The Aerovox Research Worker

The Aerovox Research Worker is edited and published by the Aerovox Corporation to bring to the Radio Experimenter and Engineer, authoritative, first hand information on capacitors and resistors for electrical and electronic application.

VOL. 25, NO. 9 AND 10 | SEPTEMBER - OCTOBER, 1955 | Subscription By Application Only

Testing Semiconductor Diodes

By the Engineering Department, Aerovox Corporation

THERE seems to be a growing impression that semiconductor diodes can be tested adequately with an ohmmeter. This results from the fact that a d-c ohmmeter will show a difference between the forward and reverse resistances of a diode or rectifier if its leads are swapped back and forth.

The unsuitability of the ohmmeter test as a sole check method lies in the fact that the meter voltage and current often bear no significant relationship to the rated d-c parameters of the diode. Thus, a diode may be checked as good at the ohmmeter voltage and still be unsatisfactory at the rated voltage, and vice versa. Also, it very often is difficult to determine by this method the actual front-to-back resistance ratio of a diode; since the ohmmeter must be operated on at least two different ranges in order to read the values accurately, and switching the ranges not only changes the applied voltage but also the value of series resistance introduced by the instrument. The consequent variations in applied voltage and load resistance change the operating point along the diode characteristic curve, *separate* diodes also have the same effect, and the readings are meaningless unless all factors and conditions are known.

Another important consideration is that a diode might check satisfactorily in a d-c test, ohmmeter-type or otherwise, yet not be suitable for an intended application as an a-c or r-f rectifier or demodulator.

Use of the ohmmeter therefore is restricted to the simplest sort of initial test for separating good diodes from bad, since all that this instrument indicates reliably is that the component under test *is* a rectifier.

Types of Tests

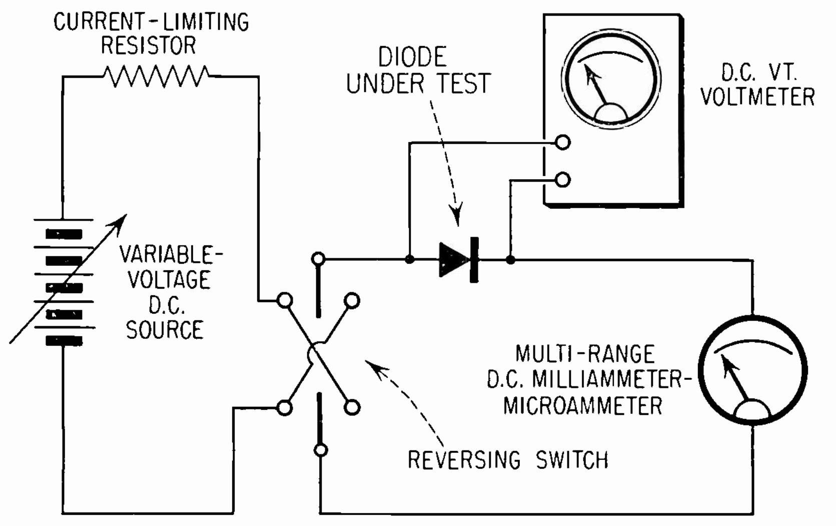
Two types of tests may be applied to semiconductor rectifiers, whether crystal diodes or power rectifiers. These are identified broadly as d-c tests and a-c tests. There can be several categories in each type.

Basically, the d-c test consists of passing a specified amount of current through the diode and checking the resulting d-c voltage drop across the diode. The test is made separately, with the proper polarities, for forward and reverse conduction through the diode. Note that this is the opposite of testing tube-type rectifiers, where the procedure is to apply a specified voltage and measure the resulting current. The d-c test may be made at a multiplicity of points and a continuous static curve plotted from data taken at these points. A short test consists of data taken at single forward and reverse check points specified by the diode manufacturer.

A-c tests fall roughly into two groups: (1) the *rectifier test* involves applying a given sinusoidal a-c voltage to the diode and measuring the resulting d-c output current, and (2) the *a-m detector test* in which an amplitude-modulated sinusoidal voltage is applied to the diode in series with an appropriate load resistance, bypassed at the carrier frequency, and the resulting modulation-frequency voltage measured across the load resistance.

Other special tests for certain diodes of specific types or for those intended for special-purpose applications will be described later.

As to which type of test is the most suitable, there is general agreement among semiconductor engineers that a diode should be tested under the conditions that more closely approximate its intended methods of operation. This does not necessarily mean that a diode which is to be used, for example, as a video detector must be tested in the actual tv receiver circuit (although that is not ridiculous). But such a diode should be given an r-f, instead of d-c test. Likewise, a diode which is to be used as a meter rectifier should be given a low-frequency a-c test. Conversely, a diode which is to be used in a direct-current application, for example as a polarity-sensitive element in series with a relay coil, should be checked at the direct current level at which it must operate. Very little significant information could be gain-



D.C. MEASUREMENT CIRCUIT

FIG. 1

ed from a d-c test regarding the r-f performance of a diode, nor could the r-f test reveal what might be expected in the way of d-c performance.

D-C Tests

Characteristic Curve. Figure 1 shows the apparatus setup for d-c measurements. The variable-voltage d-c source may be either a battery or a line-operated power supply. The reversing switch allows changeover of the d-c supply polarity. The voltmeter and current meter also must have reversing switches, although not shown in the schematic.

First, with the anode of the diode under test biased positively for forward conduction, the current is adjusted to several levels within the safe operating range of the diode, starting at zero, by varying the voltage. The current and voltage variations then are recorded. Next, the reversing switches are thrown to bias the anode negatively for reverse (back) conduction and the procedure repeated. The maximum diode voltages, both forward and reverse, and the maximum currents must not exceed the maximum *continuous* operating values given by the diode manufacturer. The current and voltage data so obtained may be used to plot a static curve of the type shown in Figure 2. The forward conduction characteristic extends from O to A, and the reverse conduction characteristic from O to B. Positive voltage values are low; negative values high.

For small diodes, forward current is expressed in milliamperes and reverse current in microamperes; while for power rectifiers, forward current is in amperes and reverse current in milliamperes.

Figure 2 shows the *general* shape of a diode static characteristic. Various diode types show some departure, one way or the other, from this curve. In gold-bonded germanium diodes, for example, section OA is steeper than in point-contact types. In germanium power rectifiers, OA is quite steep and OB moderately steep. The selenium rectifier curve has slopes which are intermediate between the preceding types. The silicon junction diode is a special case, its curve showing a characteristic such as Figure 3. The forward current rises sharply at a particular value of positive anode voltage, and the reverse current similarly increases sharply at a particular reverse potential, called the Zener voltage.

The static characteristic curve is helpful when information is desired regarding behavior of the diode throughout its operating range. Obtaining such a curve by the point-by-point d-c method, however, is laborious.

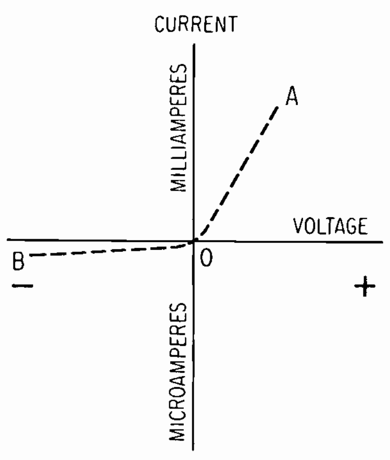
Single-Point D-C Test. In many requirements for a diode acceptance test, a complete characteristic curve is not needed. In these cases, a single forward check and single reverse check will suffice.

The same apparatus setup shown in Figure 1, or a simplification of it, is used but spot voltages and currents are employed. Most small diodes may be checked at +1 volt and —10 volts. When these diodes are to be used for blocking high reverse bias voltages, they usually are checked at —50 v or —100v, depending upon type.

Observations in D-C Tests. The main objective of the d-c test is to determine whether the diode complies with current and voltage specifications. While under test, however, observations may be made of other important features which might render the diode unsatisfactory. These include current or voltage flutter current or voltage drift, heating, and intermittents.

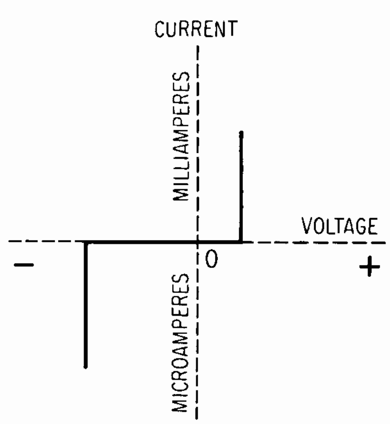
A-C Tests

Rectification. In this test, an a-c voltage of required frequency and



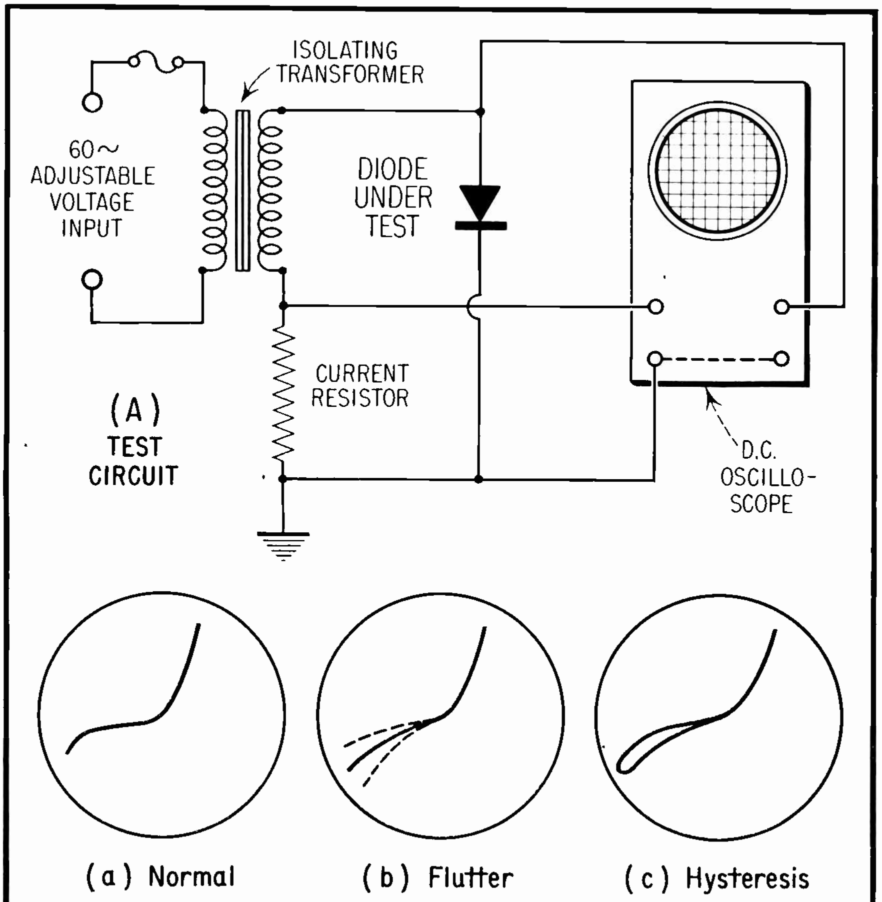
GENERAL SHAPE OF D.C. CHARACTERISTIC

FIG. 2



SPECIAL SHAPE OF SILICON JUNCTION DIODE CHARACTERISTIC

FIG. 3



(B) TYPICAL PATTERNS

VISUAL TEST METHOD

FIG. 8

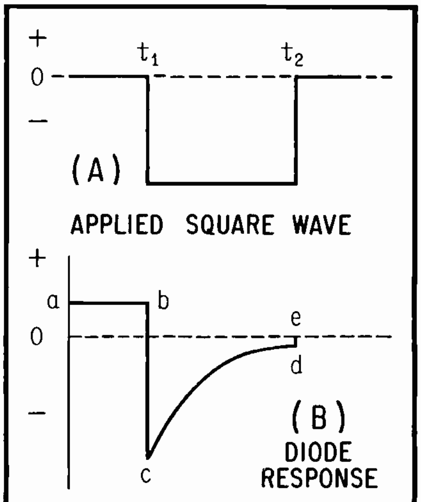


ILLUSTRATION OF DIODE RECOVERY TIME

FIG. 9

tical deflection thus is proportional to current. The transformer output voltage is applied to the horizontal input of the oscilloscope. The horizontal deflection accordingly is proportional to the diode voltage.

The reason for using a d-c oscilloscope is that the direct-coupled nature of its circuitry enables definite establishment and identification of the zero current and voltage point (origin) in the pattern. The horizontal axis may be calibrated in volts (forward and reverse) and the vertical axis in amperes, milliamperes, or microamperes forward and reverse.)

Figure 8(B) shows typical patterns displayed by the curve tracer circuit. Pattern (a) is the type normally obtained for a good diode. The negative (reverse) portion of (b) changes its position intermittently, or *flutters,* indicating instability. This condition occasionally is observed also in the forward (positive) region of the curve. In (c), the reverse portion of the curve is seen to be traced along one route from zero to maximum, but to reutrn along another route from maximum back to zero. This opening-up of the curve is termed *hysteresis,* a condition which often foretells early failure of the diode.

Checking Recovery Time

A semiconductor diode has the peculiar property that its reverse current will be relatively high (reverse resistance low) for an instant immediately after applying the reverse voltage *if the diode has just been conducting forward current.* After this initial high-current transient, the reverse current then decreases gradually (resistance increases) to a value in line with the applied voltage. The interval during which the current settles to its rated level is termed *recovery time.*

Recovery time increases with the level of recent forward current. It is longer in junction diodes than in point-contact types. Short recovery time is particularly desirable in digital computers and similar pulse-type circuits in which diode conduction is switched rapidly from forward to reverse.

The wave pattern in Figure 9(B) illustrates diode reverse-current recovery effect. The diode conducts forward current during the interval from a to b. Instant b corresponds to time t_1 (See Figure 9A). At b, a negative-going square wave of voltage (Figure 9A) is applied. Because of its recent forward-current history, the diode cannot establish a high reverse resistance immediately, and as a result the reverse current increases instantaneously to c. Subsequently, it decreases to d, and at time t_2 follows the fall of the square wave back to zero. The time interval involved in the "recovery transient" is a matter of microseconds, the maximum being of the order of 10 microseconds for large-area germanium rectifiers, and 1 or less for point-contact germanium diodes. The depth of the initial current spike likewise is greatest with large-area germanium rectifiers and is least in point-contact silicon units.

Recovery time may be checked by applying a negative square wave (usually at a repetition rate of 100 kc) to the diode carrying forward current. The diode current flows through a series resistor and the resulting voltage drop across this resistor is applied to the vertical input of a high-speed, direct-coupled oscilloscope adjusted to display one square-wave cycle. The oscilloscope screen is graduated vertically in microamperes and horizontally in microseconds.

(demodulator) circuits. In this application, the function of the diode is to separate the modulation component from the carrier component in an amplitude-modulated wave.

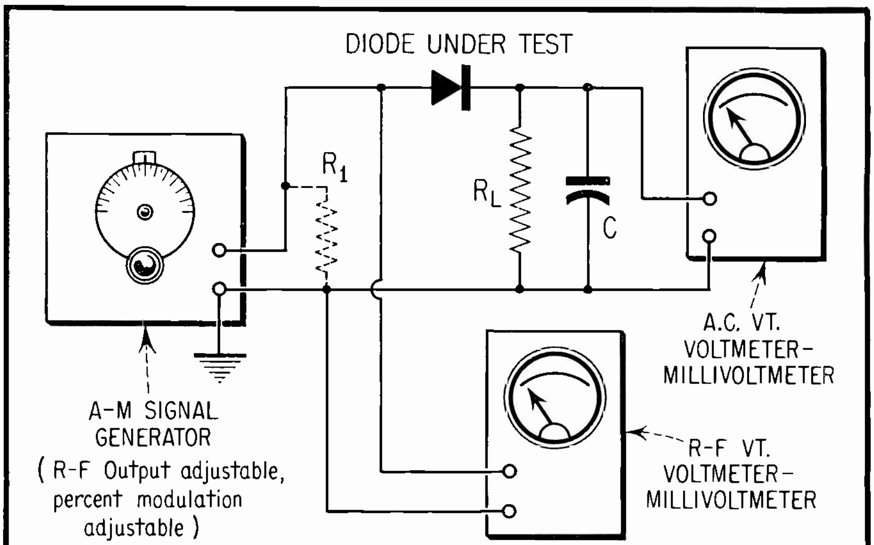
Figure 6 shows an apparatus setup for checking detector action. The a-m signal is supplied by a signal generator in which the output and the modulation percentage each are continuously variable. Resistance R_1 is a low resistance and is not required if the output circuit of the signal generator contains a low-resistance d-c return path for the diode under test. The signal level is monitored by the r-f vacuum-tube voltmeter-millivoltmeter. The diode output, developed across the load resistance, R_L, is monitored by the a-c vacuum-tube voltmeter-millivoltmeter.

At a given value of modulation percentage and carrier amplitude, the efficiency of the diode as a detector is proportional to the voltage indicated by the audio meter (a-c v-t voltmeter). For a complete evaluation, the test should be repeated at various signal-voltage and modulation-percentage levels and at several carrier frequencies. At low signal levels, response of the diode will be observed to be approximately square law.

The value of load resistance R_L usually is prescribed in the detector diode specifications. Capacitance C is chosen for effective bypassing of the carrier-frequency current component. If no value is specified for R_L, this resistance should be that value into which the diode will operate when installed in the equipment in which it is to be used.

Television Diode Test. A variation of the detector test setup, for tv diodes, is shown in Figure 7. In this arrangement, a 40-Mc, 70-percent amplitude-modulated signal is applied to the diode under test. This is the arrangement suggested by the Joint Electronic Tube Engineering Council, JETEC (See *Sylvania Engineering Information Service,* August 1954).

The test procedure is the same as in the a-m detector test described in the preceding Section, except that the carrier frequency and modulation frequency are maintained constant.



BASIC SETUP FOR A-M DETECTOR TEST

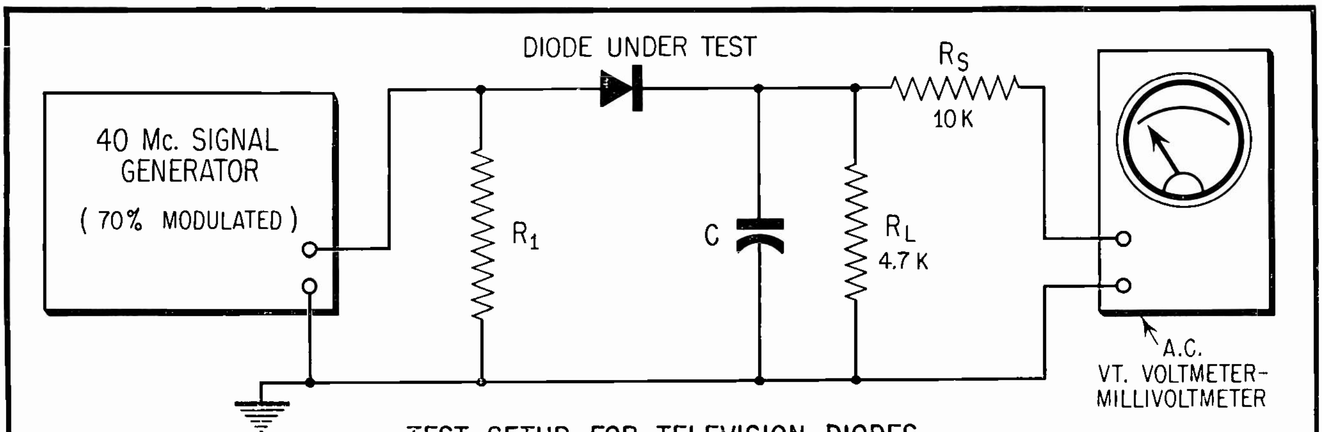
FIG. 6

Visual Test Method

It was mentioned earlier that the production of a diode conduction curve, such as Figure 2 is a tedious process requiring the painstaking accumulation of current and voltage values point-by-point. It thus becomes costly to evaluate a large number of diodes by this method.

A visual test method which is dynamic in nature gives a display of the complete curve on an oscilloscope screen. Figure 8(A) shows a circuit for visual display of the diode characteristic. The diode under test is connected in series with an a-c bias supply and a current resistor. This resistance is low with respect to the diode forward resistance and usually is between 1 and 10 ohms.

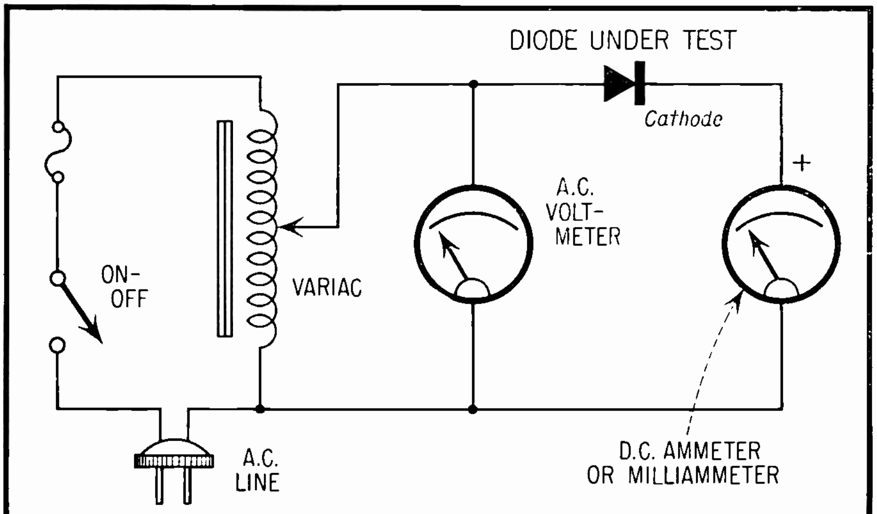
During the half-cycle of applied 60-cycle voltage when the anode of the diode is positive, high forward current flows through the current resistor. During the negative half-cycle, the anode is biased negatively and small reverse current flows through the resistor. The voltage drop across the current resistor is proportional to the forward and reverse currents and is applied to the vertical input of the oscilloscope. Ver-



TEST SETUP FOR TELEVISION DIODES

FIG. 7

amplitude is applied to the diode or rectifier, and the resulting d-c output current measured. Figure 4 shows the test setup.



BASIC RECTIFICATION TEST CIRCUIT

FIG. 4

By means of the Variac, the applied a-c voltage, as indicated by the voltmeter, is adjusted to the rated operating voltage of the diode. The output current is read from the current meter. The latter will be a d-c milliammeter for small germanium, selenium, and silicon diodes and an ammeter for power-type germanium, selenium, silicon, copper oxide, and magnesium-copper sulphide rectifiers.

At frequencies other than that of the a-c power line, the Variac must be one designed to handle the operating frequency. At high audio, and radio frequencies, a suitable adjustable-output signal generator may be substituted for the power line and Variac. The generator output impedance must be low. At high frequencies, a v-t voltmeter is needed to measure the applied voltage.

In the rectification test, the d-c output current is noted when the applied voltage is the operating value specified by the diode or rectifier manufacturer. The test is repeated at several values of recommended load resistance.

Rectification Efficiency. The ability of a diode to function satisfactorily as a rectifier may be evaluated in terms of the ratio of its d-c output voltage to an applied a-c voltage. This ratio is termed *rectification efficiency*.

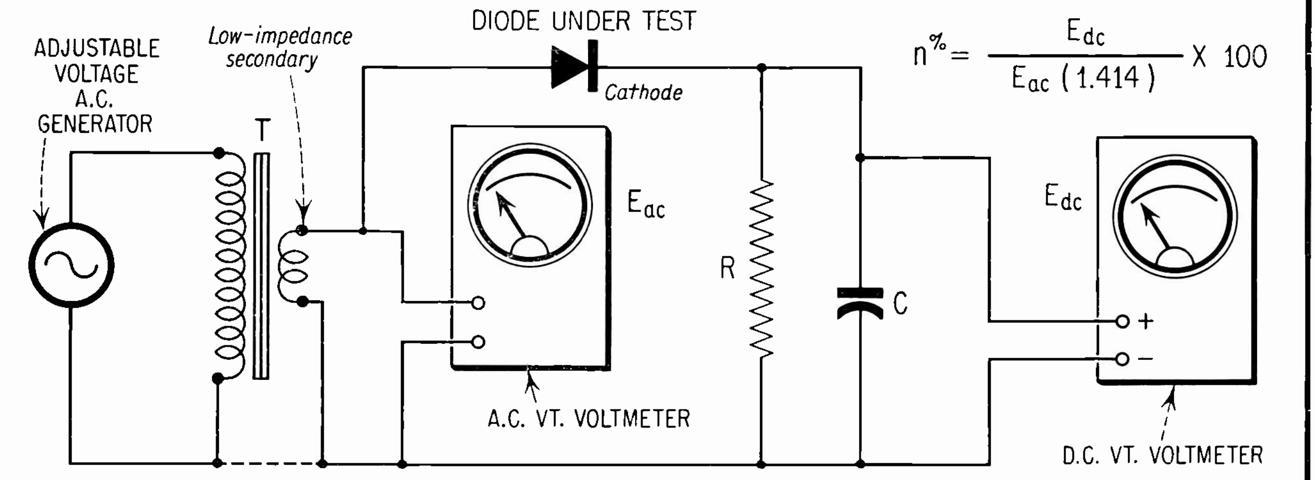
Rectification efficiency often is specified in critical applications of germanium and silicon diodes in communications and instrumentation equipment. Figure 5 shows the apparatus setup for measuring this factor.

The test signal is supplied by a suitable adjustable-output signal generator through an isolating transformer, T. The output winding of this transformer has both low impedance and low d-c resistance with respect to the diode forward resistance. The type of transformer and its characteristics depend upon the test frequency. This unit will be iron-cored for audio and power-line frequencies, and will be of either air-core, powdered-iron, or ferrite-cored type for radio frequencies.

The input voltage (E_{ac}), indicated by the a-c vacuum-tube voltmeter, is adjusted to the required level, and the d-c output voltage (E_{dc}), developed across the load resistance (R), is read from the d-c vacuum-tube voltmeter. The required values of R and C usually are given in the specifications of the diode under test (a common combination is R = 5000 ohms, C = 20 uufd, f = 10 Mc.)

The rectification efficiency (n) equals the d-c voltage (E_{dc}) divided by the *peak* a-c voltage (E_{ac} X 1.414). Expressed as a percentage, this fraction must be multiplied by 100. Thus, $n = 100E_{dc}/(1.414E_{ac})$. Rectification efficiency varies directly as the a-c voltage amplitude, frequency, and load resistance.

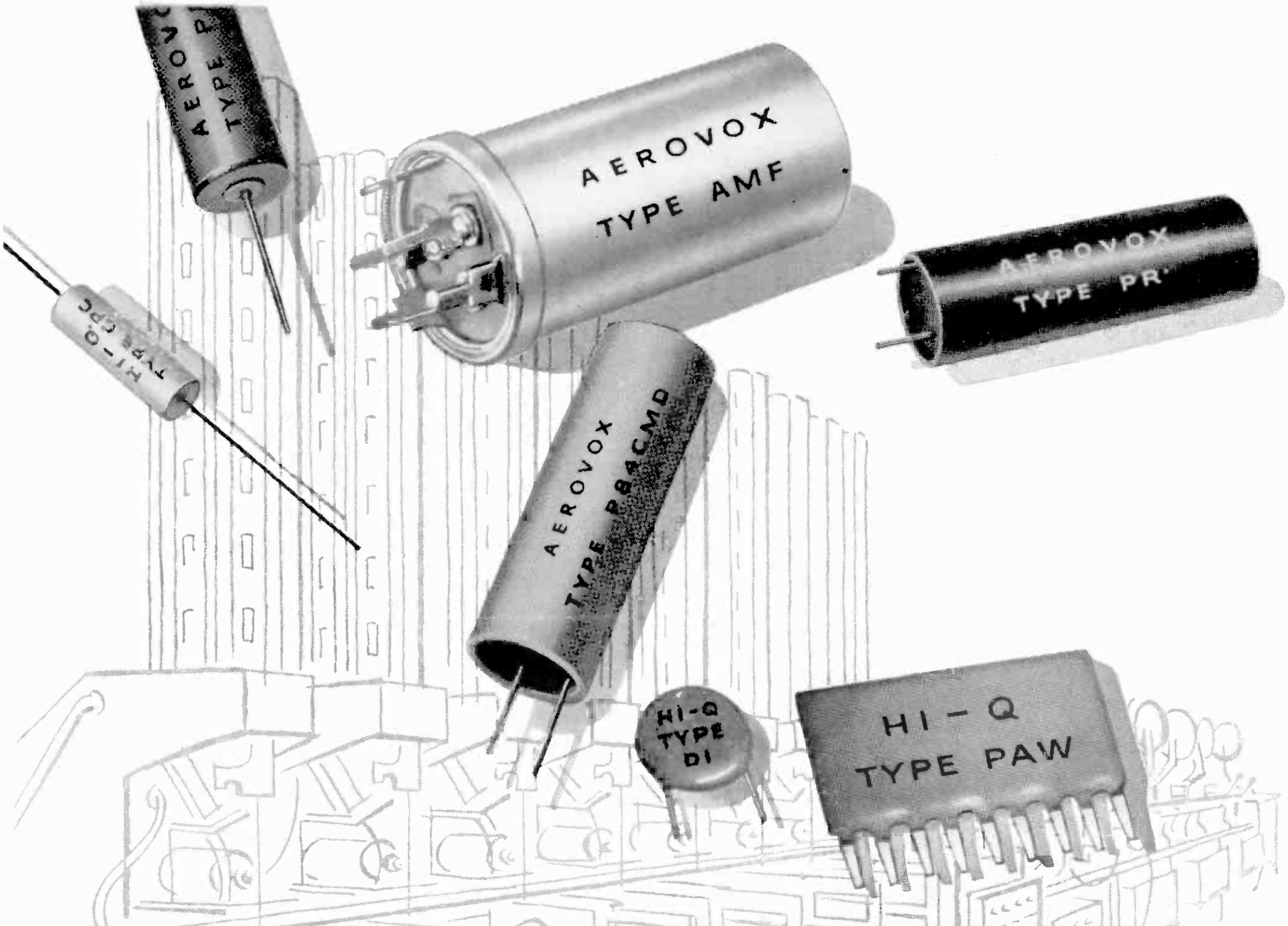
A-M Detector Test. An important use of small diodes is in detector



$$n\% = \frac{E_{dc}}{E_{ac}\,(1.414)} \times 100$$

TEST CIRCUIT FOR RECTIFICATION EFFICIENCY

FIG. 5

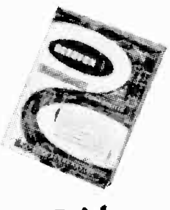


AUTOMATION COMPONENTS

All inclusive! That distinguishes the Aerovox automation program from all others. Not limited to any one phase, we are dealing with mechanical, material, electronic, electrical, production and economic aspects for **across-the-board** automation.

Here is an outstanding staff of mechanical experts. A leading machinery company is now incorporated in the Aerovox group. Notable automation developments and pilot plants, including latest printed wiring and module assemblies, are blazing new trails. Aerovox is collaborating with all the mechanized-assembly developers, while our electronic specialists, working side-by-side with mechanical geniuses, are coming up with new components and packaging, function-fitted to mechanized assembly methods.

Such **across-the-board** automation, implemented by outstanding research, engineering, components and production techniques, is available to those interested in **advanced mechanized production.**



Write on your business letterhead for this fact-packed *Automation Manual*. And submit your automation interests, requirements and problems to our *Director of Automation*.

AEROVOX Capacitors

AEROVOX CORPORATION

NEW BEDFORD, MASS.