer to 25-ohm load.

100 ma, *because the 25-ohm load on the secondary is reflected back into the primary as a 400-ohm load.* In other words, the impedance transformation is equal to the square of the turns ratio; the impedance transformation is 4^2 to 1, or 16 to 1. The primary current is stepped-up four times, from 100 ma in the primary to 400 ma in the secondary.

The generator supplies 8 watts (80 volts times 0.1 ampere) to the primary circuit. The secondary dissipates 4 watts. Half the primary power is dissipated by the internal resistance of the generator. This is the matched condition. So when impedances (in this example, resistances) are matched, half of the generated power is transferred to the load.

Transformer Test

A good audio-output transformer not only provides a match of the load to the source, but also reflects a purely resistive load. That is, if the secondary of a transformer is connected to a resistor, as in Fig. 3-25, a test with an impedance bridge across the primary should give a resistance reading only—no inductance should be measurable across the primary terminals. This is an ideal situation; in practice, there is at least a little residual inductance present in this test. The better the transformer is, the less is the inductance found at the primary. Hence, this is a good comparative test in selection of output transformers.

Note that the value of R used in the test of Fig. 3-25 is not critical—merely use a value in the general range for the intended application; it makes no difference what resistance value is reflected back into the primary. The chief concern in this test is whether excessive inductance might appear with the reflected resistance. What is the source of spurious inductance in this configuration? It stems from uncoupled inductance in the primary and secondary windings; the mutual inductance of primary and secondary is not maximized in actual transformer design. In an ideal transformer, there is no stray flux and no uncoupled inductance. A resistive load on the secondary would be reflected as a pure AC resistance at the primary terminals.

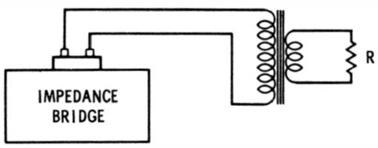


Fig. 3-25. Test of reflected resistance.

Test of Winding Ratio

The winding ratio of a transformer can be easily measured, provided the transformer has an iron core. You can apply a convenient AC voltage to the primary and measure the voltage at the secondary. The voltage ratio is equal to the winding ratio. Another easy method of testing the winding ratio is to use a ratio bridge, as previously described. Simply connect the primary leads of the transformer to one pair of terminals on the ratio bridge, and connect the secondary leads to the other pair of bridge terminals. If a null is not obtained on the first test, reverse the primary terminals. The scale of the ratio bridge reads the winding ratio when the bridge is balanced.

Note that such tests presuppose that the primary is tightly coupled to the secondary. This is almost always true of iron-core transformers. However, in the case of air-core transformers, other methods are required to accurately measure winding ratios. For reasons that will be explained in the next chapter, the winding ratio of air-core transformers is usually minor or of no concern, since other parameters dominate the action of air-core transformers in most situations.

SECTION 4

High-Frequency Components

Tests of high-frequency components have the same theoretical foundation as tests of components operating at comparatively low frequencies. However, the practical aspects differ considerably and justify treatment in a separate section. For example, consider the problem of measuring AC resistance at 20 mc. An *AC Wheatstone bridge* is commonly utilized, but its construction and range differs considerably from a 1-kc Wheatstone bridge. First, stray capacitance must be minimized in the bridge design because at 20 mc, 10 mmf stray capacitance has a reactance of only 800 ohms. Compare this value with a reactance of 16 megohms at 1 kc. Stray capacitance unbalances a bridge and prevents indication of a proper null.

When stray capacitance is minimized, its effects are still sufficiently objectionable in simple bridges that a top resistance indication of 600 ohms is provided. Although the measurement range is comparatively limited, a simple HF Wheatstone bridge finds considerable use in practical work. If higher values of AC resistance need to be measured, indirect methods are necessarily employed. IF and RF sweep generators provide practical in-circuit tests of high-frequency components. Excessive AC resistance in a plate-load coil, for example, shows up as abnormal bandwidth.

Inductance measurements at high frequencies are usually made indirectly. An accurately calibrated grid-dip meter may be employed. The distributed capacitance of the coil is first measured, as explained subsequently. When the distributed capacitance is known, the total shunt capacitance in the test circuit is then known, and the grid-dip meter indicates the resonant frequency. In turn, L is the only unknown quantity in the standard resonant-frequency formula, from which the inductance value may be calculated. You will find a reactance and resonant-frequency slide rule very convenient, since the necessity for calculation is avoided. The *Shure* reactance slide rule costs only $1.00 and is satisfactory in practical work.

Note in passing that a Q-meter is a most useful instrument for testing high-frequency components. But its cost is comparatively high and is seldom profitable to a service shop. However, when the need arises, you might be able to borrow a Q-meter from a nearby technical school or electronics factory. This instrument provides direct measurement of Q, L, R, and C at radio frequencies. Its operation is explained in most radio-engineering texts; the interested reader may refer to these.

Ohm's law applies at high frequencies in exactly the same manner as it does at low frequencies. The differences are merely that inductances have comparatively small values in any high-frequency application; stray and distributed capacitances cannot be neglected and may dominate component characteristics. The efficiency of a simple semiconductor diode may be entirely different at 40 mc than at 1 kc. A resistor that has a value of 0.5 megohm at zero frequency will have a lower (sometimes very much lower) value at 100 mc, and it will draw a leading current. Such considerations modify practical test procedures, and require suitable test setups.

HIGH-FREQUENCY RESISTANCE TESTS

High-frequency resistance cannot be measured with an ohmmeter. For example, a dipole antenna is shown in Fig. 4-1(A). An ohmmeter measures an infinite terminal resistance, but when tested with an *antenna-impedance meter* at the self-resonant frequency of the antenna, a terminal resistance of 72 ohms is measured. Again, the zero-frequency input resistance of the RF tuner depicted in Fig. 4-1(B) is infinite, whereas its resonant-frequency input resistance is 300 ohms. The DC input resistance of the tuner shown in Fig. 4-1(C) is almost zero, although its on-channel input resistance is 300 ohms.

MEASUREMENT OF ANTENNA RESISTANCE

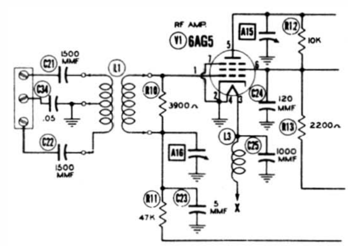
When the dipole antenna illustrated in Fig. 4-1 is driven at its self-resonant frequency, the input impedance is purely resistive; the antenna "looks like" a pure high-frequency resistance at its terminals. However, when operated off its self-resonant frequency, the antenna terminal resistance is accompanied by either a capacitive or an inductive reactance. In other words, the antenna then has an input impedance, instead of a simple input resistance.

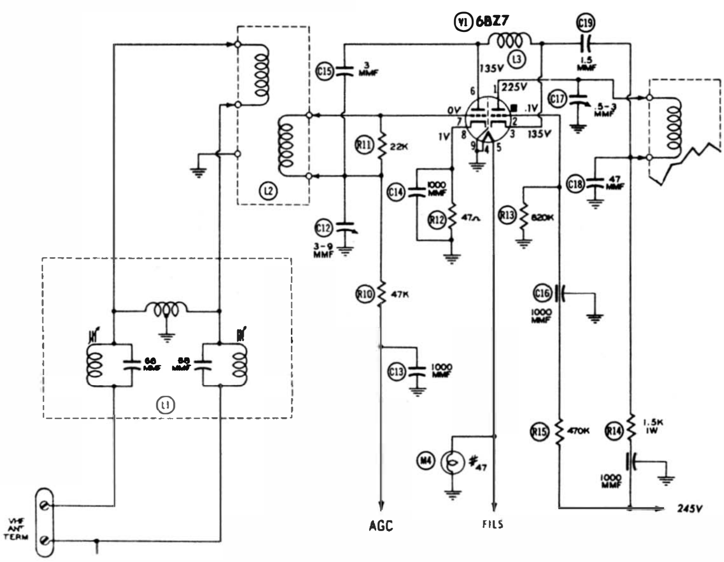
The same general observation applies to the RF tuners in Fig. 4-1. The tuner input impedance is essentially a high-frequency resistance on the channel to which the tuner is set, but when tested at an off-channel frequency, the input resist-

DIPOLE
ANTENNA

(A) DC resistance infinite; HF resistance 72 ohms.

(B) DC resistance infinite; HF resistance 300 ohms.





(C) DC resistance near zero; HF resistance 300 ohms.

Fig. 4-1. High-frequency resistance measurements.

ance of the tuner is accompanied by either inductive or capacitive reactance—and we must then consider the input *impedance* of the tuner. There has been some loose usage of the term "impedance" in the past, and the input resistance of an antenna or front end has been called an input impedance, although no reactance is present.

An antenna-impedance meter is a high-frequency bridge. Unless the arms in a high-frequency bridge have comparatively low values, the bridge accuracy will be poor at high frequencies. This inaccuracy results from the bypassing action of stray capacitances around the bridge arms. However, since most antennas have a comparatively low input resistance or impedance, a bridge such as depicted in Fig. 4-2 can be used in most applications. This type of instrument is commonly called an antenna-impedance meter, although strictly speaking it is a high-frequency resistance bridge; it does not measure impedance.

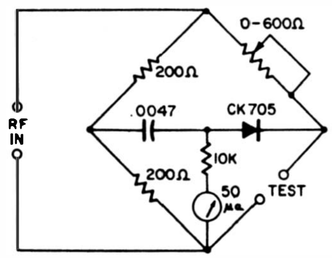


Fig. 4-2. Antenna-impedance meter circuit.

The bridge cannot be used to check DC resistance because the indicator is energized by an RF probe arrangement. One arm of the bridge is a calibrated potentiometer that is adjusted for a null-indication on the meter when a lead-in is connected across the Test terminals. The dial is calibrated from 10 to 600 ohms in a typical bridge. The bridge can be driven from any RF source having moderate output such as a grid-dip meter or RF signal generator with a high-level (1 volt) output.

Test Procedure

A suitable test setup for measuring antenna resistance is shown in Fig. 4-3. The bridge can be connected directly to the antenna terminals if they are accessible. Otherwise, the bridge must be connected to the antenna via a lead-in. In the case of a half-wave dipole antenna with accessible terminals, a direct connection can then be made to the bridge. The bridge case is left floating (ungrounded). A pickup loop can be used to drive

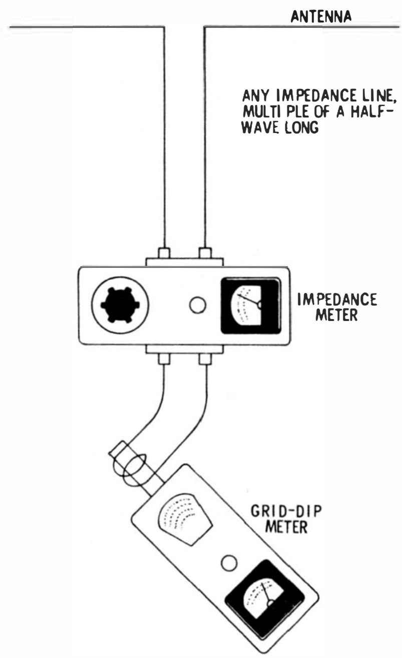


Fig. 4-3. Measurement of antenna impedance.

the bridge, with a grid-dip meter as an AC source. The test frequency should be set in the vicinity of the half-wave resonant frequency of the antenna. To determine the approximate bridge-driving frequency, use the following formula:

$$f_{mc} = \frac{467.4}{\text{length in feet}}$$

Set the grid-dip meter to this frequency. Then adjust the bridge for minimum indication on the meter—only a partial null can be anticipated at this time, and for a simple dipole antenna, the bridge reading will be less than 75 ohms. Now make back-and-forth adjustments of the bridge-driving frequency and the bridge dial to obtain a complete null (if possible). In a case a complete null is obtained, the bridge then reads the antenna input resistance. Note that this method is not reliable at frequencies above 40 or 50 mc, due to limitations of the bridge response as well as disturbances imposed by the proximity of the operator.

Cause of Incomplete Nulls

When a complete null cannot be obtained, the antenna-input resistance is actually an impedance—there is inductive or capacitive reactance present with the effective resistance. This situation is usually caused by partial resonances in nearby guy wires or other metallic objects. A metallic mast can also introduce a partial resonance coupled to the antenna. Guy wires should be split up into sections with insulators to throw their self-resonant frequencies out of range and permit a better null in the resistance test. The measured input resistance might be as low as 10 ohms, or as high as 100 ohms for a simple dipole antenna that is strongly affected by proximity of metal objects or wires. Even if the input resistance is purely resistive, the value will also vary with the dipole height above ground.

Test With Lead-In

When it is inconvenient to make the test directly at the antenna terminals, use a half-wave line between the bridge and the half-wave dipole. The question then arises concerning how to determine the electrical length of this half-wave line, inasmuch as the exact self-resonant frequency of the dipole is unknown. One method is to select the bridge-driving frequency by "guesstimation" and cut a half-wave line to this frequency. If a complete null cannot be obtained because of a poor guess, the lead-in can be shortened or lengthened to accommodate a new bridge-driving frequency.

Electrical Length of Lead-In

Although the electrical length of a dipole can be calculated with comparative accuracy from its physical length, this is not always possible in the case of a lead-in. A dipole has air dielectric, whereas a lead-in often has a solid dielectric. Solid dielectric causes the electrical length to be greater than the physical length, how much depending on the type of dielectric; so a quick method is needed for measuring the electrical length of a lead-in. To make the test, use a sample section of the lead-in, 10 or 15 feet in length. Short-circuit the conductors at one end and measure the resonant frequency of this quarter-wave stub, as illustrated in Fig. 4-4. (The grid-dip meter should be accurately calibrated.)

Convert the measured frequency into its corresponding wavelength in meters. (One meter is equal to 39.37 inches.) This divided by 4, gives the electrical length of the stub, since its electrical length is equal to ¼ of the measured wavelength. The *velocity factor* of the stub is equal to its physical length divided by its electrical length. The velocity factor is always less than 1. Knowing the velocity factor of the lead-in, you can cut it to exactly an electrical half-wavelength at the desired driving frequency.

Note that in case a half-wave lead-in is too short, you can use one wavelength, 1½ wavelengths, 2 wavelengths, etc. The reason for these choices is that each half-wave length of lead-in repeats the load. In other words, the terminal impedance of the antenna is reflected exactly by each half-wavelength of lead-in. An example of velocity-factor measurement is as follows: A sample section of twin lead was measured and found to be 170.75 inches (or 4.33 meters) long physically. One end of the stub was shorted (with a copper plate) as shown in Fig. 4-4. Now, if the velocity factor were equal to 1, its resonant wavelength would be 4 × 4.33, or 17.32 meters. Its resonant frequency would be 300,000,000/17.32 = 17.3 mc. However, a grid-dip meter indicates a resonant frequency of 14 mc. Therefore, the velocity factor is equal to 14/17.3, or 81%.

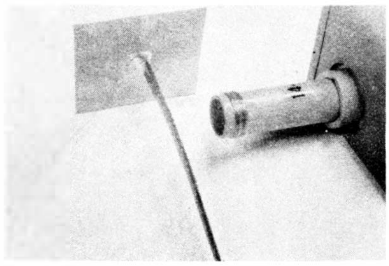


Fig. 4-4. Measuring resonant frequency of a stub.

Interference in Bridge Test

Sometimes the bridge does not read zero, even though the driving voltage is removed when testing antenna resistance. In this case, the antenna is usually picking up a strong signal that is interfering with the test. Orienting the dipole is helpful, although this is not always possible. Hence, it is occasionally necessary to wait for a quiet period to make antenna tests. High-frequency bridges are often provided with an output jack, as depicted in Fig. 4-5. If you plug a pair of earphones into the bridge, you may be able to identify the interfering signal.

RESISTANCE OF A TRAP

The HF resistance of a trap, or any series-resonant LC device, can be measured easily with the bridge depicted in Fig. 4-2. Merely connect the trap across the bridge terminals (Fig.

4-3) instead of across the antenna. Tune the grid-dip meter to the approximate frequency of the trap. Then adjust the bridge for minimum indication. The grid-dip meter must then be re-adjusted to get a better null. Finally, by working back and forth, a complete null will be obtained. The bridge dial then indicates the HF resistance of the trap. An ideal trap would have zero resistance, but in practice there is appreciable resistance present, contributed principally by the coil.

Inasmuch as simple RF bridges can measure a top resistance of only 600 ohms, this method is generally unsuitable for measuring the resistance of parallel resonant units. Another limitation applies to tests of both series and parallel LC devices; this type of bridge is not rated for test frequencies above 40 or 50 mc. However, within its limitations, this is a very useful test method.

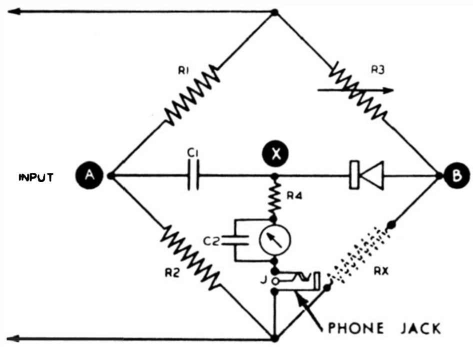


Fig. 4-5. Phone jack for earphones.

HIGH-FREQUENCY RESISTANCE OF A COIL

Inasmuch as the measured HF resistance of an LC trap is effectively the resistance of the coil, the series capacitance can be varied to test the coil at any frequency to which it can be resonated. Connect the coil under test in series with a variable capacitor, and set the grid-dip meter to the desired frequency. Measure the HF resistance as previously explained, except that in this case the variable capacitor is adjusted to resonate the coil with the test frequency. At resonance a complete null is obtained.

INPUT IMPEDANCE OF RADIO RECEIVER

The RF input impedance of a radio receiver operating up to approximately 40 mc can be measured by the method in Fig.

4-6. Tune receiver to the bridge-driving frequency. Adjust the bridge for a null, adjusting the receiver tuning slightly as required. Note that if the receiver has an overcoupled input circuit, two null points will be found at different frequencies; one of the null points is likely to provide greater receiver output than the other—the null that gives highest output is chosen for measurement.

INPUT IMPEDANCE OF TV RECEIVER

The RF input impedance of a TV receiver can be checked by means of a skeleton bridge, as shown in Fig. 4-7A. In order to minimize the error due to stray capacitances, a compact bridge is made up from three 300-ohm (or other value) composition resistors. The fourth arm of the bridge consists of the input to the RF tuner. An RF sweep generator is used to

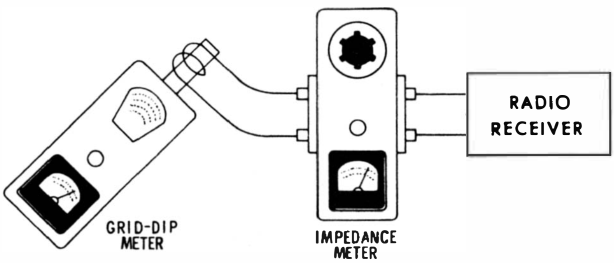
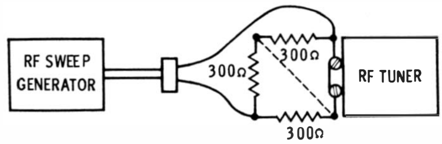


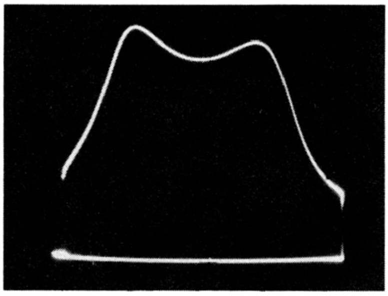
Fig. 4-6. Checking input impedance of a radio receiver.

drive the bridge. A scope is connected to the looker point on the RF tuner, and the AGC line is clamped. A response curve is displayed on the scope screen, as illustrated in Fig. 4-7B. The test is made by shorting the diagonal terminals of the bridge as indicated by the dotted line. Then, if the curve does not change in height, the RF input impedance is 300 ohms; but if the curve does change in amplitude, the input impedance is not 300 ohms.

The value of RF input impedance is determined chiefly by the coupling of the input transformer (Fig. 4-8). Tighter coupling provides a lower input impedance, and vice versa. The value of input impedance is controlled to some extent by the damping resistance R11. Of course, the HF resistance of the coil windings are also a factor. At resonance, inductive and capacitive reactances cancel each other, leaving only the effective resistance of the input circuit.



(A) Skeleton bridge for VHF test.



(B) Response curve at looker point.

Fig. 4-7. Checking input impedance of a TV receiver.

HIGH-FREQUENCY CAPACITANCE TESTS

Capacitors that operate at high frequency must have very little residual inductance. High-frequency operation for an electrolytic capacitor will usually be low-frequency operation for a mica capacitor; therefore, the consideration is relative. In a video amplifier you may find an electrolytic bypass capaci-

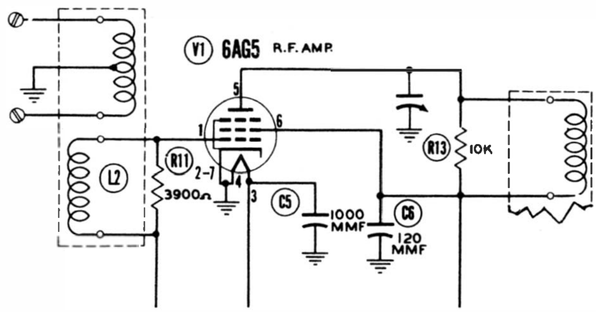


Fig. 4-8. Coupling controls input impedance.

tor shunted with a comparatively small fixed capacitor, as shown in Fig. 4-9. At higher video frequencies, the inductive reactance of various electrolytic capacitors becomes excessive and impairs the bypassing action. However, the small fixed capacitor has negligible inductive reactance, and it has a low capacitive reactance at higher video frequencies.

Thus, at 4 mc, a 5,000-mmf capacitor has about 8 ohms of reactance, while the effective reactance of some electrolytic capacitors at 4 mc is objectionably large. To demonstrate this fact in a circuit as depicted in Fig. 4-9, drive the grid of the tube with a signal generator at 4 mc. Connect a VTVM at the output of the amplifier. Then disconnect C46, and observe the reduction in gain. If C2 has excessive reactance at 4 mc, you will see the gain go down when C46 is disconnected.

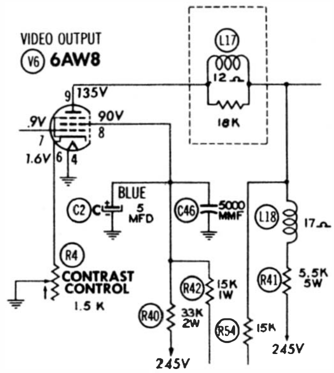


Fig. 4-9. C46 bypasses inductive reactance.

Bridge Test of Capacitor

To check the frequency dependency of an electrolytic capacitor, use an ordinary capacitance bridge, but drive the bridge at the chosen frequency of test (such as 4 mc), as illustrated in Fig. 4-10. A signal generator is suitable, provided it has a high-level output. Otherwise, a booster amplifier must be used between the generator and the bridge, or a high-level test oscillator employed. In any case, sufficient driving voltage must be applied to the bridge to obtain a useful null-indication. An

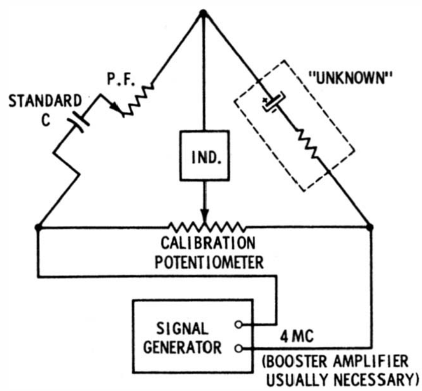


Fig. 4-10. Test for HF characteristic of electrolytic capacitor.

electrolytic capacitor which tests good at 60 cycles may show a large reduction in capacitance as the driving frequency is increased.

You may find that the null indication is not complete at higher test frequencies; at 4 mc it might be impossible to obtain even a partial null. Clearly, such an electrolytic capacitor does not even "look like" a capacitor at the test frequency. By varying the bridge-driving frequency, you can find the upper limiting frequency at which the electrolytic capacitor has substantial effective capacitance and a reasonably low power factor. Also, you can calculate the value of the small fixed capacitance that must be shunted across the electrolytic capacitor to obtain good bypassing action over the desired frequency range.

Capacitors With Negative Temperature Coefficient

You will find capacitors in critical circuits such as local-oscillator circuits, which have a negative temperature co-

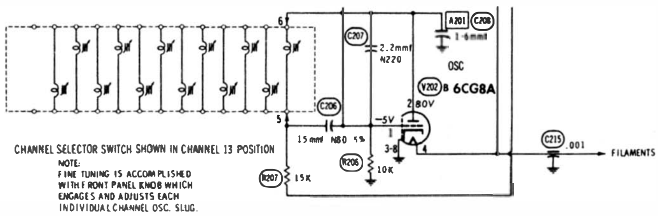


Fig. 4-11. C207 has negative temperature coefficient.

efficient. For example, C207 in Fig. 4-11 is an N220 type. This means that it normally loses 220 parts in 10^6 of its rated capacitance (2.7 mmf) per degree centigrade. This is too small a variation to check out on a service bridge and many lab-type capacitance bridges are inadequate to check this low value. Hence, the only practical test is a substitution test. If the local oscillator drifts excessively in frequency and the temperature-compensating capacitor is suspected, replace the capacitor, and observe the resulting circuit action.

Distributed Capacitance of HF Coils

The distributed capacitance of high-frequency coils is measured in the same manner as explained in Section 2 for air-core coils in general. Resonant-frequency measurements are made with a grid-dip meter or with equivalent means, with precision fixed capacitors connected across the coil. Then, L/f^2 values are plotted against capacitance values, to calculate the distributed capacitance of the coil.

Stray Capacitance of a Circuit

Direct measurement of stray circuit capacitance is usually difficult at high frequencies because the associated circuit resistance complicates the test procedure. Moreover, the circuit resistance is often associated with DC voltage. However, it is quite easy to measure stray capacitance indirectly, in terms of resonant-frequency shift. Consider, for example, the measure-

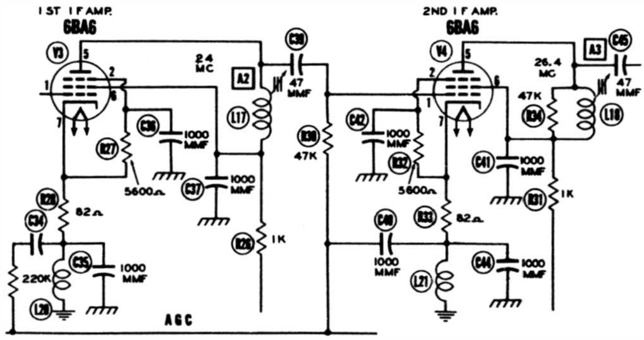


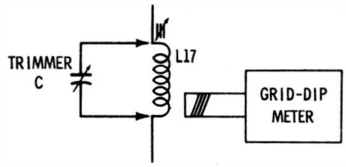
Fig. 4-12. L17 is reference in measurement of stray capacitance.

ment of stray capacitance in the plate circuit of V3, Fig. 4-12. This capacitance is different when the tubes are operating. In general, we are interested in the "hot" stray capacitance value.

With the receiver turned on, first measure the resonant frequency of L17 in Fig. 4-12 with a grid-dip meter. Then, turn the receiver off, and disconnect the leads from L17. Connect a small trimmer capacitor across L17, as depicted in Fig. 4-13. Now, adjust the trimmer capacitor to obtain the same resonant frequency as before. Clearly, the trimmer then has the same capacitance as the effective capacitance of the complex RC network in Fig. 4-12. Then disconnect the trimmer, and measure its value on a capacitance bridge. The reading obtained is the value of the effective circuit capacitance.

The coil should not be removed from the receiver in this test, because the proximity of metal surfaces and objects

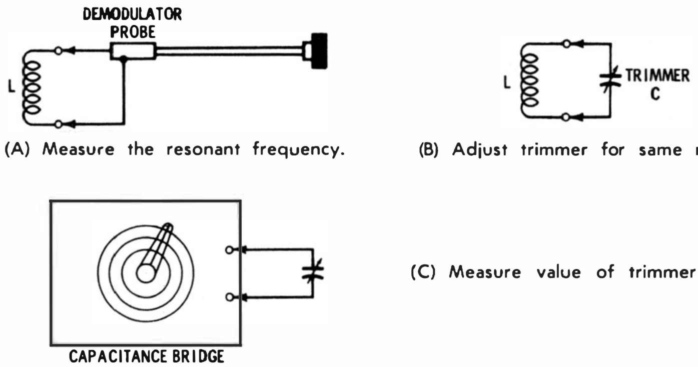
Fig. 4-13. Capacitor is adjusted for reference resonant frequency.



affects its resonant frequency. It is of no concern what this effect may be—the essential point is not to disturb its value. In addition, use the same separation between the IF coil and grid-dip meter tank in both measurements—if you change the separation, the resonant frequency will be affected, and the measurement will become inaccurate.

Input Capacitance of RF Probe

The input capacitance of an RF or demodulator probe is a figure of merit. The lower is the input capacitance, the better is the probe in signal-tracing applications. It might be supposed that the input capacitance of a HF probe is constant, but this is not so. It varies somewhat with frequency. To measure the input capacitance of a probe at a chosen frequency, select or wind a small coil that is resonant at the frequency of interest when it is shunted by the probe (Fig. 4-14A). A grid-dip meter is used to check the resonant frequency of the coil with the probe shunted across the coil.



(A) Measure the resonant frequency.

(B) Adjust trimmer for same resonance.

(C) Measure value of trimmer capacitor.

Fig. 4-14. Measurement of HF-probe input capacitance.

Next, disconnect the probe, and connect a small trimmer capacitor across the coil (Fig. 4-14B). Adjust the trimmer to obtain the same resonant frequency as before, and measure the trimmer capacitance (Fig. 4-14C). If the test is repeated at 1, 20, 50, and 100 mc, for example, somewhat different values of input capacitance will be measured. Note that when semiconductor diodes are employed in the probe under test, it makes no difference whether the probe is connected to a scope or to a VTVM. Conversely, if a vacuum-diode type of RF probe is under test, it must be powered from its associated VTVM. Otherwise, the measurement of input capacitance will be incorrect.

The input capacitance of both semiconductor and vacuum-tube HF probes depends to some extent on the signal level that is applied. This variation can be tested by using different separations of the coil (L in Fig. 4-14) from the grid-dip tank. Close coupling induces a large voltage in the coil and provides a high-level test; on the other hand, loose coupling provides a low-level test.

HIGH-FREQUENCY INDUCTANCE TESTS

Shop tests of inductance at high frequencies are seldom concerned with inductance values as such. However, laboratories, factories, and incoming-inspection departments must often measure inductance values at high frequencies. A 1-kc bridge will measure inductances as small as 10 microhenrys. To measure smaller inductance values, a higher test frequency must be used, so that the small inductance will have appreciable reactance. Various methods are utilized, the simplest of which requires only a grid-dip meter and a pair of precision fixed capacitors.

Grid-Dip Meter Test

The grid-dip meter should have good accuracy and be loosely coupled to the coil under test. The distributed capacitance of the coil is first measured, as previously explained. Here is an example for a small coil: Two fixed capacitors are employed, having values of 10 mmf and 20 mmf, respectively. When the 10-mmf capacitor is shunted across the coil, the grid-dip meter measures a resonant frequency of 18.2 mc. On the other hand, when the 20-mmf capacitor is shunted across the coil, the resonant frequency measures 14.1 mc. The corresponding $1/f^2$ values are 0.003×10^{-12}, and 0.005×10^{-12}, respectively. Accordingly, the distributed capacitance of the coil is 5 mmf, as shown in Fig. 4-15.

Inasmuch as the resonant frequency of the coil was 18.2 mc when shunted by a total of 15 mmf, these values can be substituted in the resonant-frequency formula ($f = 1/(2\pi\sqrt{LC})$), from which the inductance is calculated as 5 microhenrys. The calculation is even simpler from the plot of Fig. 4-15. The slope of the plotted line is proportional to inductance. When multiplied by $1/(4\pi^2)$ the inductance value is obtained. Note that the slope is equal to 0.005×10^{-12} divided by 20×10^{-12}, or simply 0.005/20, which is 0.0002. Now, $1/(4\pi^2)$ is approximately equal to 0.0253, which when multiplied by 0.0002 gives an inductance of 5 microhenrys as before.

Bandwidth and Q

If a coil were an ideal inductance, it would have no distributed capacitance and no resistance. Because distributed capacitance is present, the coil has a self-resonant frequency, and because high-frequency resistance is present, the coil has a certain bandwidth. Recall that $Q = X_L/R$; the Q of the coil is inversely proportional to bandwidth. Generally, the Q and bandwidth of an isolated coil is of minor concern; the practical consideration is two bandwidth or Q in a particular circuit. For example, in an IF amplifier the coil is shunted by the dynamic plate resistance of a tube, as depicted in Fig. 4-16A.

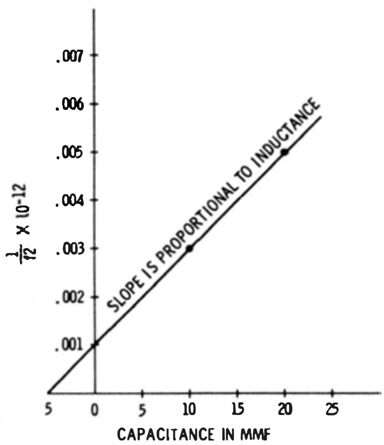
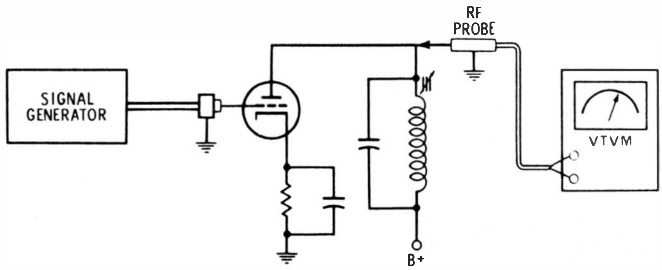


Fig. 4-15. Distributed capacitance is 5 mmf.

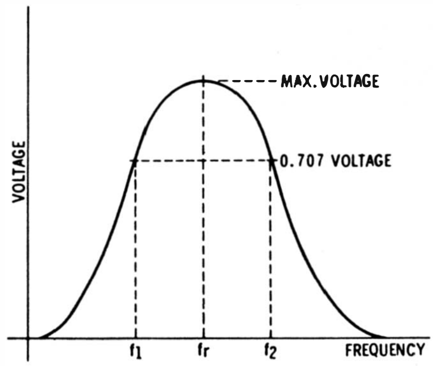
To test the coil for its in-circuit bandwidth, three measurements are made. The signal generator is first tuned for maximum reading on the VTVM; this determines the resonant frequency, f_r. Then, the generator is tuned below f_r to obtain a VTVM reading that is 70.7% of the initial reading. This determines the frequency f_1 (Fig. 4-16B), which is one of the "half-power" frequencies. Next, the generator is tuned above f_r to determine the other half-power frequency f_2. The bandwidth is then equal to $f_2 - f_1$. The Q-value is given by the formula $f_r/(f_2 - f_1)$.

Half-Power Points

The half-power points are called that, because the power in the circuit is equal to E^2/R. The VTVM reads E. When the power drops one-half, its value is given by $E^2/(2R)$. Since the VTVM does not read E^2 but instead reads E, the half-power point occurs where the VTVM reading is 70.7% of maximum. Now, the Q is equal to the resonant frequency divided by the frequency interval between the half-power points. However, the bandwidth is defined by convention, and in the case of communication circuits it is defined as the frequency interval between the half-power points.



(A) Setup for bandwidth and Q measurement.



$$Q = \frac{f_r}{f_2 \; f_1}$$

(B) Bandwidth at the half-power points.

Fig. 4-16. Measurement of Q and bandwidth.

A different bandwidth is customarily defined in video circuits. In this case, the bandwidth is taken as the frequency interval between the half-voltage points, as illustrated in Fig. 4-17. Since power is equal to E^2/R, the half-voltage points correspond to the ¼ power points on the curve. Beginners are sometimes confused by the difference in bandwidth definitions for radio and TV receivers. Another source of confusion is the tendency of some apprentices to assume that that bandwidth is given by the frequency interval along the baseline (where the ends of the curve meet the baseline). The foregoing discussion should clarify these considerations.

Coils in Front Ends

The coils in a front end can be checked effectively only by sweep-alignment procedures. Of course, if a coil is shorted or open, the RF signal does not pass, and it can be localized by analysis of receiver operation analysis or by signal-tracing tests. However, the usual problem in the service shop is to adjust the coil inductances to exact values for optimum operation. You will find that coils in front ends may have no slugs or trimmer capacitors. Inductance adjustment is made simply by compressing or expanding the coil turns. This is not difficult, because the coils are wound from soft copper wire, which easily takes a set.

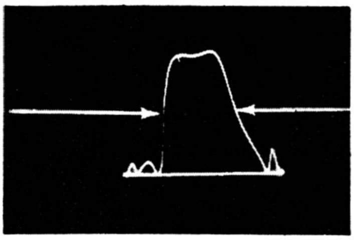


Fig. 4-17. Bandwidth is measured at half-voltage points.

High-band coils may have less than one complete turn. They often have a "hairpin" shape. To adjust their inductance, simply spread the hairpin out wider, or squeeze it closer together. Correct inductance is obtained when the RF response curve matches as closely as possible the shape specified in the receiver service data. RF alignment is exacting and cannot be discussed in detail here. Interested readers are referred to specialized texts, such as *Practical TV Tuner Repairs,* published by Howard W. Sams.

Detector Diodes

Detector diodes, such as used in video-detector circuits and demodulator probes, operate at comparatively high frequencies. An ohmmeter test at zero frequency shows only roughly whether a diode is good or bad. Two diodes, both of which check out satisfactorily on an ohmmeter test, might have widely different efficiencies in high-frequency detector application. Laboratories utilize suitable test equipment to test detection efficiency at a chosen frequency. However, in the service shop, the cost of this specialized test equipment cannot be justified—instead, a comparison test is employed and is almost as effective.

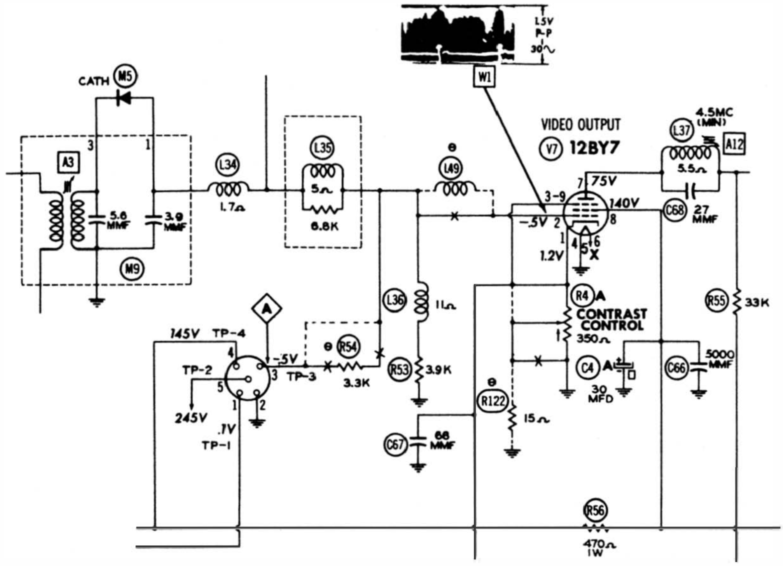


Fig. 4-18. Typical video-detector circuitry.

A typical video-detector and output configuration is shown in Fig. 4-18. To make a comparison test of sample diodes, proceed as follows: Connect a scope with a low-capacitance probe to the grid of the video-amplifier tube. Clamp the AGC line. Apply a test signal to the receiver from a pattern generator, or the output from an AM generator can be used. W1 in Fig. 4-18 shows a typical video-signal pattern. In this test, only the amplitude of the pattern is of interest. When different types of diodes or different diodes of the same type are connected in the M5 circuit, the pattern amplitude will be seen to change. The best detection efficiency, of course, is indicated by maximum pattern height.

Diode in Demodulator Probe

The diode in a demodulator probe operates as a simplified video detector. However, the requirements are specialized. The probe is often used in very low-level signal circuit, and so

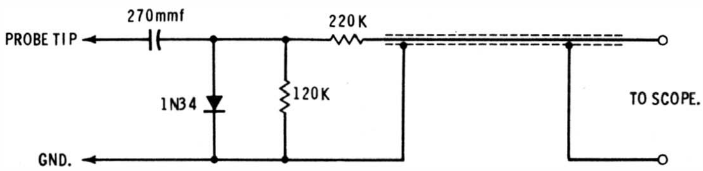


Fig. 4-19. Schematic of a demodulator probe.

we are chiefly concerned with its small-signal efficiency. A small-signal test can be made as follows: Connect the probe output cable to the vertical-input terminals of a scope. Drive the probe from an IF sweep generator. Advance the scope gain to maximum, and reduce the output from the sweep generator until a pattern about one inch high is displayed on the scope screen.

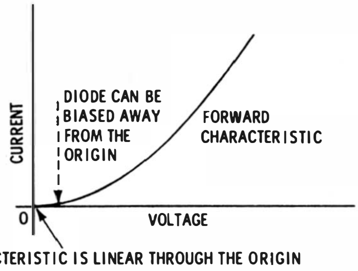


Fig. 4-20. Characteristic of a diode at low signal level.

Now, try substituting different types of diodes, and different diodes of the same type, in place of the 1N34 depicted in Fig. 4-19. The pattern height on the scope screen will change. The best small-signal efficiency, of course, is indicated by maximum pattern height. Although it is not generally known, the small-signal efficiency of a semiconductor diode can often be improved by a low forward bias. The reason follows:

Improving Detection Efficiency

Recall that a semiconductor diode is a nonlinear resistance. Best detection efficiency is obtained when the characteristic curve changes most rapidly. Now, all semiconductor diodes

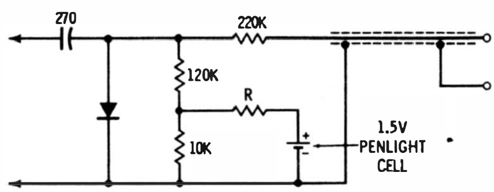


Fig. 4-21. Biased-diode demodulator probe.

have a practically linear characteristic through the origin, as depicted in Fig. 4-20. In other words, at extremely small signal levels, the detection action is practically zero. However, as the operating point is moved into the forward-current region of the diode, the characteristic is no longer linear but starts curving upward. Hence, if the diode is biased a fraction of a volt into the forward-current region, the small-signal detection efficiency improves considerably, at least for most commercial diode types.

You can add a penlight cell in a voltage-divider circuit to a demodulator probe, as shown in Fig. 4-21, and usually obtain improved small-signal sensitivity. The value of R can only be determined by experiment—it varies for different diodes. Choose the value that provides maximum pattern height on the scope screen.

SECTION 5

Components With Distributed Parameters

The history of *distributed-parameter* discovery and its technical understanding is interesting. Before long cables were used for communication, inductance, capacitance, and resistance were recognized only as lumped parameters. A cable was regarded simply as two conductors for a circuit, and its distributed parameters were neglected. This soon led to a serious disappointment since very long cables would only carry very low frequencies. This was a complete puzzle at first, and it was solved by intensive research. It was discovered that distributed resistance, which was operating in combination with distributed inductance and capacitance in a long cable, caused the cable to act as low-pass filter.

Suitable means, such as loading at intervals with lumped inductances, were developed to control the characteristics of long cables, at least within useful limits. These investigations also led to recognition of the fact that so-called lumped components actually have distributed parameters, simply because those components occupy space. At comparatively low frequencies, the concept of ideal, lumped parameters is justified. However, at high frequencies the distributed character of lumped parameters must often be contended with.

Consider an open pair of test leads, perhaps three feet long. Ordinarily, the leads are not regarded as a distributed LCR configuration. But at a suitably high test frequency the pair of leads becomes a resonant component called a tuned stub, and now the distributed L and C become the dominant parameters.

Interference traps, Lecher wires, and UHF tuners accordingly make practical use of distributed parameters. Most antennas are distributed-parameter components. At radar frequencies, metallic insulators which are simply quarter-wave stubs that operate on the basis of distributed parameters are often employed.

Evidently, there can be no sharp dividing line between lumped parameters and distributed parameters, because all parameters have at least a residual distributed aspect. However, for practical convenience, components with distributed parameters are classified as those in which concepts of lumped parameters cannot be justified. Thus, a delay line in a color-TV receiver cannot be described satisfactorily as a lumped component; its distributed characteristics are very prominent. On the other hand, a peaking coil is satisfactorily described as a lumped component.

With this preliminary understanding, it is possible to proceed to a closer analysis of distributed parameters, and review the basic methods of testing this class of components. Some of the important background has been covered in the preceding section, to which you may need to refer.

MEANING OF DISTRIBUTED PARAMETERS

Circuit configurations comprise resistance, capacitance, and inductance either in lumped or distributed form. A plate-load resistor is an example of lumped resistance; a screen-bypass capacitor is an example of lumped capacitance; a filter choke is an example of lumped inductance. The term "lumped" signifies that resistance is the dominant parameter in a plate-load resistor and any capacitance or inductance which the resistor may have is ordinarily neglected. Of course, this is not always a valid assumption—wirewound resistors, for example, may have substantial inductance as well as distributed capacitance.

Recall that an electrolytic capacitor might have objectionable inductance at high frequencies. Rolled paper capacitors, likewise, can have excessive residual inductance when operated at high frequencies. An electrolytic capacitor may have excessive resistance (high power factor) at high frequencies. In other words, an electrolytic capacitor can be considered a lumped capacitance only when it is operated within the frequency limit for which it was designed.

Also, a filter choke can be regarded as a lumped inductance only in appropriate applications. Chokes usually have substantial resistance. They also have comparatively high distributed capacitance. At certain higher frequencies of operation, a filter choke can be expected to "look like" a capacitor instead of an inductor. To put it another way, a filter choke is an impedance in a strict analysis, although it is often convenient to assume that the choke is a lumped inductance.

The term "distributed" signifies that the parameter is "spread out" uniformly. The stray capacitance of a lead in a

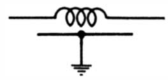


Fig. 5-1. Symbol for a delay line.

circuit is distributed. If a wire is wound into a coil, the capacitance between turns throughout the coil is distributed. A *delay line* for a color-TV receiver consists of a coil wound on a powdered-iron core; its distributed capacitance is increased by enclosing the coil in a metal sheath. The symbol for a delay line is shown in Fig. 5-1.

A delay line never has a completely smooth distribution of inductance and capacitance. However, a high-quality delay line is a practical approximation of this ideal. A low-pass filter (Fig. 5-2) also approximates a smooth distribution of L and C, provided a very large number of sections are used. Such filters are employed as delay lines in lab-type scopes

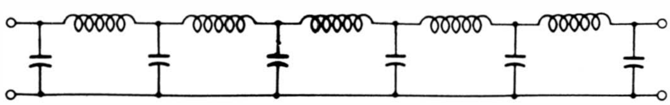


Fig. 5-2. Multisection low-pass filter.

where as many as 30 sections may be utilized. Now, if a low-pass filter had an infinite number of sections, it would approximate a coaxial cable in effect.

Reading Between the Lines

Distributed parameters are ordinarily not explicit, but only implied in conventional symbols, therefore you must visualize the distributed parameters. Fig. 5-3 shows the meaning of this requirement. An ordinary potentiometer is symbolized as a resistor with a variable arm. But, as will be demonstrated subsequently, a potentiometer often has a significant distributed capacitance that must be taken into consideration in high-frequency or square-wave operation. You must visualize the distributed capacitance as depicted in the equivalent-circuit symbol for a potentiometer in Fig. 5-3. This representation is in accordance with the conventional representation of distributed capacitance in a delay line, as shown in Fig. 5-1.

It will subsequently be demonstrated that a wirewound resistor cannot be visualized as a simple resistance at video frequencies. Instead, it is necessarily considered as an RLC component; the three parameters are distributed, and an at-

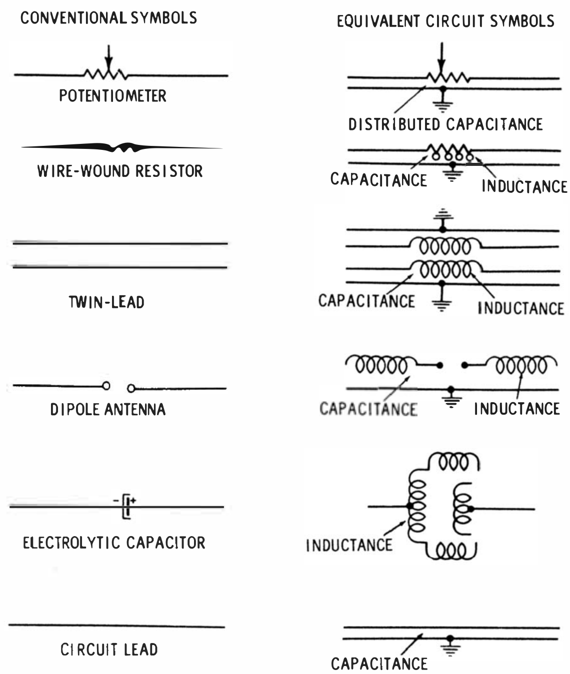


Fig. 5-3. Distributed parameters of components.

tempt to visualize the electrical picture is given in Fig. 5-3. The small loops shown in the equivalent symbol for a wire-wound resistor indicate the distributed inductance—the distributed capacitance is indicated as before.

Note that the conventional symbol for twin lead denotes the presence of distributed capacitance only. As a matter of fact, resonant stubs could not exist if the twin leads lacked distributed inductance. An attempt to visualize the physical facts is shown in Fig. 5-3; the conductors are shown as long small coils, with distributed capacitance as previously explained.

An electrolytic capacitor, as you will recall, often exhibits objectionable inductance when operated at high frequencies. Hence, in Fig. 5-3, this distributed inductance is represented as the electrodes of the capacitor.

Properties of Coaxial Cables

A coaxial cable clearly has distributed capacitance because the central conductor is surrounded by a metal sheath. The two metal surfaces form the "plates" of a capacitor. Although it is not obvious, a coaxial cable also has distributed inductance, since a wire has inductance, even if it is not wound into a coil. The inductance of a straight wire is comparatively small, but it becomes an important parameter when a coaxial cable is driven at high frequencies. Note that a coaxial cable also has resistance—the wire has a DC resistance, although it may be very small. At very high frequencies skin effect causes a wire to have a considerably higher AC resistance.

The resistance of a coaxial cable cannot be neglected unless it is comparatively long. For example, stubs are evaluated on the basis of distributed capacitance and inductance only. Note that there are two forms of resistance in a coaxial cable; the metal has a small resistance, and the dielectric has a small leakage. Since the series resistance is very low, and the shunt resistance is very high, both can be disregarded unless the cable is very long, as in a community TV system. Briefly, the series and shunt resistance in a very long cable cause the cable to respond as a low-pass filter. To extend the cut-off frequency, large-diameter conductors are used with air spacing.

TESTS OF STUBS, CABLES, AND LINES

A stub is a comparatively short length of coaxial cable or twin lead. If it is shorted at the far end, it is called a shorted stub. Conversely if it is left open at the far end, it is called an open stub. The terminals of the stub will appear as an inductance, capacitance, very high resistance, or very low resistance, depending on the applied frequency. When a stub looks like a very high resistance, it is operating as a parallel-resonant circuit. When it looks like a very low resistance, it is operating as a series-resonant circuit. When it looks like a capacitance or inductance, it is operating off resonance.

Shorted Stub

The most common test of a stub is a measurement of its resonant frequency. A grid-dip meter is most convenient for the purpose. Simply hold the tank of the grid-dip meter near the end of the stub, and tune the instrument for a dip indication. A shorted stub (Fig. 5-4A) has an infinite number of resonant frequencies. The lowest resonant frequency corresponds to an electrical length of one-quarter wavelength. The electrical length is almost the same as the physical length for an air-spaced line. At its lowest resonant frequency, a shorted stub has the voltage and current distribution depicted in Fig. 5-4B.

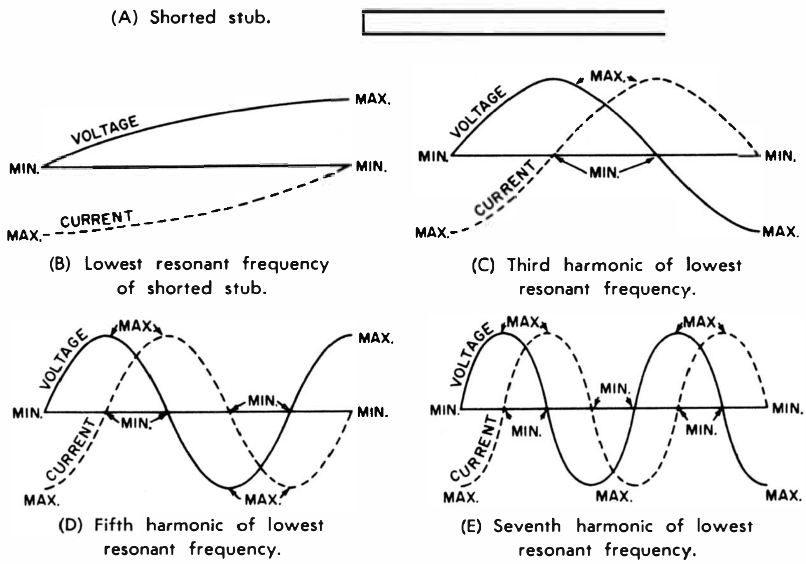


Fig. 5-4. Voltage and current distribution along a shorted stub.

The quarter-wave stub is the equivalent of a parallel-resonant circuit, so its terminal impedance is very high. If you apply Ohm's law to the terminal voltage and current depicted in Fig. 5-4B, this fact becomes clear. Since R = E/I, then in this case, R = E/0, or the input resistance is infinite, at least in theory. In practice, the stub wires have a small RF resistance, and there is a little loss from radiation, which is equivalent to RF resistance also. Hence, the terminal impedance is not infinite, although it is very high. The better is the design of the stub, the higher is its input impedance in quarter-wave operation.

Because the wires are short-circuited, the voltage is zero at the shorted end of the stub. The current flow is maximum through the short-circuit. Ohm's law is written R = 0/I for the shorted end, which indicates that the stub has minimum impedance at the shorted end. The actual impedance is not quite zero in practice, due to the RF resistance of the conductors and the small radiation loss. It is clear from the voltage and current distribution depicted in Fig. 5-4B that the impedance at intermediate points along the stub varies; if you tap in at a suitable point along the stub, you can obtain any impedance value from (almost) zero to infinity.

Reflection of Voltage and Current

A grid-dip meter test will show the next stub resonance at the third harmonic of the first resonant frequency. The voltage and current distribution for third-harmonic resonance is illustrated in Fig. 5-4C. As before, the input impedance is very high since the third-harmonic shorted stub is also the equivalent of a parallel-resonant circuit. The question may be asked why we find the voltage and current distributions depicted in Fig. 5-4B and C. The answer is that the electrical energy does not travel down the stub instantaneously; instead, the energy flows at about the speed of light. When a voltage is applied at the terminals, the RF power travels down the wires until it reaches the short-circuited end.

Obviously, when the RF energy reaches the short-circuit, its voltage must drop to zero—a voltage drop cannot exist across zero resistance. Inasmuch as there is no load to consume power at the end of the stub, the energy must be reflected since energy cannot be destroyed—if it is not consumed (changed into some other form of energy), it must be reflected. The only way that a voltage can be reflected at a short-circuit is for it to be reflected 180° out of phase; then, the resultant voltage at the short circuit is zero.

When the RF energy reaches the short circuit, the current encounters a zero-resistance path, so the current flows through the short circuit without loss. Again, its energy cannot be destroyed, and since there is no load to absorb the incident energy, the current must also be reflected. The only way that a current can be reflected at a short circuit is for it to be reflected in phase; then the resultant current at the short circuit is maximum.

It will be seen that voltage and current reflections at the open end of the stub are exactly opposite to the reflections at the shorted end. Reflection must occur at the open end, because there is no load provided, and the energy cannot be destroyed. No current can flow across an open circuit, and hence the current reflection at the open end is 180° out of phase, which brings the current to zero. However, the voltage reflection at the open end is in phase, which brings the current to maximum.

Higher Harmonic Resonances

A grid-dip meter test will show that the shorted stub has resonances at each odd-harmonic frequency. Figs. 5-4D and E illustrate the voltage and current distributions for fifth- and seventh-harmonic resonances. From the foregoing discussion, it is clear that if the stub is tapped at the current minimum, the impedance at that point will be very high. If the stub is tapped at a voltage minimum, the impedance at that point will be very low. As surprising as it might seem, you can solder a short circuit across a stub at a voltage minimum, and no change occurs in stub characteristics. This is the reason that supports of the "metallic-insulator" type are often used to support stub installations, as shown in Fig. 5-5.

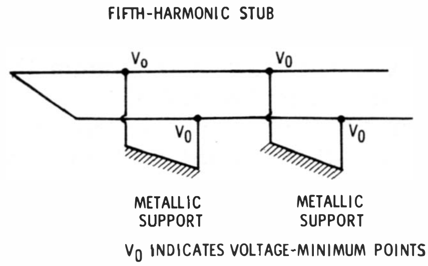
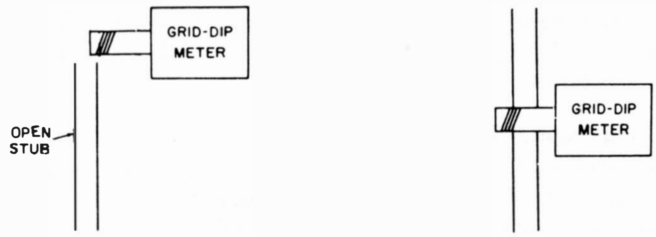


Fig. 5-5. Metallic insulators at minimum voltage points.

It also follows from Fig. 5-4A that in case the "metallic insulators" are made one-quarter wavelength in length, that they may be secured at any point along a stub or line, without causing any change in operating characteristics. In this case, the "insulators" are simply quarter-wave stubs. Of course, this method of "metallic insulation" is effective only at the correct frequency—in case of frequency drift, there will be an appreciable loss of energy.

Open Stubs

An open stub is a line section that is open at the far end (Fig. 5-7A). The resonant frequencies of an open stub can be measured with a grid-dip meter, as depicted in Fig. 5-6. Because as the stub has infinite resistance at both ends, the voltage rises to a minimum at each end. At the lowest resonant frequency of the stub, a voltage minimum occurs at the center

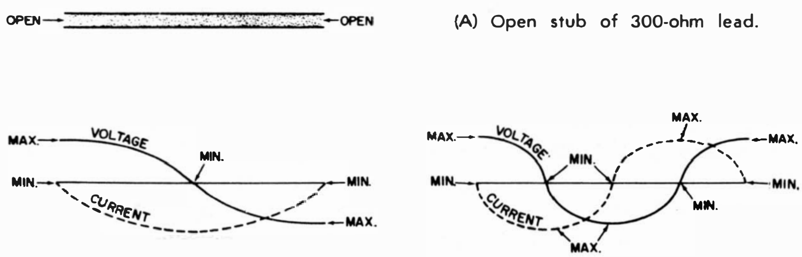


(A) Capacitive coupling to end of stub. (B) Inductive coupling to center of stub.

Fig. 5-6. Coupling to an open stub.

of the stub (Fig. 5-7B). The resonant frequency can be checked by capacitive coupling to one conductor, as shown in Fig. 5-6A. Or, inductive coupling can be used to the center of the stub, as shown in Fig. 5-6B.

At comparatively low frequencies, it is preferable to use inductive coupling, since the dip is more pronounced. When inductive coupling is utilized, the most effective test point is at a current maximum (voltage minimum). Thus, an open stub exhibits its second resonance at the second-harmonic frequency (Fig. 5-7C). The current maximum then occurs one-fourth of the distance from the end of the stub. An open stub has an infinite number of resonant frequencies. Note that these are all the harmonics of the lowest resonant frequency. Unlike a shorted stub, which resonates on odd harmonics only, an open stub resonates on both even and odd harmonics of the lowest resonant frequency.



(A) Open stub of 300-ohm lead.

(B) Lowest resonant frequency of open stub.

(C) Second harmonic of lowest resonant frequency.

Fig. 5-7. Voltage and current distribution on an open stub.

INDUCTANCE AND CAPACITANCE OF CABLE OR LINE

It is difficult to measure the inductance of coaxial cable or twin lead directly, unless specialized laboratory test equipment is used. However, the inductance per foot can be determined indirectly. Recall that you can measure the capacitance of cable of twin lead with an ordinary capacitance bridge. For example, a 6-foot length of 300-ohm twin lead measured 20 mmf of capacitance; therefore the capacitance in this example is 3.33 mmf per foot.

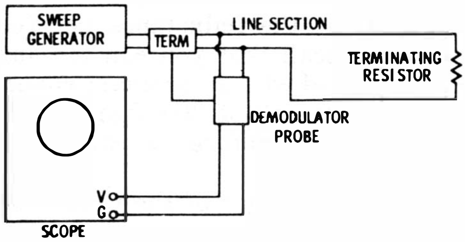
The characteristic impedance of the twin lead is 300 ohms, and for short lengths (which are considered lossless in practice), $Z_0 = \sqrt{L/C}$. Rearranging, we have $L = CZ_0^2$, or $L = 90{,}000 \times 3.33 \times 10^{-12} = 0.3$ microhenry per foot. In this example, the rated characteristic impedance of the twin lead has been used, but if the characteristic impedance were unknown, it would have to be measured. This inductance of 0.3 microhenry per foot is called the loop inductance. In other words, it is the inductance of both conductors in the twin lead.

CHARACTERISTIC IMPEDANCE OF CABLE OR LINE

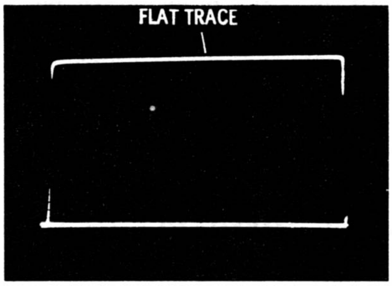
The characteristic impedance of a cable or line is defined as the input impedance of an infinitely long sample. This is the theoretical definition, but in practice, the characteristic impedance is defined as the termination which makes the input impedance of the cable (or line) constant, regardless of length. For comparatively short length of cable or line, the characteristic impedance will be a pure resistance, because the short section may be considered as lossless.

A test is made most conveniently as follows: Use a line section at least five feet long, and apply the RF output from a sweep generator to one end of the line. Connect a demodulator probe and a scope across the generator-output terminals, as shown in Fig. 5-8A. Terminate the cable with a composition resistor that has a value near the expected characteristic impedance of the line, and observe the scope pattern (Fig. 5-8B). If the trace is not flat, change the value of the terminating resistor to obtain a flat trace. The value of the resistor is then equal to the characteristic impedance of the line section. Any VHF high-channel output from the generator is suitable in this test.

Of course, the evaluation of this test assumes that the sweep generator has a flat characteristic. In case of doubt, this should be cross-checked; simply disconnect the line section from the test setup in Fig. 5-8A, and connect the terminating resistor directly across the sweep-generator output terminals. The trace should be flat if the generator is in good operating condition. If the trace is not flat, note the curvature carefully. Then re-



(A) Test setup.



(B) Flat response.

Fig. 5-8. Characteristic impedance measurement.

connect the line section to see whether this curvature is duplicated. Choose a terminating resistance that provides duplication of the reference curvature.

STANDING-WAVE RATIO ON A LINE

An open or shorted stub has an infinite standing-wave ratio, at least in theory. With reference to Fig. 5-7, the voltage distribution passes through maxima and minima. In the ideal situation, the minimum voltage is zero, and $V_{max}/V_{min} = \infty$. Now, suppose that a line is terminated in a resistance that is less in value than the characteristic impedance (Z_0) of the line. Reflection is incomplete, because some of the electrical energy is converted into heat by the terminating resistor. Hence, the resultant of incident and reflected waves produces a voltage minimum that is greater than zero, as depicted in Fig. 5-9.

Suppose again that the line is terminated in a resistance that is greater in value than the characteristic impedance of the line. As before, reflection is incomplete, due to conversion of some of the electrical energy into heat. The resultant of incident and reflected waves produces a voltage minimum that is greater than zero (Fig. 5-9). The ratio of V_{max}/V_{min} is called the standing-wave ratio, or the voltage standing-wave ratio

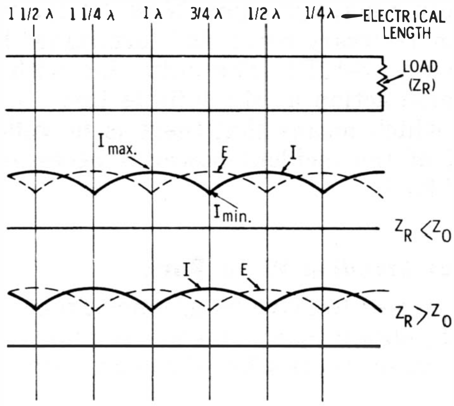
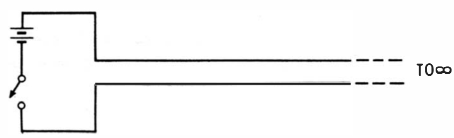


Fig. 5-9. Standing waves on a resistively terminated load.

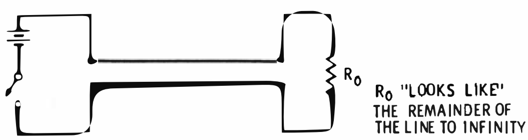
(VSWR). It is equal to Z_o/Z_R, or Z_R/Z_o, whichever the case may be.

If $Z_R = Z_o$, there is no reflected voltage or current at the termination. All of the incident power is absorbed by the terminating resistor and converted into heat. The reason for this *matched* condition is not entirely obvious. The electrical meaning of a matched load is given in Fig. 5-10. Consider a theoretical one-ended line of infinite length. If a battery voltage is switched into the line, a steady current is drawn; theoretically this constant current will flow forever, because the line is infinitely long. The line can never be charged up, and no reflected energy can exist.

What is the characteristic impedance (resistance) of the infinite line (Fig. 5-10A)? It is, of course, E/I as defined by Ohm's law. It has some value which is determined physically by the diameter of the conductors and their spacing. For ex-



(A) Infinite line has no reflected energy.



(B) Matched load can reflect no energy.

Fig. 5-10. Theoretical presentation of a matched load.

ample, E/I might equal 300 ohms. Now, let the infinitely long line be cut at an arbitrary point, and terminated by a 300-ohm resistor (R_0 in Fig. 5-10B). The finite line with the matched load has the same action as the infinite line—it provides the same demand, which means that there is no reflected voltage or current. All of the incident power is necessarily absorbed by the matched load.

Measurement of Standing-Wave Ratio

When a line is used to drive an antenna from a transmitter, it is desirable to obtain maximum power transfer. The maximum power transfer occurs when the characteristic impedance

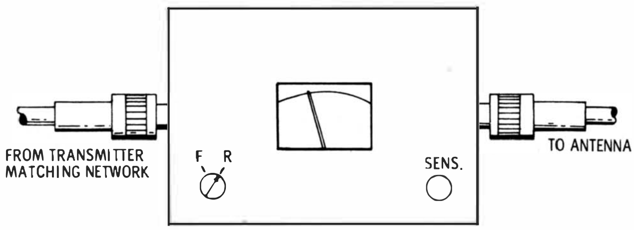


Fig. 5-11. SWR meter connected in a transmission line.

of the line matches the impedance of the antenna. Under this condition, there is no reflected power on the line, or, the VSWR is 1. Hence, measurements of VSWR are used as an indication of efficiency. Several methods of testing a line for VSWR are available, the most accurate of which are time-

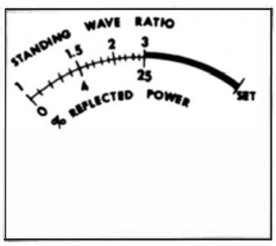


Fig. 5-12. Dial scale of SWR/reflected power meter.

consuming. For practical purposes, a direct-reading, standing-wave-ratio meter is adequate.

An SWR meter is connected in series with the high-frequency transmission line, as depicted in Fig. 5-11. The characteristic impedance of the meter must match the line—50 ohms and 75 ohms are widely used impedances. If a meter is to be used with a line of different impedance, impedance transformers are required at input and output, or if a single-ended meter is to be used in a double-ended line, balun coils must be connected at both input and output.

To make a VSWR test, the function switch of the meter is first set to its forward position, and the sensitivity control is turned to obtain full-scale deflection ("Set" calibration mark in Fig. 5-12). Next, the function switch is turned to the reflected power position. The pointer then indicates the VSWR and the percentage of reflected power. Note that an appreciable amount of power is required to provide full-scale deflection; hence, an SWR meter cannot be used with transmitters that have very low power. The lower is the operating frequency, the higher is the power level required to obtain full-scale deflection.

The schematic of a typical standing-wave-ratio meter is shown in Fig. 5-13. It is essentially a section of coaxial line, to

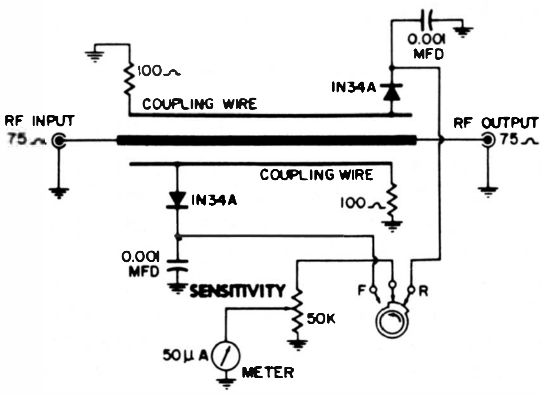
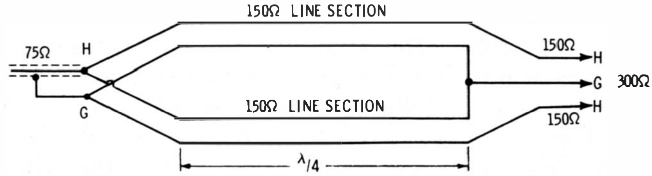


Fig. 5-13. Circuit of typical SWR/reflected-power meter.

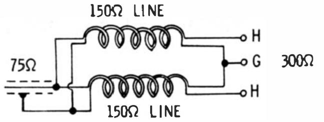
which two parallel wires are coupled. Both inductive and capacitive coupling is provided by the wire. Each wire is terminated by a suitable resistance, and the terminated ends are opposed. Diode rectifiers are connected near the unterminated ends of the coupling wires. Forward power flow produces output from one diode, and reflected power flow produces output from the other diode.

Balun Configuration

Tests in which a coaxial cable is required to drive a twin-lead line (or vice versa) require the use of a balun to convert a single-ended output to a double-ended output or vice versa. The construction of a simple balun is depicted in Fig. 5-14A. The balun should be at least a quarter-wavelength long at the operating frequency, although it may be longer. The balun illustrated is suitable for matching a 75-ohm, single-ended



(A) Straight-line type.



(B) Bifilar coil type.

Fig. 5-14. Typical balun matching couplers.

output to a 300-ohm, double-ended line. The spacing between the 150-ohm line sections should be appreciably greater than the spacing of the conductors in the line section itself.

The line sections can also be wound into loose coils, as illustrated in Fig. 5-14B. The spacing between turns should be greater than the spacing between the conductors of the line sections. This provides a more compact construction. Note that a balun can make only a 4/1 impedance transformation. The exact values of the input and output impedances can be varied by choosing suitable characteristic impedances for the line sections—however, the input/output impedance ratio is always 1/4 or 4/1. The balun can be tested for proper operation as shown in Fig. 5-15.

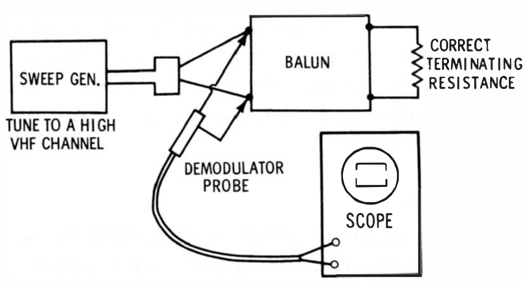
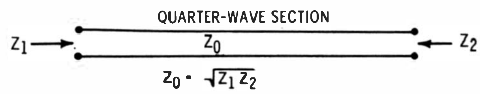


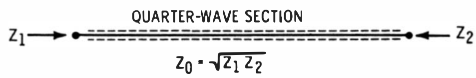
Fig. 5-15. Efficient balun shows flat trace.

Stub Matching

Any two impedances can be matched by means of resonant stubs. The most convenient method employs a single, series, quarter-wave section as shown in Fig. 5-16. Suppose you wish to match a 50-ohm line (or cable) to a 250-ohm line (or cable).



(A) Twin-lead impedance transformer.



(B) Coaxial impedance transformer.

Fig. 5-16. Impedance matching with resonant stubs.

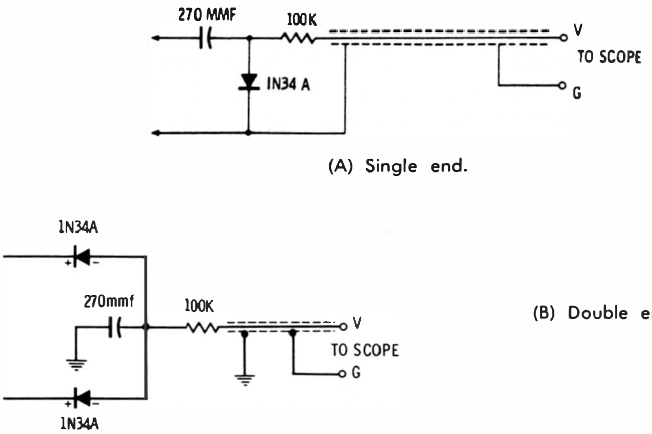
The quarter-wave section must then have a characteristic impedance equal to $\sqrt{50 \times 250}$, or 111.8 ohms. The only difficulty you will encounter is obtaining line or cable having the desired characteristic impedance. It is often necessary to construct the desired quarter-wave section experimentally and to verify its characteristic impedance with a sweep generator and scope by the method depicted in Fig. 5-18.

Demodulator Probes

Two different types of demodulator probes are used to test components having distributed parameters. Single-ended components such as coaxial stubs are tested with a single-ended probe (Fig. 5-17A). Double-ended components such as twin-lead stubs are tested with a double-ended probe. As shown in Fig. 5-17B. If you attempt to use a single-ended probe to test a balanced stub or line, the display is likely to be erroneous due to upset of the balanced current flow in the two conductors.

Sweep-Generator Output Termination

Most sweep generators have a single-ended output cable. This arrangement is used directly to drive a single-ended component. However, if the generator is used to drive a double-ended component, its single-ended output should be converted to double-ended output. This can be done most effectively by means of a balun (Fig. 5-14B). However, a simpler though less efficient resistive balun can be used, as shown in Fig. 5-18.



(A) Single end.

(B) Double end.

Fig. 5-17. Demodulator probes.

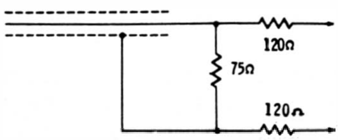


Fig. 5-18. Simple resistive balun.

TEST OF DELAY LINE

Delay lines in color-TV receivers are usually tested initially by displaying the frequency-response curve of the Y-amplifier. A video-frequency sweep generator, demodulator probe, and scope are used, as shown in Fig. 5-19. A typical response curve is seen in Fig. 5-20. The curve shape should be checked against the receiver service data specification. If substantial distortion is present, and the delay line is suspected, disconnect the line and check it out with an ohmmeter. The winding might be open or leaking to ground.

Because the inductance and capacitance in a delay line does not have a completely smooth distribution, the line develops minor resonance at various frequencies. Hence, the contour of a Y-amplifier curve is not smooth but instead displays undulations as shown in Fig. 5-20. This characteristic is normal for delay lines used in TV receivers.

TESTING WIREWOUND RESISTORS FOR REACTANCE

A wirewound resistor is a coil of resistance wire; hence it has inductance and distributed capacitance. As the operating frequency is increased, the impedance of most wirewound

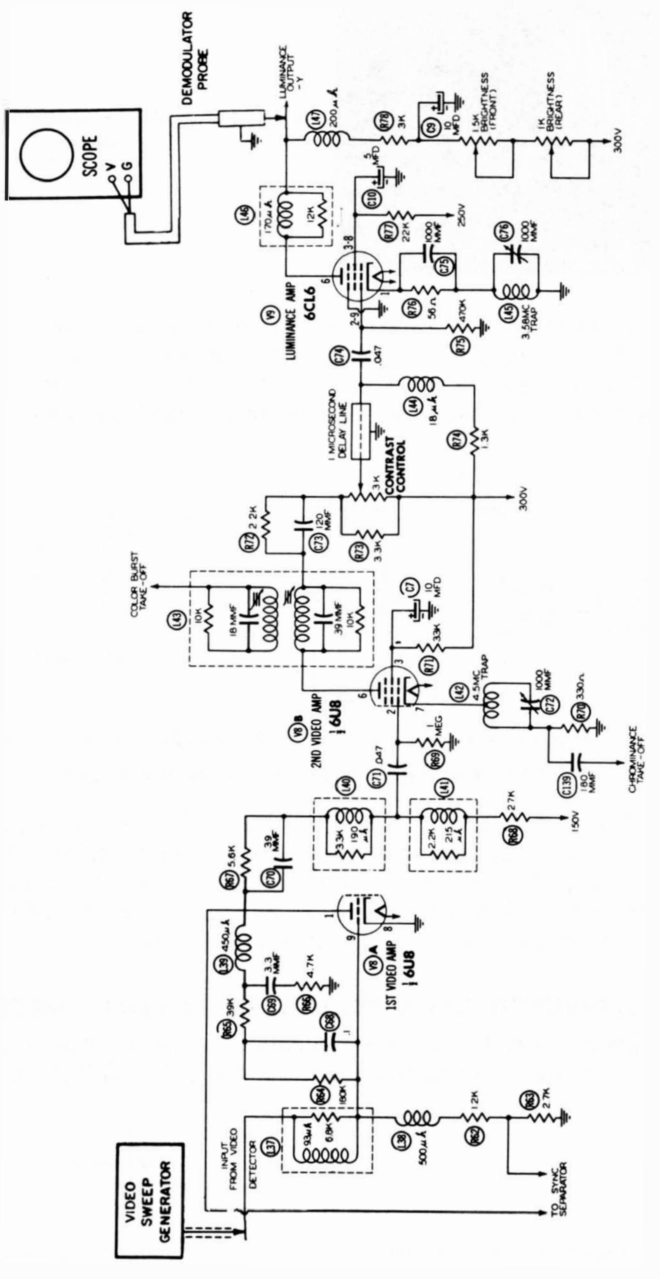


Fig. 5-19. Test method for a delay line.

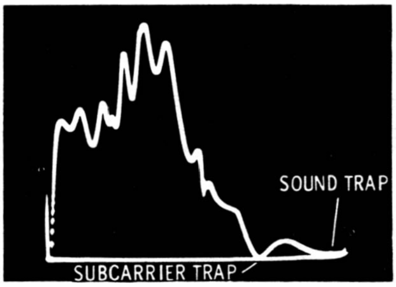
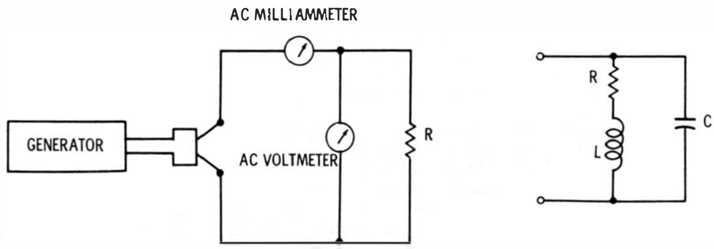


Fig. 5-20. Typical response curve of delay-line test.

resistors exceeds the resistance value measured on an ohmmeter. An impedance measurement is made as shown in Fig. 5-21. The impedance is given by Ohm's Law: $Z = E/I$. Ordinary wirewound resistors will show a small increase in im-



(A) Test setup for measurement. (B) Equivalent circuit of resistor.

Fig. 5-21. Measuring reactance of a wirewound resistor.

pedance at 1 mc, compared with their DC resistance. As the test frequency is increased to several megacycles, the impedance usually increases substantially. For example, a 50-watt, wirewound resistor with a DC resistance of 1,000 ohms measured an impedance of 1,600 ohms at 5 mc.

DISTRIBUTED CAPACITANCE OF POTENTIOMETER

In theory, a potentiometer consists of resistance only, but in practice its distributed capacitance (Fig. 5-22) must be

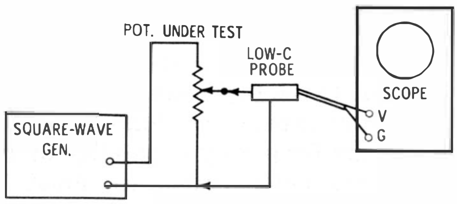
(A) Conventional schematic symbol for a potentiometer. (B) Schematic of equivalent distributed capacitance.

Fig. 5-22. Distributed capacitance in a potentiometer.

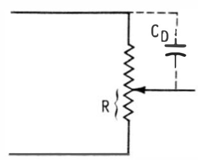
taken into account. The higher the resistance value, the more significant is the effect of the distributed capacitance. For example, a vernier attenuator in a 4-mc scope might be a 2K potentiometer. The vernier attenuator imposes negligible distortion on complex waveforms, regardless of the attenuator setting. On the other hand, if a 5K potentiometer were used as a vernier attenuator in a 4-mc scope, serious distortion of complex waveforms would be observed at various settings of the potentiometer.

Test of Potentiometer

A practical test of a potentiometer for distributed-capacitance effects can be made by applying a square-wave voltage as depicted in Fig. 5-23. Increase the square-wave frequency in steps, and observe the square-wave reproduction. Note



(A) Setup for square-wave test.



(B) Spikes indicate high C_D/R ratio.

Fig. 5-23. Square-wave test of a potentiometer.

that when the potentiometer is "wide-open," no distortion will be observed in the square-wave pattern, regardless of the test frequency. On the other hand, at some upper square-wave frequency, distortion appears when the potentiometer is set below its maximum position—the distortion changes as the pot is set to lower output.

Distortion of Test Waveform

At some settings of the pot, you will observe differentiation of the square wave, and at other settings integration occurs. Often you will be able to find one critical setting of the pot at which the differentiation cancels out the integration, and the output square wave is undistorted. At this critical setting, depicted in Fig. 5-24, the time constants of the two potentiometer sections happen to be equal.

Obviously, a potentiometer should not be used in a given application if it shows distortion at any setting. A pot with a lower resistance must be selected, in which the distributed

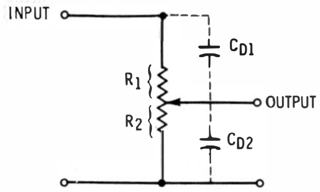


Fig. 5-24. Output is undistorted when $R_1C_{D1} = R_2C_{D2}$.

capacitance has negligible effect over the frequency range required. The output capacitance of the potentiometer circuit is also a factor of importance. For example, in Fig. 5-23, a low-capacitance probe is used in the test. If the probe should have 10-mmf input capacitance, this is the output capacitance load on the potentiometer. If the test were made with a direct cable to the scope, the output capacitance load might be increased to 100 mmf, reducing the frequency capability of the pot. Hence, the section of potentiometer resistance must be made with respect to the output capacitance in the circuit application, as well as the distributed capacitance of the pot.

SECTION 6

Gaseous Components

Gaseous components have a long history in electronics technology. If you are a grandfather, you may recall the "soft" detector tubes used during World War I. These tubes were triodes with a certain trace of gas and provided unusually sensitive detection when the tube was critically biased. And if you happen to be a great-grandfather, you may remember singing arcs and Poulsen arcs. These were the first gaseous components used to transmit voice by radio.

Today gaseous components have evolved into more sophisticated types, as exemplified by familiar *neon* bulbs, *voltage-regulator* tubes, and *thyratrons*. The advantages of gaseous components are realized in applications which require switching action or current control with low internal resistance. Since ionized gas glows, gaseous components are also used as indicators. Low internal resistance is desirable in high-current applications because efficiency is improved—the I^2R loss through a thyratron is very small, compared to the loss in a comparable high-vacuum tube.

When a gas tube is designed so that more of the cathode and anode area is covered by the glow discharge as the current is increased, the voltage drop remains quite constant between anode and cathode over a wide current range. This type of gas tube is used as a voltage regulator. Gas tubes can be connected in series to increase the available voltage drop.

Tests of gaseous components differ somewhat from tests of high-vacuum tubes, for example, because a basic switching action is involved, instead of a valving action. Many tests can be made satisfactorily with meters, although a scope provides more complete data. Beginners are sometimes surprised to find that most gaseous components have negative-resistance intervals. This fact becomes apparent in scope tests.

BASIC PRINCIPLES OF GASEOUS COMPONENTS

A wide range of gaseous components is encountered in electronics technology. Air, of course, is a gas and probably the simplest gaseous component is the air spark-gap. Occasionally a color-TV receiver utilizes a spark gap in the high-voltage section to protect the picture tube against excessively high voltage surges. The spark gap acts as a switch. Spark gaps have been used to measure voltages, and in the absence of a high-voltage probe, a needle gap can be used for approximate measurements of potentials less than 30,000 volts. Fig. 6-1 shows the maximum gaps for various voltages for No. 1 sharp needles, as well as for 1-inch brass spheres. Note that gap spacing versus voltage is linear for needle points and is nonlinear for spheres.

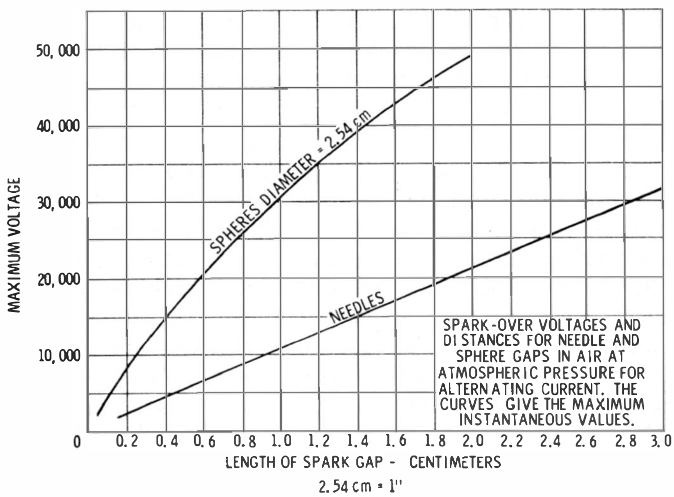


Fig. 6-1. Voltage-to-space relationship for spark gaps.

Most gaseous components operate at pressures that are less than that of the atmosphere. Some familiar examples are neon bulbs, thyratrons, and voltage-regulator tubes. A neon bulb is similar to a spark gap in that it does not conduct until the applied voltage passes a certain critical value. Then the gas ionizes and glows. The resistance of the neon bulb suddenly drops from infinity to a finite value. For example, at 54 volts a neon bulb typically draws 1 ma; therefore its DC resistance is 54K. However, within its conduction region, its DC resistance is much lower, for example, say 2,500 ohms.

Conductance Resistance

As shown in Fig. 6-2, the characteristic of a neon bulb is a special type of nonlinear resistance. It has a point of discontinuity called the firing point, and past the firing point, the bulb is a conductor instead of an insulator. The slope of the conduction interval gives the conduction resistance of the bulb. This is a parameter of central concern in voltage-regulator applications. Note that the power dissipated by the bulb is simply the product of the voltage across the bulb and the current flow. Thus, referring to Fig. 6-2, the power dissipation at 40 volts is zero, and the power dissipation at 55 volts is 1.21 watts. This power is dissipated as heat.

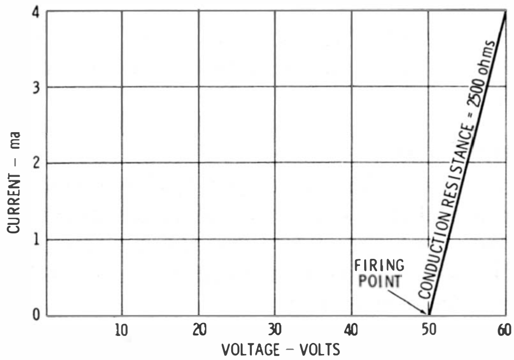


Fig. 6-2. Neon-bulb characteristic.

The conduction resistance of a thyratron is much lower than that of a neon bulb, and is regarded as practically zero in a good tube. As a thyratron ages to the extent that it is considered defective, its conduction resistance becomes appreciable and can be measured with a simple oscilloscope test, as will be explained subsequently. Also, the conduction resistance of a voltage-regulator tube is very low and is also commonly regarded as practically zero. However, the conduction resistance does slightly vary in a perhaps unexpected manner.

As shown in Fig. 6-3, a typical voltage-regulator tube has a very low conduction resistance over a current range of 10 to 40 ma. However, between 10 and 15 ma, the current increases as the voltage decreases—this is the negative-resistance interval. If appreciable circuit reactance is connected across the tube during this interval of current demand, spurious oscillation will occur. During the higher current interval, the tube

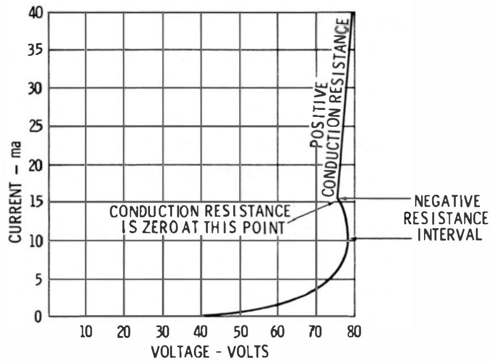


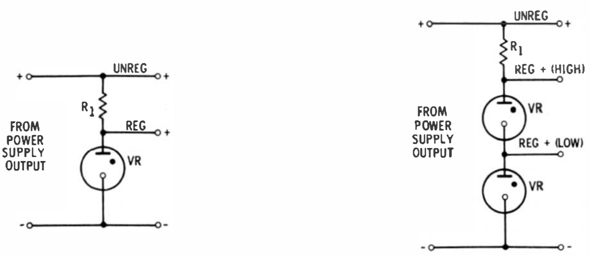
Fig. 6-3. VR tube often has a negative-resistance interval.

has a low, positive conduction resistance. The voltage drop across a typical VR tube varies only 3 or 4 volts over its rated current range.

Zero-Resistance Point

Any component that has adjacent positive and negative resistance intervals also has a zero-resistance point on its characteristic. This point occurs where the slope of the tangent is infinite—The zero-resistance point is indicated on the VR characteristic indicated in Fig. 6-3.

Since gas tubes have a conduction resistance that is a low positive, negative, or zero value, external circuit resistance must always be provided (Fig. 6-4A) to limit the current flow



(A) One-tube regulator. (B) Two tubes in series.

Fig. 6-4. Basic configuration for VR tubes.

and not exceed the rating of the tube; otherwise, the tube will overheat and explode. Beginners often explode neon bulbs by connecting them across a 117-volt line without a series resistor. Typical, small neon bulbs are rated for a maximum current of 2 ma. Therefore, a 56-K resistance, or greater must be connected in series with the bulb for 117-volt operation. "High-brightness" neon bulbs are commonly rated for a maximum current flow of 6 ma.

Series Connection of Gas Tubes

Note that voltage-regulator tubes can be connected in series (Fig. 6-4B) to double the output voltage. VR tubes are rated for conduction drops of approximately 75, 90, 105, or 150 volts. Thus, if two, 150-volt, VR tubes are connected in series, the available output is approximately 300 volts. The series limiting resistor must maintain current flow within the maximum rating of a single tube. For example, suppose that a 150-volt VR tube is rated for a maximum current of 40 ma. If two of these tubes are connected in series and powered from a 450-volt source, the series resistor must have a value of at least 3,750 ohms.

Thyratron Ratings

A thyratron is an electron-relay tube, which means that it acts as a switch. The grid has the ability to turn the "switch" on, but it cannot control anode current flow once the tube fires. An elementary thyratron configuration is shown in Fig. 6-5. An adjustable, negative DC bias is applied to the first grid. The anode is powered from an AC-voltage source (117 volts rms in this example). A type 2050 thyratron (Fig. 6-5) is rated for a peak anode voltage of 650 volts. Since a 117-volt rms source has a peak voltage of 1.4×117, or 163.8 volts, the tube operates well within its peak-voltage rating.

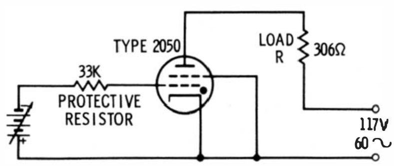


Fig. 6-5. Elementary thyratron configuration.

A 2050 thyratron has a maximum anode current rating of 0.5 ampere. If the grid bias is raised until the tube fires on the peak of the anode voltage, the anode load resistor must have a value of *at least* 306. This value follows from the fact that the drop across a 2050 is 8 volts during conduction, which makes the maximum applied anode potential 109 volts. In turn, the peak voltage at the firing point is 152.6 volts in this example. Since $R = E/I$, the series resistance must be not less than 306 ohms.

The anode could also be operated from a DC source, in which case the 2050 would conduct continuously (once it has been fired), instead of conducting only on positive half-cycles from the AC source depicted in Fig. 6-5. When operated from a DC source, the 2050 is rated for 0.1 ampere anode current; therefore, in this application, the series resistance must be chosen by Ohm's law to limit the anode current to 0.1 ampere, or less. The voltage drop from anode to cathode of the thyratron is the same during conduction, whether AC or DC voltage is employed.

Some thyratrons have lower ratings, and others have considerably higher ratings. In any case, a tube manual should be consulted and the tube operated within its maximum ratings. Otherwise, its life expectancy will be decreased. Note that all mercury-vapor thyratrons require a brief warm-up time before voltage is applied to the anode—to prevent damage to the tube. The mercury droplets in the tube must be sufficiently heated to form vapor before applying high voltage.

Extinction Voltage

No current flows in a thyratron until the grid and anode voltages permit the tube to fire (Fig. 6-6). At an anode po-

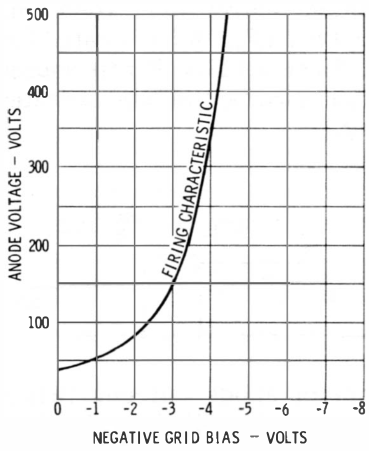


Fig. 6-6. Relation of grid bias and anode voltages to firing.

tential of 150 volts, a typical thyratron will fire if the grid voltage is −3 volts. However, it will not fire at a grid voltage of −4 volts. Once the tube fires, the grid loses control, and conduction continues regardless of grid bias; but the tube will stop conducting suddenly when the anode voltage is brought down to the extinction voltage. This anode extinction voltage might be zero, or slightly negative, depending upon the particular thyratron. Once the thyratron is thus deionized, the grid regains control.

It is clearly advantageous to employ AC anode voltage so that the anode is driven negative, insuring that the tube will deionize during the desired time. Test instruments that utilize on-off DC anode voltage for a thyratron commonly inject a small ripple voltage into the anode circuit so that a small negative extinction voltage is provided during the DC-off time.

TESTING NEON BULBS

The firing voltage of a neon bulb is readily measured with the test setup shown in Fig. 6-7. As the supply voltage is advanced, the voltmeter reading rises to the firing voltage and then suddenly falls back to the conduction voltage of the bulb. The conduction voltage will rise slightly as the supply voltage is advanced further. However, the rated current of the bulb should not be exceeded during a check of conduction-voltage variation. The extinction voltage is less than the firing voltage.

A typical neon bulb fired at 75 volts, and then it fell back to 57.5-volts conduction drop. When the applied voltage was reduced to make the conduction voltage slightly less than 57.5 volts, the bulb was extinguished, and the voltmeter reading suddenly rose slightly (due to removal of the bulb current). Various bulbs of the same type will vary appreciably in firing and extinction voltages. As the bulbs age, the critical voltages increase, and eventually a bulb will fail to fire at any reasonable value of applied voltage.

Oscilloscope Test

When bulbs are tested at quality-control positions, or on incoming inspection, an oscilloscope test provides faster and more complete test data. A suitable test setup is shown in Fig. 6-8. A 1 :1 transformer is used to obtain isolation from ground. An electrostatically shielded transformer is the best device to minimize possible spurious ground circulating currents. The

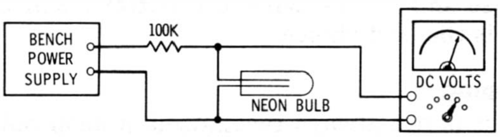


Fig. 6-7. Neon bulb firing-voltage test.

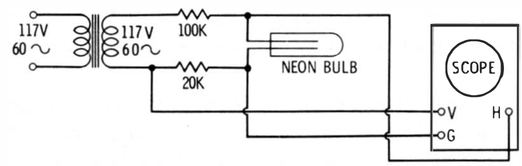


Fig. 6-8. Scope test of a neon bulb.

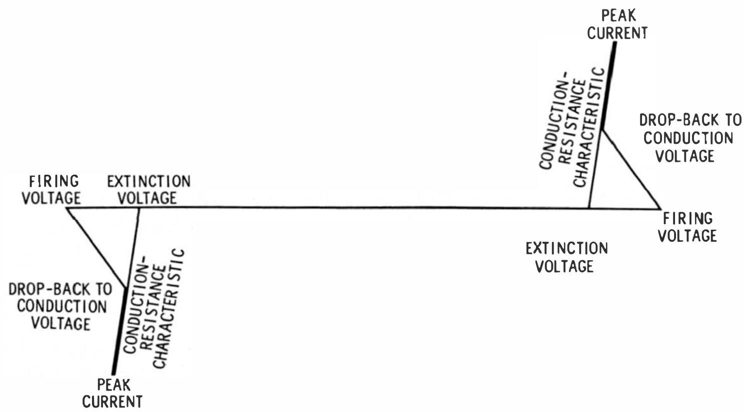


Fig. 6-9. Pattern obtained in the test of Fig. 6-8.

voltage drop across the neon bulb produces horizontal deflection. The current flow (voltage drop across the 20K resistor) produces vertical deflection. If the vertical and horizontal channels are previously calibrated, voltage and current measurements can also be made from the screen pattern.

The resulting pattern for a good bulb is depicted in Fig. 6-9. It shows that the bulb is a bilateral and symmetrical nonlinear resistance with discontinuities at the firing and extinction points. Now, if you advance the vertical and horizontal gain considerably, to expand the pattern in the region of the extinction voltage, you will see that the conduction-resistance characteristic is not quite linear but is slightly curved, as depicted in Fig. 6-10. In other words, the conduction resistance is not quite constant at different voltage drops across the bulb. Note that the scope should have full response at 60 cycles without phase shift; otherwise, the pattern will be distorted. A DC scope is the best choice.

Pattern Looping

Although it is not always recognized, a neon bulb has negative resistance over the striking interval of its characteristic.

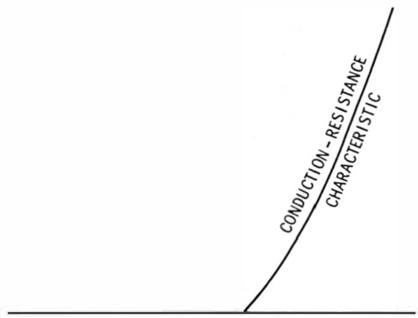


Fig. 6-10. The characteristic reveals some nonlinearity.

Fig. 6-9 shows how the voltage drop across the bulb decreases or drops back after the critical firing voltage is passed. But although the voltage is decreasing, the current is increasing. Ohm's law for this interval of the characteristic is written $I = E/-R$. If the external circuit reactance is negligible, the negative-resistance interval is displayed as a straight line. However, if the transformer in Fig. 6-8 has appreciable leakage reactance, the negative-resistance interval appears looped, as typically shown in Fig. 6-11. In this case the neon bulb oscillates briefly during the striking interval.

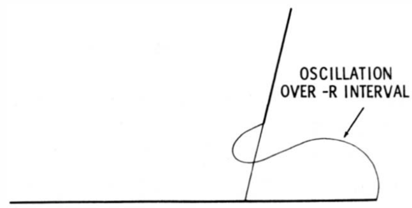


Fig. 6-11. Oscillation due to leakage reactance and distributed capacitance.

Display on Linear Time Base

Neon bulbs can also be tested to determine whether they are within fixed limits by displaying voltage or current waveforms on a linear time base (sawtooth deflection). For example, the test setup illustrated in Fig. 6-12 displays the voltage across the bulb versus time. If the vertical channel of the scope has been previously calibrated, the firing voltage can be measured, as well as the conduction voltage drop. Variation in internal resistance of the bulb over the conduction interval appears as a small curvature and a downward slope.

The test setup shown in Fig. 6-13 displays the current through the bulb versus time. A calibrated scope will show

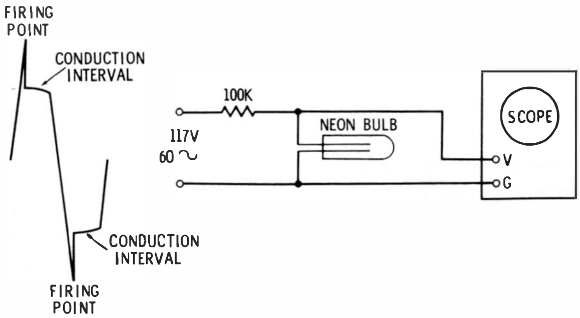


Fig. 6-12. Voltage drop displayed on a linear time base.

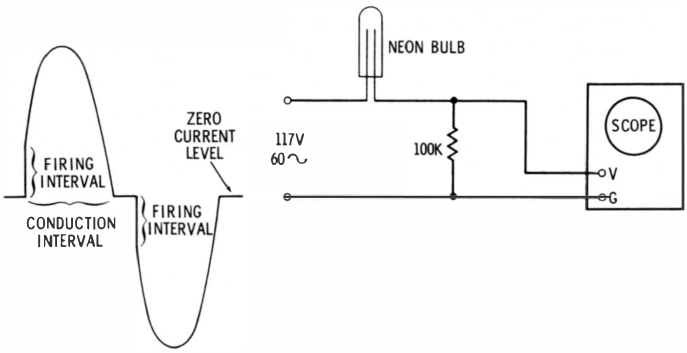


Fig. 6-13. Current flow versus time.

whether the current proportions and durations are within limits for a given type of neon bulb. It is clear that if the waveform in Fig. 6-12 applied to the horizontal channel of the scope, and the waveform in Fig. 6-13 is applied to the vertical channel of the scope, the pattern depicted in Fig. 6-9 results. Since the cyclogram of Fig. 6-9 displays both current and voltage information, it provides the most inclusive test.

TESTING VOLTAGE-REGULATOR TUBES

Service-type tube testers often provide a configuration, such as the one shown in Fig. 6-14, to check voltage-regulator tubes. A variable DC voltage is applied to the tube in series with a current-limiting resistor. A voltmeter is connected across the tube. As the test voltage is increased, the meter reading rises until the critical firing voltage is reached. Then the pointer suddenly drops back on the scale. For example, if a VR tube fires at 110 volts, the pointer may drop back to 105 volts.

Next, the regulation of the tube is checked by increasing the current through the tube to rated maximum and observing the voltage drop across the tube. A typical VR tube varies less than 4 volts over its rated current range. This is basically a test of the conduction or dynamic resistance of the tube. A VR tube such as an OA3 has a normal dynamic resistance of 100 ohms or less. As a VR tube ages, the firing-voltage point raises, and its conduction-voltage level also increases. The regulating action becomes poor, due to increase of dynamic resistance.

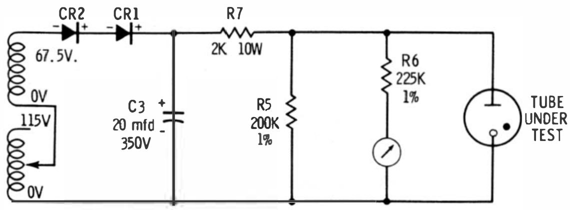


Fig. 6-14. A test circuit for VR tubes.

As the tube symbol indicates (Fig. 6-14), the anode of a VR tube has a comparatively large area. The anode also has a probe projecting toward the cathode, as depicted in Fig. 6-15. These structural features affect the tube operation if the applied

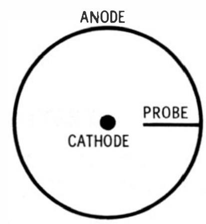
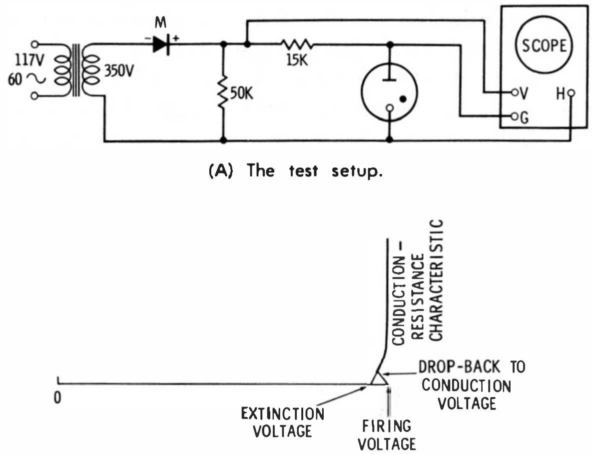


Fig. 6-15. Structure of a VR tube showing the anode probe.

voltage is reversed. The tube has very poor regulation if the cathode is operated as an anode.

Oscilloscope Test

Quality-control or incoming-inspection tests of VR tubes are facilitated by oscilloscope tests. A typical test setup is shown in Fig. 6-16. A rectifier (M) is employed in order to apply the DC voltage in correct polarity to the VR tube. A bleeder resistor insures that leakage in the rectifier does not apply reverse voltage to the tube. If the vertical and horizontal channels of the scope have been previously calibrated, voltage and current values can be measured on the screen.



(A) The test setup.

(B) The scope pattern.

Fig. 6-16. Quality-control test for VR tubes.

The VR tube has a negative-resistance interval during the drop from firing to conduction voltage. Hence, the drop-back trace might have various shapes, depending on the leakage reactance of the transformer. The conduction resistance generally has a higher value near the start, but with increasing current the tube resistance then stabilizes at a constant, low value.

TESTING THYRATRON TUBES

Service-type tube testers usually check the grid-bias voltage level at which a thyratron fires, and the conduction voltage (arc drop) from anode to cathode. A milliammeter is connected in series with the anode lead, as shown in Fig. 6-17.

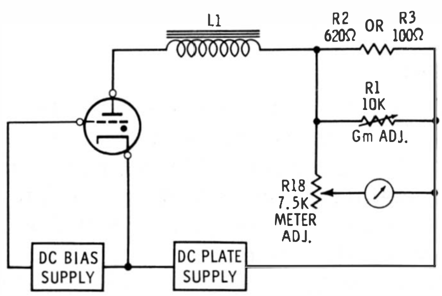


Fig. 6-17. Test circuit for a thyratron tube.

The tube is initially held beyond cutoff by a high negative grid bias. The bias voltage is reduced until the critical firing point is reached, as indicated by a sudden flow of anode current. There is a substantial tolerance for most thyratrons. At a 200-volt anode potential, a thyratron might be specified to fire at a grid bias between −2 and −6 volts, approximately. Fig. 6-18 illustrates the rated tolerance on firing voltage for a typical thyratron.

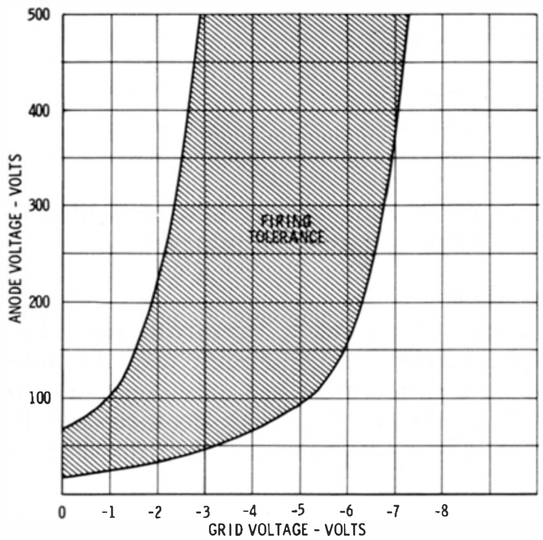


Fig. 6-18. Firing tolerance for a typical thyratron.

The second part of the test depicted in Fig. 6-17 is a measurement of anode current after the thyratron has fired. Since the tube normally has an extremely low conduction resistance, the current flow should be limited essentially by the anode circuit resistance only. Conversely, if the thyratron has abnormally high conduction resistance, this fact is indicated by a current reading lower than specified.

Oscilloscope Test

Failing thyratron tubes are easily detected with a scope test during routine maintenance procedures. Scope patterns provide more complete data than meter tests, as previously described. Practically all thyratrons in industrial equipment operate with AC anode voltage and when a scope is connected between anode and cathode of an operating thyratron, patterns are displayed as shown in Fig. 6-19. The most significant portion of the pattern is the arc-drop interval. If the tube is in good operating condition, and has adequate emission and correct gas pressure, without vapor contamination the thyratron will have a small and flat arc drop. A failing tube has a

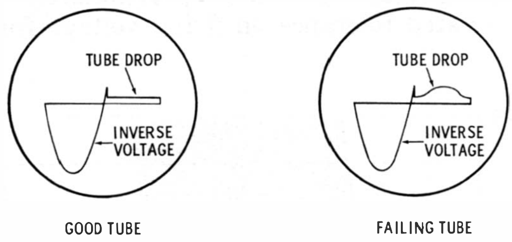


Fig. 6-19. Scope patterns obtained in thyratron test.

comparatively high conduction resistance, which is displayed as a high and irregular arc-drop interval.

Conduction Angle

The conduction angle of a thyratron can also be easily checked with a scope on an in-circuit test. Although the control grid in a thyratron tube has only "on" switching action, the phase of an AC grid voltage does control the *average* anode current. Fig. 6-20 shows a circuit in which the relative

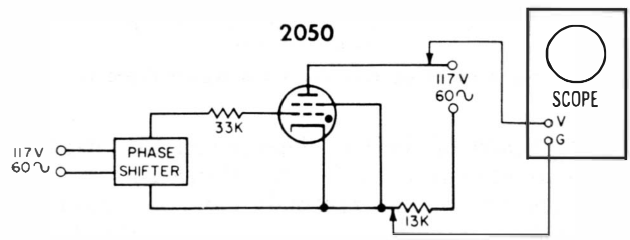


Fig. 6-20. A conduction-angle scope test.

phases of grid and anode voltages determine the conduction angle, which varies from zero to 180° as the grid phase-shifter is turned through its range. The phase shifter is often calibrated, and a scope test gives a check of thyratron response.

In Fig. 6-21, the anode-cathode voltage displayed in the first photo is a complete sine wave. There is no arc-drop interval (no anode-current flow)—the grid phase shifter has been adjusted so that the grid voltage is 180° out of phase with the anode voltage. In the remaining photos, the grid voltage is

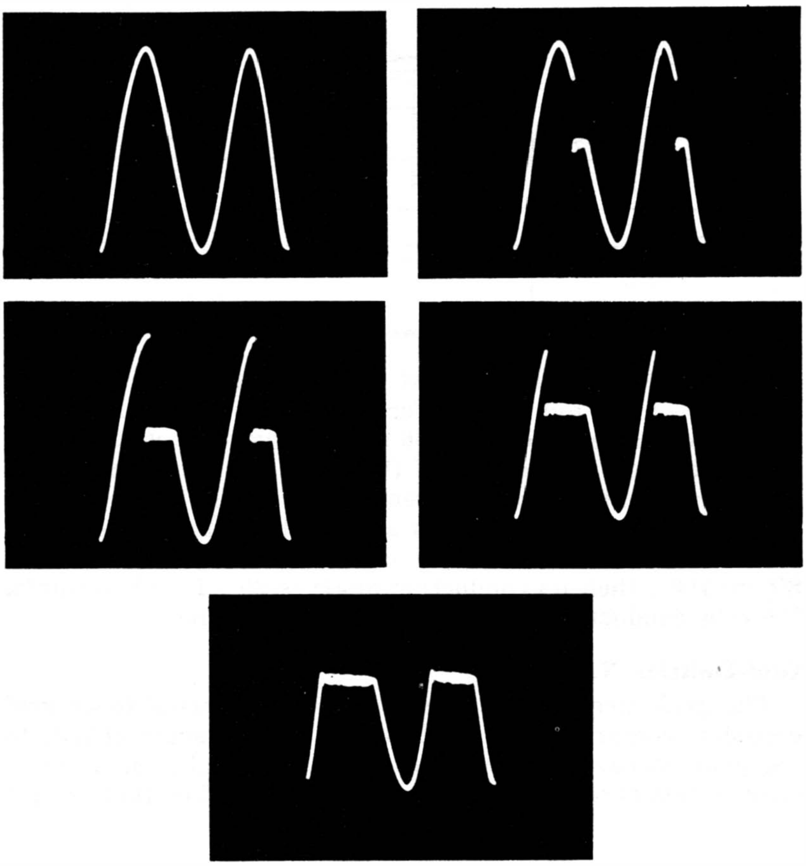


Fig. 6-21. Voltage waveforms from anode to cathode of a thyratron, showing the conduction time for various phase relationships between grid and plate voltage.

brought progressively into phase with the anode voltage, causing the conduction angle (arc-drop interval) to increase accordingly. The average anode current increases as the arc-drop interval lengthens. Note that the arc-drop intervals appear "fuzzy." This is a *plasma oscillation,* which is often observed in thyratron circuits.

The meaning of "conduction angle" is illustrated in Fig. 6-22, which shows the construction of a sine wave from a circle. The full circle contains 360° by definition. If you travel counterclockwise around the circle from zero and stop at P_1, you have gone 1/12 of the total circumference, or 30°. At point P_1 the vertical distance is half the maximum value. That is, the angle theta is 30° at P_1, and the related sine wave has

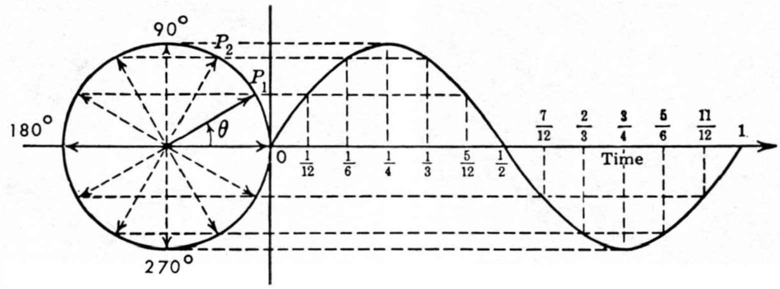


Fig. 6-22. Construction of sine wave based on angles of a circle.

half its peak value. If you next proceed to point P_2, you have gone 1/6 of the total circumference, or 60°. At point P_2 the vertical distance is about 0.866 of the maximum value.

The conduction intervals of the various waveforms in Fig. 6-21 correspond to two different angles in the circle of Fig. 6-22. The conduction angle is simply the difference between these two values. For example, if the thyratron conducts from 80° to 100°, then its conduction angle is 20°. In other words, the tube conducts 1/18 of the total elapsed time.

Grid-Emission Test

The grid current in a thyratron, often referred to as grid emission, comprises current from the ionized space charge to the grid, leakage current, and actual grid emission. A grid-current test is made as depicted in Fig. 6-23. The tube is first

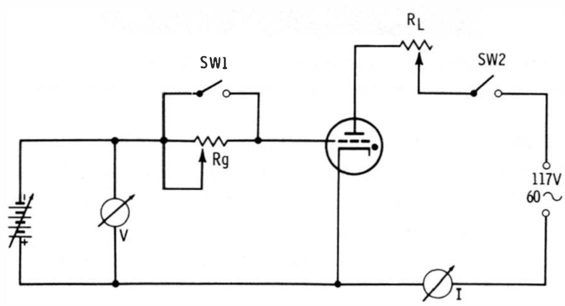


Fig. 6-23. Grid-emission test of a thyratron.

warmed up thoroughly with Sw1 and Sw2 closed. R_L is adjusted for maximum-rated average plate current. Then R_g is shorted, and the grid bias made more negative until the thyratron stops conducting. The reading on V is noted, and may be designated as V_1. Next, Sw1 is opened and the grid bias adjusted to just stop conduction; the reading on V again noted and this second reading is designated V_2. If V_2 is not considerably higher than V_1, repeat the test with a larger value of R_g. A value of 10 to 100 megohms will provide a substantial difference between V_2 and V_1 for typical good thyratrons.

Since both readings were made with the tube at the cut-off point, the grid-cathode voltage is clearly the same in both tests. Hence, the difference between V_2 and V_1 is due to grid-current flow through R_g. By Ohm's law, the grid current is given by: $I_g = (V_2 - V_1)/R_g$. If the grid current exceeds the manufacturer's rating, the thyratron should be rejected.

ELECTRONIC COMPONENT

TESTS & MEASUREMENTS

by ROBERT G. MIDDLETON

Technicians, experimenters, designers, and others concerned with testing and measuring of electronic components all too often feel that elaborate test setups and instruments are necessary for effective results. Don't believe it! It can be done by anyone with basic knowledge and experience.

This book, by one of the leading experts on the subject, prescribes simple, practical, and easy-to-perform methods for testing and measuring circuit components. Normal operation of a component is discussed only where necessary, and test configurations along with the test equipment needed are illustrated.

The only instruments required are those commonly found on the average service bench. Diagrams of the various test instruments are so complete that, in many cases, you can construct the necessary equipment if it is not immediately at hand.

Methods are shown for testing and measuring capacitors, resistors, coils, transformers, antennas, transmission lines, delay lines, tubes, transistors, and diodes. Also included are not-so-common tests for thermistors, thyratrons, neon bulbs, and voltage-regulator tubes.

Some examples of tests and measurements included are: heater warm-up time, tests of surge resistors, bilateral and unilateral resistances, zener resistance and negative resistance; switching tests for tunnel diodes, capacitance measurement, leakage resistance in electrolytic capacitors, power factor, and distributed capacitance of coils.

Electronic Component Tests & Measurements is designed as a simple guide to all types of component testing. The text is arranged so that complete details for specific tests can be quickly located. Each test is indexed in the table of contents for convenient reference.

All of the methods included have been thoroughly tested by the author. If you follow this text and its many illustrations, accurate and consistent results are guaranteed.

ABOUT THE AUTHOR

Bob Middleton is one of the few full-time professional free-lance technical writers in the electronics field. His many books have proven invaluable to technicians and engineers because they are based on his own practical experience. His home workshop is filled with a wide variety of test instruments, receivers, and other equipment which he uses to develop faster and easier ways to diagnose electronic equipment troubles.

Other SAMS books by Mr. Middleton include: nine volumes of his famous **101 Ways to Use Test Equipment** series, four volumes of **101 Key Troubleshooting Waveforms, TV Tube Symptoms and Troubles, Using the Oscilloscope in Industrial Electronics, Solving TV Tough-Dogs, Bench Servicing Made Easy, Troubleshooting With the Oscilloscope, Troubleshooting With the VOM & VTVM, Electronic Tests and Measurements, Test Equipment Circuit Manual, Practical TV Tuner Repairs, Elements of Transistor Technology, Scope Waveform Analysis, TV Servicing Methods Guidebook, and Test Equipment Maintenance Handbook.**

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