Designation: F 528 – 99

Standard Test Method of Measurement of Common-Emitter D-C Current Gain of Junction Transistors [1]

This standard is issued under the fixed designation F 528; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the measurement of common-emitter d-c current gain (forward, h_{FE}, or inverted, h_{FEI}) of bipolar transistors, for which the collector-emitter leakage current, I_{CEO}, is less than 10 % of the collector current, I_C, at which the measurement is to be made, and for which the shunt leakage current in the base circuit is less than 10 % of the base current required.

1.2 This test method is suitable for measurement of common-emitter d-c current gain at a single given value of test transistor collector current or over a given range of collector currents (for example, over the range of the transistor to be tested).

1.2.1 The nominal ranges of collector current over which the three test circuits are intended to be used are as follows:

1.2.1.1 *Circuit 1*, less than 100 µA,

1.2.1.2 *Circuit 2*, from 100 µA to 100 mA, and

1.2.1.3 *Circuit 3*, greater than 100 mA.

1.3 This test method incorporates tests to determine if the power dissipated in the transistor is low enough that the temperature of the junction is approximately the same as the ambient temperature.

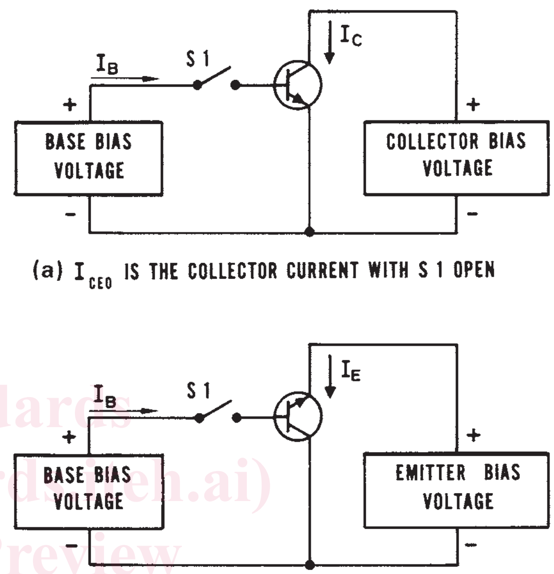
1.4 The values stated in International System of Units (SI) are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Terminology

2.1 *Definitions:*

2.1.1 *common-emitter d-c current gain,* h_{FE}—the ratio of d-c collector current (in excess of collector-emitter leakage current I_{CEO}) to base current when the transistor is connected in the common-emitter configuration (see Fig. 1a); that is:



(a) I_{CEO} IS THE COLLECTOR CURRENT WITH S 1 OPEN

(b) I_{ECO} IS THE EMITTER CURRENT WITH S 1 OPEN

NOTE 1—The transistor shown is an *npn* type; for *pnp* types the polarities of the bias supplies are reversed.

FIG. 1 Explanatory Circuits to Illustrate the Meaning of Terms Used in Calculation of h_{FE} and h_{FEI}

$$h_{FE} = (I_C - I_{CEO})/I_B$$

2.1.2 *inverted common-emitter d-c current gain,* h_{FEI}—the ratio of d-c emitter current I_E(in excess of emitter-collector leakage current I_{ECO}) to base current when the transistor is connected in the common-collector configuration (see Fig. 1b); that is:

$$h_{FEI} = (I_E - I_{ECO})/I_B$$

NOTE 1—In the remainder of this test method only h_{FE} is discussed. Measurements and calculations for h_{FEI} are identical and the same apparatus and procedures apply.

3. Summary of Test Method

3.1 Sufficient current, I_B, is driven into the base of a transistor to achieve the desired collector current at the required collector-emitter voltage. The magnitude of the base current is measured and the gain calculated. Three test circuits are available for tests at low, intermediate, and high transistor

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collector currents, respectively. The measurements and calculations are repeated for all collector-current values of interest.

3.2 The following quantities are unspecified in the method and are to be agreed upon by the parties to the test:

3.2.1 The collector currents, I_C, at which the measurements are to be made,

3.2.2 The collector-emitter voltage, V_{CE}, to be used when making the measurements, and

3.2.3 The temperature at which the measurements are to be made.

4. Significance and Use

4.1 The current gain of a transistor is basic to its operation and is its single most important parameter.

4.2 Ionizing radiation, that is, gamma radiation due to a nuclear burst, will degrade the current gain due to lifetime damage in the bulk material. Degradation of gain will be greatest immediately following a burst of ionizing radiation and the gain will rapidly recover to a quasi steady-state value. Defect annealing may continue for weeks but usually the current gain recovery is small or negligible.

4.3 This method provides a procedure that does not require special-purpose test equipment.

4.4 This method is suitable for use for specification acceptance, service evaluation, or manufacturing control.

5. Interferences

5.1 *Shunt Leakage*— When the magnitude of the impedance between the base and emitter connections on the test fixture is comparable to the base-emitter impedance of the transistor being tested, the measurement results are invalid.

NOTE 2—The shunt leakage current can be affected by high humidity. Since the range over which valid current gain measurements can be made is reduced by shunt leakage, transistors that require measurement of very low currents must be tested in an environment of less than 40 % relative humidity.

5.2 *Temperature*— For referee measurements, the temperature of the device must be controlled or a set of correction factors developed for adjusting the data to a common temperature since h_{FE} may vary as much as 1 to 3 %/°C. Care must be exercised in handling the device as well as in controlling the ambient temperature. The operator may use one or any combination of the following to reduce operator-induced temperature increases:

5.2.1 *Gloves*.

5.2.2 *Tongs* or some other suitable means for inserting the device into the test fixture.

5.2.3 Procedure of waiting for the device to reach thermal equilibrium (usually 20 to 30 s is sufficient).

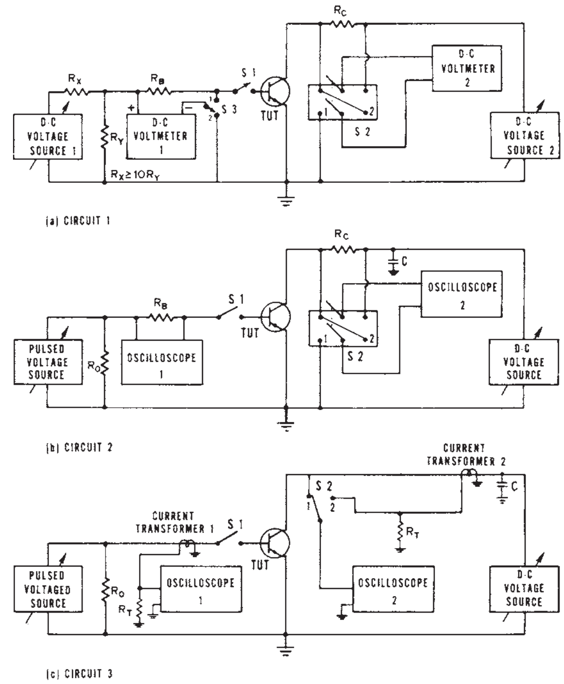
6. Apparatus

6.1 *Circuit 1*— Measuring circuit for low currents with the following components (see Fig. 2a):

6.1.1 *D-C Voltage Source 1*—d-c power supply meeting the following specifications:

6.1.1.1 Stable to within ±0.1 % of the set voltage,

6.1.1.2 Noise and ripple less than 0.5 % of the output voltage,



NOTE 1—Capacitor C in Circuits 2 and 3 is a bypass capacitor that is used if required. (see Note 4).

NOTE 2—Oscilloscopes 1 and 2 may be digitizers.

FIG. 2 Schematics of Circuits for Measurement of h_{FE}

6.1.1.3 Adjustable over a nominal range of 0 to 30 V, and

6.1.1.4 Capable of supplying currents up to 250 mA.

6.1.2 *D-C Voltage Source 2*—d-c power supply meeting the following specifications:

6.1.2.1 Stability, noise and ripple, and current specifications the same as d-c voltage source 1 (see 6.1.1), and

6.1.2.2 Adjustable over the range from 0 to $V_{CE} + I_C R_C$ (typically less than 0.1 V_{CE}).

6.1.3 *D-C Voltmeters 1 and 2*—d-c digital voltmeters meeting the following specifications:

6.1.3.1 At least 3½-digit display,

6.1.3.2 Accuracy of at least ±0.5 % of full-scale reading,

6.1.3.3 Resolution of ±1 least-significant digit,

6.1.3.4 Scales of at least 100 mV and 1, 10, and 100 V, and

6.1.3.5 Input impedance at least 100 times that of the resistor (R_B or R_C) across which the voltmeters are used to measure voltages.

6.1.4 *Resistors*, specified as follows:

6.1.4.1 R_B—1 % resistor in the nominal resistance range 10 Ω to 100 kΩ, depending on the base current being used.

6.1.4.2 R_C—1 % resistor in the nominal resistance range 10 Ω to 10 kΩ, depending on the collector current.

6.1.4.3 *Voltage Divider Resistors R*—$_X$ and R $_Y$—R_X shall be at least equal to 10 R_Y.

NOTE 3—These resistors form a voltage divider used to simplify the adjustment of base current. No further tolerance or value specifications are applicable (see Fig. 2a).

6.2 *Circuit 2*—Measuring circuit for intermediate currents with the following components (see Fig. 2b):

6.2.1 *D-C Voltage Source*, meeting the specifications of d-c voltage source 2 (see 6.1.2), and with the capability of supplying current pulses of the magnitude required for the transistor under test.

NOTE 4—For power transistors that need large current pulses, this requirement can be met with a power supply inadequate in itself by placing a large capacitor (1000 to 10 000 μF) across the output terminals of the power supply. To compensate for possible inductive components of the impedance of this large capacitor, it should be paralleled by a small capacitor (0.001 to 0.1 μF).

6.2.2 *Pulsed Voltage Source*, meeting the following specifications:

6.2.2.1 Polarity selectable as positive or negative,

6.2.2.2 Rise time, t_r, and fall time, t_f, (see Fig. 3) less than or equal to 0.1 times the width of the pulse to be used,

6.2.2.3 Pulse width, t_p, (see Fig. 3) adjustable from 1.0 to 350 μs, inclusive,

6.2.2.4 Pulse top flat within 3 % over interval, t_m(see Fig. 3),

6.2.2.5 An output adjustable over a nominal range from 0 to 20 V, and

6.2.2.6 Capability of driving the maximum base current required for the transistor to be tested.

NOTE 5—The nonuniform impedance of the base-emitter diode of the transistor under test may cause the output of some pulse sources to vary to such a degree that the requirement of 6.2.2.4 cannot be met. The use of a resistive termination and judicious choice of R_B, R_X, and R_Y to provide an essentially resistive and constant load to the pulse source may help to avoid this difficulty.

6.2.3 *Oscilloscopes or Digitizers*:

6.2.3.1 General-purpose laboratory oscilloscopes meeting the following specifications:

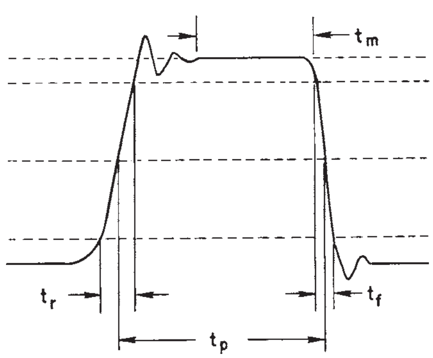
(*a*) Bandwidth of dc to 10 MHz minimum,

(*b*) Deflection factors covering, as a minimum, the range from 5 mV/div to 1V/div, inclusive,

(*c*) Input impedance greater than or equal to 100 times the d-c resistance across which the oscilloscopes are used to measure voltages,

(*d*) Capability of differential measurements with both inputs isolated from test-circuit common,

(*e*) Common-mode rejection ratio of 20 dB minimum, and



NOTE 1—t_m must be at least equal to t_p/3.

FIG. 3 Minimum Width t_p of Pulse that May Be Used in h_{FE} Test Measurements

6.2.3.2 *Digitizers with Bandwidth, Sampling Interval, and Time-base Capabilities*, adequate for handling the transient signals with good resolution for all pulse widths utilized in the test may be used. Hard copy printouts of the recorded signal may be a part of the capability of this apparatus.

6.2.4 *Resistors*, specified as follows:

6.2.4.1 R_O—1 % resistor of the proper value to match the output impedance of the pulsed source,

6.2.4.2 R_B—1 % resistor in the nominal resistance range 1 Ω to 10 kΩ, depending on the base current being used, and across which the voltage developed by the base current is measured, and

6.2.4.3 R_C—1 % resistor in the nominal resistance range 1 Ω to 1 kΩ, depending on the collector current being used, and across which the voltage developed by the collector current is measured.

6.3 *Circuit 3*—Measuring circuit for high currents with the following components (see Fig. 2c):

6.3.1 *D-C Voltage Source*, as specified in 6.2.1,

6.3.2 *Pulsed Voltage Source*, as specified in 6.2.2,

6.3.3 *Oscilloscopes or Digitizers*, as specified in 6.2.3, with the exception that differential measurement capability is not required,

6.3.4 *Current Transformers 1 and 2*, meeting the following specifications:

6.3.4.1 Sensitivity of 0.1 V/A or better,

6.3.4.2 Calibrated accuracy of ±3 % or better,

6.3.4.3 Core saturation rating exceeding the product of the current to be measured and its pulse width,

6.3.4.4 Rise and fall times less than or equal to 0.1 times the width of the pulse used, and

6.3.4.5 Low-frequency response such that a square pulse of the width used in the test results in a droop (voltage drop) of less than 3 % over the interval t_m.

6.3.5 *Resistors*, specified as follows:

6.3.5.1 R_O—1 % resistor of the proper value to match the output impedance of the pulsed voltage source, and

6.3.5.2 R_T—1 % resistor of the value specified by the manufacturer as the termination for the current transformer.

6.4 *Test Fixture*— Transistor socket suitable for transistor under test, to be used as required in each of the three test circuits (see Fig. 2).

6.5 *Miscellaneous Circuit Components*, to be used as required in each of the test circuits (see Fig. 2). The switches, leads, and connections shall be of a quality customarily used in electronic circuit fabrication.

6.6 *Temperature-Measuring Device*, capable of measuring the temperature in the vicinity of the device under test to an accuracy of± 1°C at the temperature specified for the measurement.

7. Sampling

7.1 This test method is not intended for use as a 100 % inspection test.

7.2 In any test program utilizing this test method, sample sizes and selection techniques shall be agreed upon by the parties to the test.