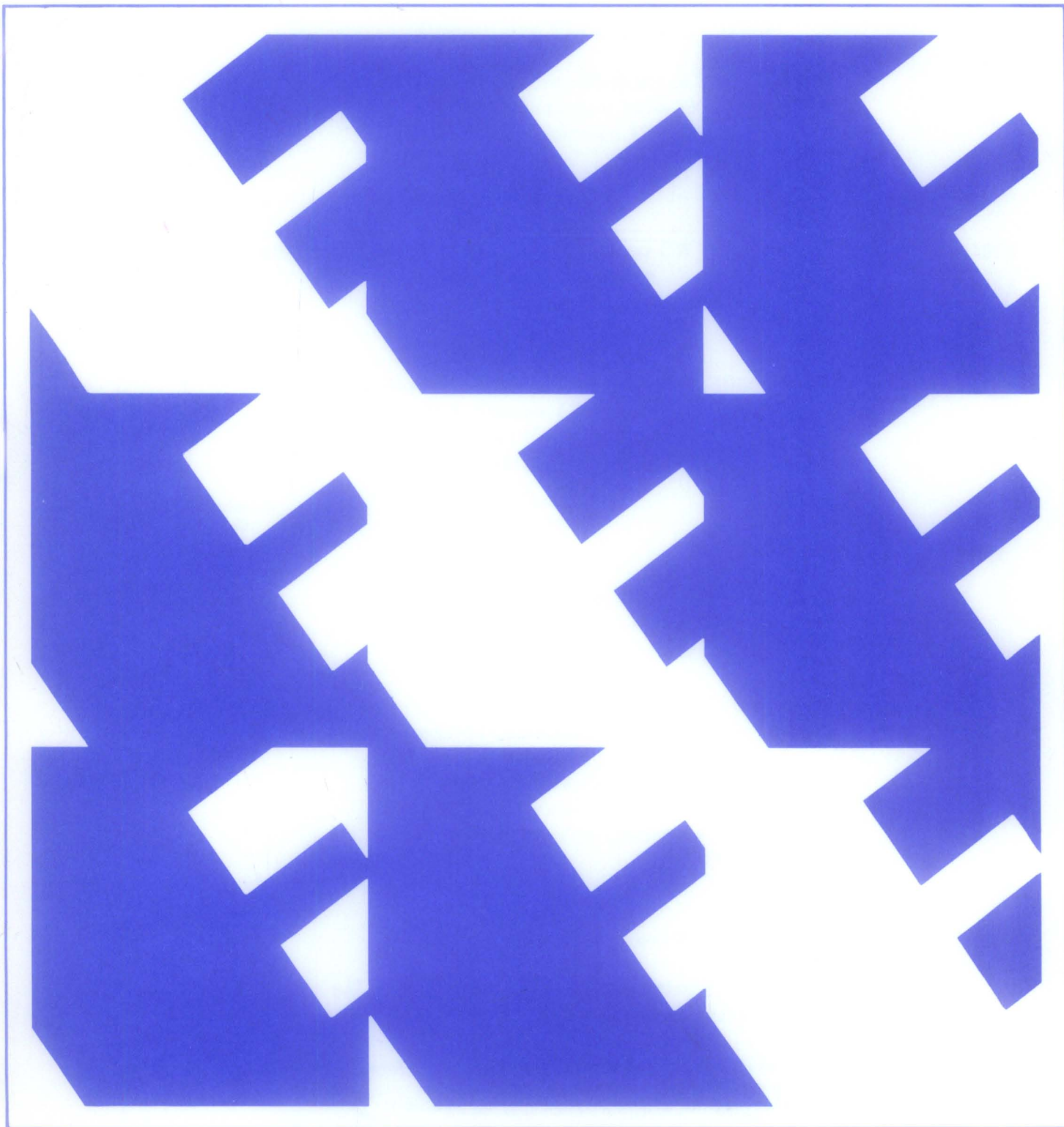


IEEE Standard Methods of Testing Transistors

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IEEE Standard Methods of Testing Transistors

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1.0 GENERAL

1.1 Scope

This standard deals with the methods of measurement of important characteristics of transistors. In general, these characteristics are referred to as parameters of the devices.

Because of the youthfulness of the transistor art, methods of testing transistors will continue to change considerably before the art can be considered to have "stabilized" sufficiently for complete standardization. This standard corresponds to the current state of transistor testing methods, and its publication by the IRE is considered preferable to waiting for a future stabilization of the many rapid changes now characteristic of this field.

1.2 General Precautions

Attention is called to the necessity, especially in tests of apparatus of low power, of eliminating, or correcting for, errors due to the presence of the measuring instruments in the test circuit. This applies particularly to the currents taken by voltmeters.

Attention is also called to the desirability of keeping the test conditions, such as collector voltage and collector current, within the safe limits specified by the manufacturers. If the specified safe limits are exceeded, the characteristics of the transistors may be permanently altered and subsequent tests vitiated. When particular tests are required to extend somewhat beyond a specified safe limit, such portions of the test should be made as rapidly as possible and preferably after the conclusion of the tests within the specified safe limit.

1.2.1 Repeatability: Care must be taken that the measured parameter values are repeatable within precision of measurement after performance of any one or all tests performed on the device.

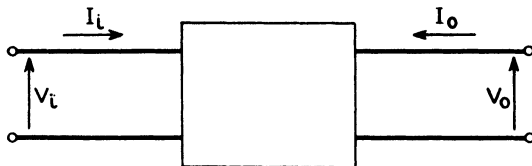


Fig. 1—General four-terminal network.

1.3 Four-Terminal Representation

Fig. 1 shows a 4-terminal network sometimes known as a 2-terminal pair. The behavior of this network may be defined in terms of the quantities V_i , V_o , I_i , and I_o . The ac input current and voltage are I_i and V_i and the output current and voltage are I_o and V_o . Similarly, the dc characteristics may be represented in terms of the input and output voltage, V_I and V_O , and the input and output current, I_I and I_O .

Since the transistor may be employed in three circuit configurations usually referred to as common base, common emitter, and common collector, there is a possible

ambiguity in the definition of any one parameter unless the circuit configuration is stated definitely. Six possible sets of parameters exist for defining the 4-terminal network and the choice of the appropriate set therefore depends on the nature of the device to be characterized.

The h parameters are used throughout the standard since they are peculiarly adaptable to the physical characteristics of transistors. In previous literature these have been referred to as the series-parallel parameters, but a recent paper¹ coined the name "hybrid" which has become a significant method of identification and will, in the interests of clarity, be used throughout this standard.

A specific method of notation involving the letter subscript is used throughout this standard, but no preference over number subscripts is implied thereby. See IRE Standards on Letter Symbols for Semiconductor Devices, 1956 (56 IRE 28. S1).²

The three most commonly used sets of parametric equations are:

Open-circuit impedance parameters

$$V_i = z_i I_i + z_r I_o \quad (1)$$

$$V_o = z_r I_i + z_o I_o \quad (2)$$

Short-circuit admittance parameters

$$I_i = y_i V_i + y_r V_o \quad (3)$$

$$I_o = y_r V_i + y_o V_o \quad (4)$$

Hybrid parameter

$$V_i = h_i I_i + h_r V_o \quad (5)$$

$$I_o = h_f I_i + h_o V_o \quad (6)$$

The input impedance h_i is the impedance between the input terminals when the output terminals are ac short-circuited

$$h_i = V_i / I_i \text{ when } V_o = 0.$$

The voltage feedback ratio h_r is the ratio of the voltage appearing at the input terminals, when they are ac open-circuited, to the voltage applied to the output terminals

$$h_r = V_i / V_o \text{ when } I_i = 0.$$

The forward current multiplication factor h_f is the ratio of the current flowing into the output terminals, when they are ac short-circuited, to the current flowing into the input terminals

$$h_f = I_o / I_i \text{ when } V_o = 0.$$

The output admittance h_o is the admittance between the output terminals when the input terminals are ac open-circuited

$$h_o = I_o / V_o \text{ when } I_i = 0.$$

¹ D. A. Alsberg, "Transistor metrology," 1953 IRE CONVENTION RECORD, Part 9, pp. 39-44. Also IRE TRANS., vol. ED-1, pp. 12-15; August, 1954.

² Proc. IRE, vol. 44, pp. 934-937; July, 1956.

LIST OF TERMS

V_i = ac input voltage.
 V_o = ac output voltage.
 I_i = ac input current.
 I_o = ac output current.
 V_I = dc input voltage.
 V_O = dc output voltage.
 I_I = dc input current.
 I_O = dc output current.
 z_i = input impedance, small signal, output open-circuited.
 z_o = output impedance, small signal, input open-circuited.
 z_f = forward transfer impedance, small signal, output open-circuited.
 z_r = reverse transfer impedance, small signal, input open-circuited.
 y_i = input admittance, small signal, output short-circuited.
 y_o = output admittance, small signal, input short-circuited.
 y_f = forward transfer admittance, small signal, output short-circuited.
 y_r = reverse transfer admittance, small signal, input short-circuited.
 h_i = input impedance, small signal, output short-circuited.
 h_I = input resistance, static value, output short-circuited.
 h_o = output admittance, small signal, input open-circuited.
 h_O = output conductance, static value, input open-circuited.
 h_f = forward current transfer ratio, small signal, output short-circuited ($= -\alpha_f$).
 h_F = forward current transfer ratio, static value, output short-circuited ($= -\alpha_F$).
 h_r = reverse voltage transfer ratio, small signal, input open-circuited.
 h_R = reverse voltage transfer ratio, static value, input open-circuited.
 z_{in} = input impedance, small signal, output termination Z_o .
 z_{out} = output admittance, small signal, input termination Z_i .
 V_e = ac emitter voltage.
 I_e = ac emitter current.
 V_c = ac collector voltage.
 I_c = ac collector current.
 r_e = ac emitter resistance derived from T -equivalent circuit.
 r_b = ac base resistance derived from T -equivalent circuit.
 r_c = ac collector resistance derived from T -equivalent circuit.
 r_m = ac transfer resistance derived from T -equivalent circuit.
 C_o = collector capacitance measured at collector electrode.

Note: See also IRE Standards on Letter Symbols for Semiconductor Devices, 1956 (56 IRE 28. S1).²

2.0 METHODS OF TEST FOR DC CHARACTERISTICS

The static characteristics of a transistor represent its performance only at zero or low frequency. The static characteristics are the input, output, and transfer. In general, these characteristics may be obtained up to the point where thermal effects become significant, or where critical voltages or currents are exceeded. High frequency or pulse methods such as those described in section 2.1.3 may be used to obtain information beyond this point.

2.1 DC Point-by-Point Method

The point-by-point method of obtaining characteristics requires the introduction of a direct voltage or current at one pair of terminals, and the measurement of the current or voltage at either the same or a different pair of terminals, depending upon the characteristics under examination. A family of characteristics can be obtained by measuring a voltage-current characteristic while another voltage or current is changed stepwise over the range of interest in accordance with usual practice. A representative arrangement for the determination of the common base characteristics of transistors is shown in Fig. 2.

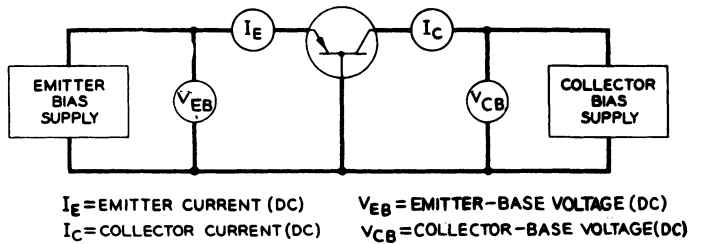


Fig. 2—General dc measurement arrangement.

2.1.1 General Precautions in Transistor Measurement:

Test conditions which cause large voltage or current surges, or exceed the safe limit of dc power dissipation should be avoided. Large overloads even for a small fraction of a second may cause damage to a transistor or modify its characteristics.

The correct voltage polarity must be observed at all times. Incorrect voltage polarity may seriously damage the transistor and test equipment.

Transistors are inherently temperature sensitive devices. The effect of the ambient temperature must be taken into account, and possibly also the internal temperature rise due to the dissipation in the device occurring during the test.

2.1.2 Visual Displays: Visual displays of transistor static characteristics are useful for prediction of performance in circuits up to frequencies at which reactance effects become important. Oscilloscopic displays are useful in disclosing small irregularities in the voltage-current characteristics which may escape observation

by the point-by-point method. The visual display is particularly useful for determination of trends or orders of magnitude in transistor parameters.

The transistor static characteristics normally displayed visually are: input voltage vs input current; input voltage vs output current; output voltage vs input current; output voltage vs output current; and output current vs input current.

2.1.2.1 General Precautions in Oscilloscopic Display: As a preliminary step a passive network may be used as a dummy transistor to check the over-all circuit performance before actual application to transistors, and the voltage-current characteristic may be compared with known or published curves.

Cumulative heating effects must be anticipated. If extreme care to prevent overloading is not taken a gradual shift in the observed characteristic is noted.

Instability may result if suitable series resistance is not provided, particularly in the case of point-contact transistors which are in general short-circuit unstable.

In addition, the general procedures noted in section 3.5 must be observed.

2.1.3 Pulse Methods: It is often of considerable importance to know the static characteristics of transistors beyond the normal operating range where thermal effects would be significant if point-by-point methods were used. In such cases it is necessary to employ pulse methods in which the transistor is allowed to pass currents only for short intervals of such duration and recurrence frequency that the average power dissipation is small.

Pulse methods may be employed for obtaining input, output, and transfer characteristics. The basic circuit elements required for a pulse method are pulse generators and suitable current and voltage indicators. Where one pulse generator is employed, it is usually connected to the appropriate terminals depending upon the characteristic desired, with provision for introducing bias. If more than one pulse generator is used, it is necessary to synchronize the pulses. In general, one pulse generator is adequate and simpler to employ.

A variable amplitude pulse voltage or current is applied to one pair of terminals and simultaneously the corresponding pulse amplitude of current or voltage is measured at the same or a different pair of terminals.

2.1.3.1 Precautions: Care must be taken that the original static characteristics are reproducible after the device has been pulsed.

2.2 Load (Dynamic) Characteristics

The methods used for the determination of load characteristics from static characteristic curves, and the direct measurement of load characteristics have been published.³ Load characteristics permit calculation of the performance data for the transistor such as input

power, output power, efficiency, dissipations, etc.

2.2.1 Direct Measurement of Load Characteristics: The load characteristics of a transistor can be measured directly, without resorting to calculation from the static characteristics. When reactive effects are significant, they will have considerable effect upon the load characteristic. It is therefore advisable to measure load characteristics at the frequency at which the transistor is to be used.

2.3 Maximum Electrode Voltage

When the voltage-current characteristic of a transistor is presented by any appropriate technique, marked changes in slope and/or discontinuities may be noted as a function of electrode voltage and circuit configuration. These may be due to either junction breakdown, thermal gradients, or internal instabilities. In general, a junction breakdown may be correlated with the resistivity of the material in the base layer, while that due to thermal gradients is generally much lower, and is characteristically poorly defined.

2.3.1 General: A maximum electrode voltage is measured by the potential which results in a specified change in the parameter being measured. It may also represent a potential above which destructive irreversible changes occur in the transistor. In either event it represents a locus of electrode bias voltages and currents which define maximum usable operating conditions. The maximum electrode voltage will be a function of the common electrode utilized when the characteristics are taken.

When specifying the peak voltage, even though non-destructive, the duration of the peak and the duty cycle must be specified because of the short thermal time constants of the semiconductor element.

2.3.2 Definition: A maximum electrode voltage may be defined on any of the following bases:

- 1) Junction voltage breakdown.
- 2) Maximum power dissipation capability of the transistor.
- 3) Nonlinearity of the electrode voltage-current characteristic.

An example of these limitations is shown for a typical collector voltage-current characteristic in Fig. 3 on the following page. In this figure it may be seen that the definitions just given will govern in different regions of the characteristic. The maximum electrode voltage for the characteristic shown will be given by V_{C2} , V_{C3} , and V_{C4} .

V_{C2} is defined as the voltage corresponding to the point of tangency of the voltage saturation tangent with the $I_C - V_C$ curve, with input current specified as shown in Fig. 3.

V_{C3} defines the voltage at which the rated power dissipation is attained.

V_{C4} defines the voltage at which the nonlinearity of the characteristic becomes a substantial limitation to use.

³ "IRE Standards on Electron Tubes, Methods of Testing," PROC. IRE, Part I, vol. 38, pp. 917-948, August, 1950 (see sec. 4.2, p. 925); Part II, vol. 38, pp. 1079-1093, September, 1950.

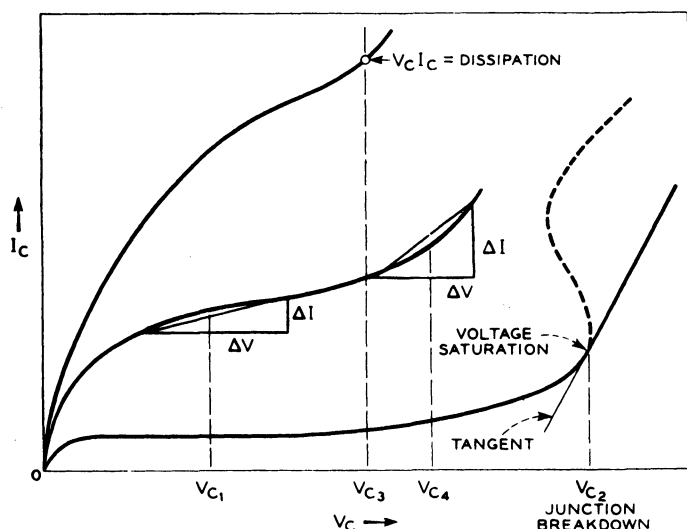


Fig. 3—Maximum electrode voltages.

2.3.3 Precautions: The following specific precautions should be followed in addition to those noted in section 2.1.1. a) High-speed oscilloscopic sweep methods may be preferable to point-by-point and other low-speed methods, because inaccuracies due to thermal gradients and incipient junction breakdown are minimized. b) The electrical characteristics must be reproducible within the margin of error after a determination of maximum collector voltage.

3.0 METHODS OF TEST FOR SMALL SIGNAL APPLICATIONS

For purposes of this section small signal operation assumes linearity over the operating range. For linear operation the transistor is completely specified by means of four independent parameters which are in general complex quantities whose value may depend upon frequency, operating point, and environment. For linear operation the value of the parameter must be independent of the amplitude of the signal.

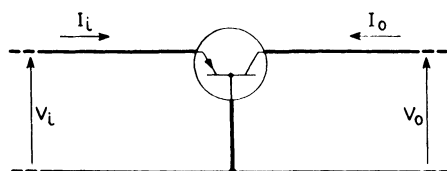


Fig. 4—Transistor four-pole representation.

Most transistors can be characterized by a 4-pole representation in which two terminals are usually common as in Fig. 4 above. It is often found that the measurement of transistors having a common base current amplification of less than unity is more practicable with either the short-circuit admittance or hybrid (y or h) parameters while with those having a common-base current amplification greater than unity the open-circuit impedance or hybrid (z or h) parameters are more practicable.

In the illustrations which follow, the common-base configuration is generally shown for purpose of economy. It will be understood that the parameters may be taken in any possible stable configuration.

3.1 General Precautions

It is necessary that the test signals employed be small enough so that the transistor operation is linear. Generally, the greater the parameter accuracy desired, the smaller the test signal must be. A method of determining whether the signal is sufficiently small is to decrease the amplitude of the test signal progressively until a further decrease in amplitude produces no change within the accuracy desired in the value of the parameter.

Methods of determining test signal amplitude include the checking of voltage or current amplification derived from combinations of 4-pole parameters with those measured experimentally. If the test signal is sufficiently small, the derived and measured values will check within the accuracy desired.

In the methods of measurement to be discussed, it is preferable to either ac short-circuit or ac open-circuit different terminal pairs to carry out the measurement. In order to be certain of the accuracy of the measured data, it is necessary to ascertain the adequacy of the ac short or open circuits employed. Stray series elements such as lead inductance may seriously alter ac short circuits. One method of ascertaining the adequacy of the ac short or open circuit employed is to change progressively by known amounts the terminal admittance or impedance while making measurements of the parameter under investigation. A graphical plot, as shown typically in Fig. 5, of the measured parameter as a function of absolute magnitude of the terminal admittance or impedance would show an asymptotic approach to the correct value.

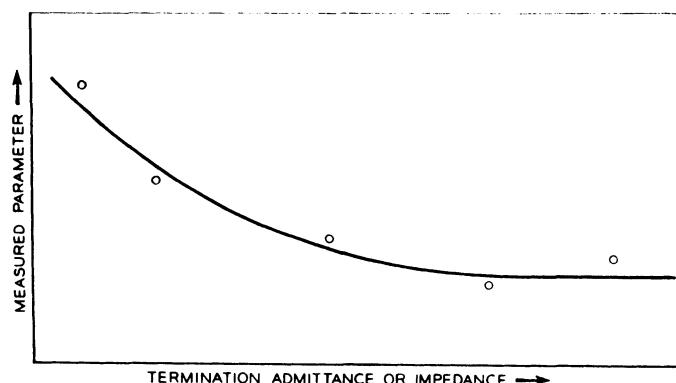


Fig. 5—Adequacy of termination.

For preliminary measurements or for approximate results, the basic idea of this check method may be applied by making certain that there is negligible change in the parameter being measured when the ac short or open circuit is changed by an appreciable amount.