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Standard Test Method for Small-Signal Scattering Parameters of Low-Power Transistors in the 0.2 to 2.0-GHz Frequency Range[1]

This standard is issued under the fixed designation F 466; 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 the scattering parameters of transistors operating under small-signal conditions at power levels low enough to permit continuous operation at safe junction temperatures without the use of elaborate heat sinks. It is generally applicable in the frequency range between 0.2 and 2.0 GHz.

1.2 Procedures are given for the use of manual measuring equipment.

1.3 Mathematical transformations for converting scattering parameters to *h, y,* or *Z* parameters are listed in Appendix X1.

1.4 *This standard does not purport to address all of the safety problems, 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. Referenced Document

2.1 *ASTM Standard:*

E 1 Specification for ASTM Thermometers[2]

3. Terminology

3.1 *Description of Terms Specific to This Standard:*

3.1.1 *scattering parameters*—For linear two-port networks terminated at input and output by the same reference impedance, scattering parameters are complex numbers that describe the relative magnitude and phase of the reflected signals V_R and ϕ_R (see Fig. 1) and transmitted signals V_T and ϕ_T (see Fig. 1) with respect to signals applied to the input and output terminals of the network, V_D and ϕ_D (see Fig. 1).

3.1.1.1 *Discussion*—Although the most commonly used reference impedance is 50 Ω, other values may be used. The reference impedance must be known to determine the input and output impedances of the device under test and to convert scattering parameters by *h, y,* or *Z* parameters.

3.1.1.2 *transistors*—Can be considered linear networks if measurements are made under small-signal conditions.

3.2 *Symbols:*

3.2.1 *S*—The symbol *S* is used to designate the scattering parameters. A capital *S* is used when referring to the entire matrix (for example, *S* matrix), and a lowercase *s* is used when referring to individual elements of the matrix (for example, s_{11}, s_{21}, etc.).

3.2.1.1 In the symbols for the individual *S* parameters, the first digit of the subscript indicates the port (pair of terminals) at which the signal is to be read with respect to the signal incident on the port indicated by the second digit. The numbers 1 and 2 are used to designate the input and output ports, respectively. The four *S* parameters that describe a two-port network are defined as follows:

(*1*) The input reflection coefficient, s_{11}, is the complex ratio of the signal reflected from the input terminals of the device under test (forward V_R, ϕ_R, (see Fig. 1)) to the signal incident on the input terminals (forward V_D, ϕ_D, (see Fig. 1)) when the source and terminating resistances are each equal to the reference impedance (R_0 in Fig. 1).

(*2*) The output reflection coefficient, s_{22}, is the complex ratio of the signal reflected from the output terminals of the device under test (reverse V_R, ϕ_R (see Fig. 1)) to the signal incident on the output terminals (the applied signal, V_D, ϕ_R (see Fig. 1) is incident on the output terminals) when the source resistance and the termination at the input of the device under test are each equal to the reference impedance (R_0 in Fig. 1).

(*3*) The forward transmission coefficient, s_{21}, is the complex ratio of the signal transmitted through the device under test from input to output terminals (forward V_T, ϕ_T (see Fig. 1)) to the signal incident on the input terminals (forward V_D, ϕ_D (see Fig. 1)) when the source and terminating resistances are each equal to the reference impedance (R_0 in Fig. 1).

(*4*) The reverse transmission coefficient, s_{12}, is the complex ratio of the signal transmitted through the device from output to input terminals (reverse V_T, ϕ_T (see Fig. 1) to the signal incident on the output terminals (the applied signal, V_D, ϕ_D (see Fig. 1) is incident on the output terminals) when the source resistance and the termination at the input to the device under test are each equal to the reference impedance (R_0 in Fig. 1).

4. Summary of Test Method

4.1 Scattering parameters of transistors are determined by placing the transistor in cascade with a transmission line that is terminated in its characteristic impedance, generally 50 Ω, and measuring the ratios of the reflected and transmitted signals to the incident signal in both the forward and reverse directions. The two reflected signals are functions of the input and output impedances of the transistor, respectively,

[1] This test method is under the jurisdiction of ASTM Committee F-1 on Electronics, and is the direct responsibility of Subcommittee F01.11 on Quality and Assurance.

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[2] *Annual Book of ASTM Standards*, Vol 14.03.

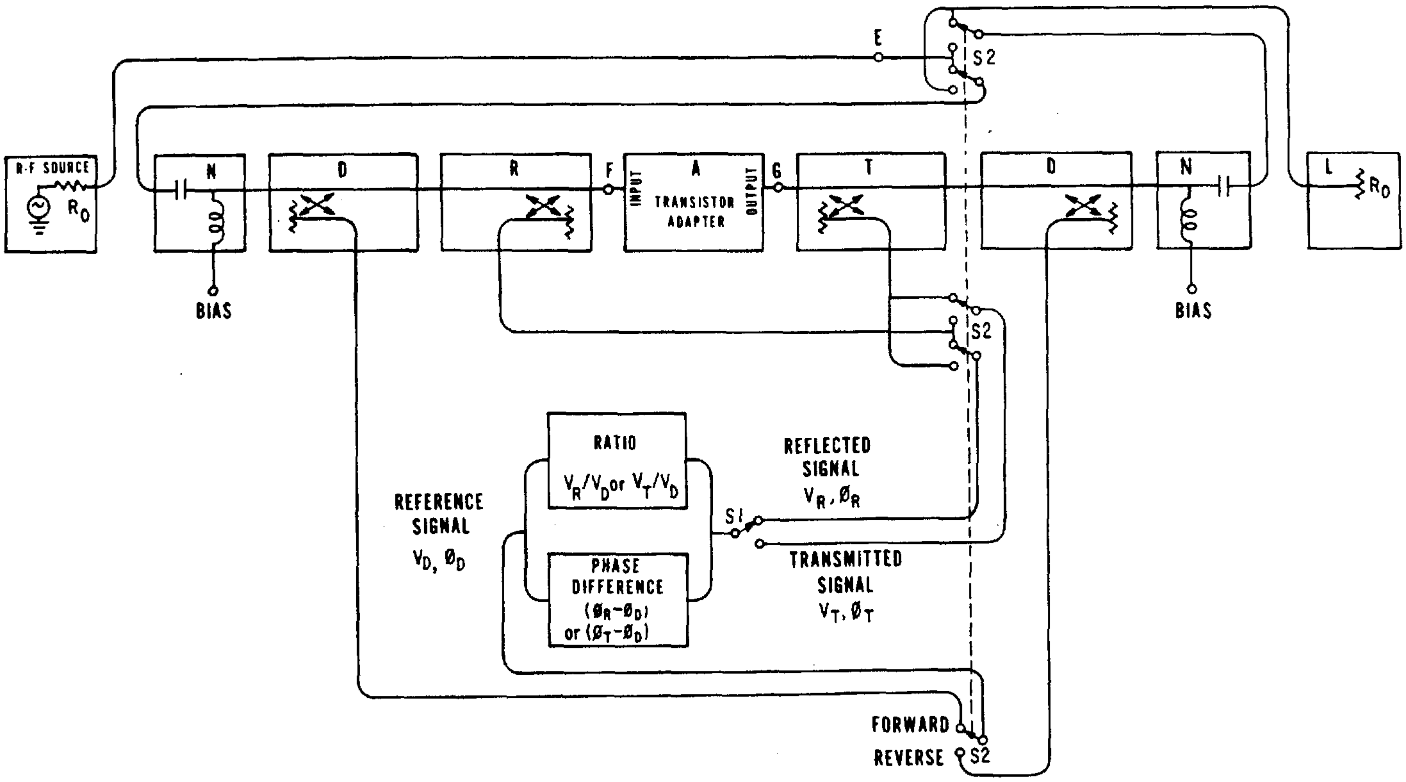

FIG. 1 Diagram of S Parameter Measurement System

and the two transmitted signals are related to its forward and reverse transfer characteristics.

5. Significance and Use

5.1 This test method provides a means of characterizing transistors in a frequency range in which the measurement of *h, y*, and *Z* parameters is impractical because of the difficulty of obtaining adequate short-circuit and open-circuit terminations. Scattering parameters can be used directly for circuit design. If desired, they can be transformed mathematically to *h, y*, or *Z* parameters as indicated in Appendix X1.

6. Interferences

6.1 The signal level applied to transistors for the measurement of small-signal parameters is very critical, especially in the measurement of forward characteristics. For this reason, it is important not to exceed the signal level specified in 11.1.3. If there is doubt, the test specified in 9.4 should be applied to determine if the signal level is low enough to satisfy small-signal conditions.

7. Apparatus

7.1 *r-f Source*—Source capable of furnishing 6 to 20 mW of r-f power over a frequency range from 0.2 to 2.0 GHz. The frequency shall be accurate within ±1 % of the set value, and the level of the predominant harmonic shall be at least 20 dB below that of the fundamental.

7.2 *r-f Load* (labeled *L* in Fig. 1), terminating the system in its characteristic impedance, R_0. The reflection coefficient of the load shall not exceed 0.005 (−46 dB).

7.3 *Bias Decoupling Networks* (labeled *N* in Fig. 1), providing for the connection of bias to the device under test. These networks shall be capable of attenuating the r-f signal coupled to the power supply by at least 80 dB.

7.4 *Directional Couplers* (labeled *D, R*, and *T* in Fig. 1) for sampling the incident, reflected, and transmitted signals, respectively. The directivity of the directional couplers shall not be less than 35 dB; the reflection coefficients at terminals *F* and *G* shall not exceed 0.1 (−20 dB).

NOTE 1—The directivity of the directional couplers and the load and source match at terminals *F* and *G* can be considered to meet the requirements of 7.4 if the residual reflection coefficients at terminals *F* and *G* do not exceed 0.023 (−32.8 dB), as specified in Annex A1.4.10.

7.5 *Transistor Adapter* (labeled *A* in Fig. 1), connecting the transistor socket to the coaxial system. The reflection coefficient caused by mismatch between the transistor adapter and terminals *F* and *G* shall not exceed 0.05 (−26 dB), as specified in Annex A1.5.5. When the transistor socket is empty, the coupling through the adapter between terminals *F* and *G* shall not be greater than 0.005 (−46 dB), as specified in Annex A1.6.4.

7.5.1 *Transistor Socket* providing repeatable, low-resistance contact between the transistor leads and the transistor socket within 0.5 mm of the reference plane established by the calibration standards (see 7.7). The socket shall provide for the elimination of high-frequency effects caused by unused portions of the transistor leads.

7.6 *Ratio- and Phase-Measuring Instruments*—Instruments capable of measuring the ratio and phase difference between the signal incident on the device under test and either the signal reflected from it or the signal transmitted through it, depending on the setting of coaxial switch *S1* (see Fig. 1). When identical signals are applied to both terminals of these instruments, the indicated ratio shall be within 2 %

(0.2 dB) and the phase difference shall not exceed 0.25°.

7.7 *Calibration Standards*—Equipment for calibrating the system for measurement of reflection and transmission parameters, consisting of the following:

7.7.1 *Short Circuit*—A device to be inserted into the transistor socket for providing a short-circuit termination at the reference plane on which measurements are to be made.

7.7.2 *Through Line*—A device to be inserted into the transistor socket for connecting the input and output terminals of the socket in a manner which preserves the characteristic impedance of the system.

7.8 *Accessories for Performance Verification*—Equipment for checking the performance of the system, consisting of the following:

7.8.1 *Attenuator*—A 3-dB fixed coaxial attenuator for determining if the r-f signal level meets the requirements for small-signal operation of the device under test. The attenuator shall be designed for operation in a system with impedance R_0 and shall be fitted with connectors that mate with those used at the r-f input of the measurement system.

7.8.2 *Resistive Termination (Transistor Socket)*—A resistive termination to be inserted into the transistor socket for determining the reflection coefficients at the socket. The reflection coefficient of the termination shall not exceed 0.005 (−46 dB).

7.8.3 *Short Circuit (Coaxial)*—A short circuit for calibrating the system at terminals *F* and *G* (see Fig. 1). The device shall be fitted with a connector that mates with those of the terminals (not required if 7.8.2 is available).

7.8.4 *Resistive Termination (Coaxial)*—A resistive termination for measuring the reflection coefficients at terminals *F* and *G* (see Fig. 1). The reflection coefficient of the termination shall not exceed 0.005 (−46 dB); the connector shall mate with those of terminals *F* and *G* (not required if 7.8.2 is available).

7.9 *Coaxial Switches* (labeled *S1* and *S2* in Fig. 1), for connecting the ratio- and phase-measuring instruments to the reflected and transmitted signals and for facilitating the conversion of the system for the measurement of the forward and reverse characteristics of the device under test.

7.10 *Coaxial Transmission Lines*—Coaxial lines of impedance R_0 connecting the components of the system.

7.11 *Thermometer* for measuring temperature in the vicinity of the transistor fixture. It shall be capable of measuring temperatures in the vicinity of room ambient temperature within 0.1°C (0.2°F). ASTM Precision Thermometer 63F-62 (18 to 89°F) or 63C-62 (−8 to 32°C) as prescribed in Specification E 1 is suitable for this purpose.

8. Sampling

8.1 This test method determines the properties of a single specimen. If sampling procedures are used to select devices for test, they must be agreed upon in advance by the parties to the test.

9. Preparation of Apparatus

9.1 Assemble the apparatus as shown in Fig. 1.

9.2 Energize the system and allow it to warm up for at least 1 h.

9.3 Set the r-f source to the frequency prescribed in 11.1.4.

9.4 Adjust the test signal to the level prescribed in 11.1.3. If no signal level has been agreed upon, perform the following test to determine if the test signal level is low enough to assure linear operation of the device being measured:

9.4.1 Select the lowest frequency at which measurements are to be made.

9.4.2 Calibrate the system for the measurement of s_{21} (see 10.4).

9.4.3 Insert a typical transistor of the type to be measured into the test socket, apply the prescribed biases (see 12.5), and measure s_{21} (see 12.7.3).

9.4.4 Reduce the signal applied to the transistor by a factor of two by inserting a coaxial, 3-dB attenuator (see 7.8.1) in series with the r-f input to the system; for example, at terminal *E* of Fig. 1.

9.4.5 Recheck the calibration of the system.

9.4.6 Remeasure transistor s_{21}.

9.4.7 If the change in the magnitude of s_{21} is greater than 1 % (0.1 dB), reduce the signal level to the device under test and repeat 9.4.2 through 9.4.6 until the change in s_{21} magnitude caused by the 3-dB reduction in signal level is less than 1 % (0.1 dB).

10. Calibration and Standardization

10.1 Select a circuit configuration (for example, common base) that is compatible with the calibration standards to be used. This may be different from the circuit configuration used for transistor measurement.

10.2 Check to see that biases are *not* applied to the transistor socket.

10.3 Calibrate for the measurement of reflection coefficients if both reflection and transmission coefficients are to be measured or if reflection coefficients only are to be measured. Choose for calibration the reflection coefficient that is the more critical in the intended application of the transistor. Adjust this reflection coefficient to the correct response to a short circuit (that is, unity at 180°) and record the residual values of the other *S* parameters. The procedure which follows in 10.3.1 through 10.3.4 should be followed when s_{11} is the more critical of the reflection parameters; if s_{22} is the more critical, substitute the material in brackets.

10.3.1 Adjust s_{11} [s_{22}] as follows:

10.3.1.1 Connect the system for the measurement of forward [reverse] characteristics (see Fig. 1).

10.3.1.2 Insert the short circuit (see 7.7.1) into the transistor socket.

10.3.1.3 Connect the ratio and phase-difference indicators for measurement of the reflected signal.

10.3.1.4 Adjust the ratio and phase-difference indicators to read 1 (0 dB) and 180 deg, respectively.

10.3.1.5 Record these readings as the initial values of s_{11} [s_{22}] on a data sheet such as the one illustrated in Fig. 2.

10.3.1.6 Remove the short circuit from the transistor socket.

10.3.2 Determine the residual value of s_{21} [s_{12}] as follows:

10.3.2.1 Insert the through line (see 7.7.2) into the transistor socket.

10.3.2.2 With the system still connected for the measurement of forward [reverse] characteristics, connect the ratio and phase-difference indicators for measurement of the transmitted signal.

10.3.2.3 Read the values of V_T/V_D and $(\phi_T - \phi_D)$ dis-

DATA SHEET

Frequency or name of device[A]

Date ____________

Ambient temperature ____________ [B]

Input signal level ____________ [C]

Operator ____________

Common ____ [D] circuit

V_{xx} = ___ [E] V; I_x = ___ [E] A

Frequency/Device	s_{11} Magnitude, dB[F]	s_{11} Phase, degree	s_{21} Magnitude, dB[F]	s_{21} Phase, degree	s_{12} Magnitude, dB[F]	s_{12} Phase, degree	s_{22} Magnitude, dB[F]	s_{22} Phase, degree
			Calibration data: Reference [G]; common [G] circuit					
[I]	[H]	[H]	[H]	[H]	[H]	[H]	[H]	[H]
[I]								
[I]								
[I]								
[I]								

[A] Enter name of device, including designation for the specimen if the same device is to be measured at several frequencies. Enter the frequency if several devices are to be measured at the same frequency.

[B] Ambient temperature in the vicinity of the transistor socket.

[C] Estimate the signal input to the device under test.

[D] Identify circuit configuration by entering emitter, base, source, etc.

[E] Enter bias voltage and current and units for each.

[F] Omit units (dB) if magnitude is measured as a dimensionless ratio.

[G] Indicate reference (short circuit or through line) and circuit configuration used for calibration.

[H] Enter residual values determined during calibration.

[I] If several devices are being measured, identify each specimen. If the same device is being measured at several frequencies, enter the frequency and the calibration data for each frequency, as well as the measurement data.

FIG. 2 Typical Data Sheet

played on the ratio and phase-difference indicators and record these residual values of s_{21} [s_{12}] on the data sheet.

10.3.3 Determine the residual value of s_{12} [s_{21}] as follows:

10.3.3.1 Connect the system for the measurement of reverse [forward] characteristics (see Fig. 1).

10.3.3.2 With the ratio and phase-difference indicators still connected for the measurement of the transmitted signal, and with the through line still in the transistor socket, read the values of V_T/V_D and $(\phi_T-\phi_D)$ displayed on the ratio and phase-difference indicators and record these residual values of s_{12} [s_{21}] on the data sheet.

10.3.3.3 Remove the through line from the transistor socket.

10.3.4 Determine the residual value of s_{22} [s_{11}] as follows:

10.3.4.1 Insert the short circuit into the transistor socket.

10.3.4.2 With the system still connected for the measurement of reverse [forward] characteristics, connect the ratio and phase-difference indicators for measurement of the reflected signal.

10.3.4.3 Read the values of V_R/V_D and $(\phi_R-\phi_D)$ displayed on the ratio and phase-difference indicators and record these residual values of s_{22} [s_{11}] on the data sheet.

10.3.4.4 Remove the short circuit from the transistor socket and proceed with the transistor measurements unless the value of s_{22} [s_{11}] deviates from a magnitude of 1 and a phase of 180° by more than 5 % (0.4 dB) in magnitude or 3° in phase. If the deviation of s_{22} [s_{11}] exceeds these limits, verify system performance by one of the test methods specified in Annex A1 before proceeding.

10.4 Calibrate for the measurement of transmission coefficients when only transmission coefficients are to be measured. In this case, adjust the more critical of the transmission coefficients, here assumed to be s_{21}, to the correct response to a through line (that is, unity at 0°) and record the residual value of the other. If s_{12} is the more critical of the transmission parameters, the procedure should be reversed: adjust the value of s_{12} to unity at 0° with the through line in the transistor socket, and record the residual value of s_{21}. When s_{12} is the more critical transmission parameter, substitute the bracketed material in the procedure which follows in 10.4.1 and 10.4.2.

10.4.1 Adjust s_{21} [s_{12}] as follows:

10.4.1.1 Connect the system for the measurement of forward [reverse] characteristics (see Fig. 1).

10.4.1.2 Insert the through line (see 7.7.2) into the transistor socket.

10.4.1.3 Connect the ratio and phase-difference indicators for measurement of the transmitted signal.

10.4.1.4 Adjust the ratio and phase-difference indicators to read 1 (0 dB) and 0°, respectively.

10.4.1.5 Record these readings as the initial values of s_{21} [s_{12}] on a data sheet such as the one illustrated in Fig. 2.

10.4.2 Determine the residual value of s_{12} [s_{21}] as follows:

10.4.2.1 Connect the system for the measurement of reverse [forward] characteristics (see Fig. 1).

10.4.2.2 With the ratio and phase-difference indicators still connected for measurement of the transmitted signal, and with the through line still in the transistor socket, read the values of V_T/V_D and $(\phi_T-\phi_D)$ displayed on the ratio and phase-difference indicators and record these initial values of s_{12} [s_{21}] on the data sheet.

10.4.2.3 Remove the through line from the transistor socket and proceed with the transistor measurements unless the value of s_{12} [s_{21}] deviates from a magnitude of 1 and a phase of 0° by more than 5 % (0.4 dB) in magnitude or 3° in phase. If the deviation of s_{12} [s_{21}] exceeds these limits, verify system performance by one of the test methods specified in Annex A1 before proceeding.

10.5 Check the calibration at least once every 4 h. If the drift exceeds 2 % (0.2 dB) in magnitude or 0.5° in phase, recalibrate the system and halve the period between calibration checks.