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Interface Practices Subcommittee

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**Test Procedure for Measuring
Transmission and Reflection**

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1. Introduction

1.1. Executive Summary

This test procedure describes the techniques used to characterize radio frequency (RF) components and subsystems by measuring their transmission and reflection characteristics. The resulting measurements can be used to compare the performance of various devices as well as predict overall network performance when multiple devices are used together.

1.2. Scope

The purpose of this test procedure is to determine the reflection at any port, or the transmission between any two ports of a properly terminated device, as measured across a frequency range of interest. Depending on use of the data, return loss, insertion gain or loss, isolation, response variation or bandwidth can be derived.

This specification is designed for devices with a characteristic impedance of 75 ohms. However, these principles can easily be extended to devices of other characteristic impedances.

1.3. Benefits

This test procedure will yield accurate and consistent measurements of RF reflection and transmission characteristics for the device under test. Use of this test method provides the user a means to verify manufacturer published product specifications and certificates of compliance (when available).

1.4. Intended Audience

The intended audience for this test method, are manufacturers and end-users with proper laboratories and equipment to perform this test.

1.5. Areas for Further Investigation or to be Added in Future Versions

At this time, there are no considerations being given for further investigation.

2. Normative References

The following documents contain provisions which, through reference in this text, constitute provisions of this document. The editions indicated were valid at the time of subcommittee approval. All documents are subject to revision and, while parties to any agreement based on this document are encouraged to investigate the possibility of applying the most recent editions of the documents listed below, they are reminded that newer editions of those documents might not be compatible with the referenced version.

2.1. SCTE References

No normative references are applicable.

2.2. Standards from Other Organizations

No normative references are applicable.

2.3. Other Published Materials

No normative references are applicable.

3. Informative References

The following documents might provide valuable information to the reader but are not required when complying with this document.

3.1. SCTE References

[SCTE 96] ANSI/SCTE 96 Cable Telecommunications Testing Guidelines

3.2. Standards from Other Organizations

No informative references are applicable.

3.3. Other Published Materials

No informative references are applicable.

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5. Abbreviations and Definitions

5.1. Abbreviations

CW	continuous wave
dB	decibel
dBm	decibel milliwatt
dBmV	decibel millivolt

DUT	device under test
IL	insertion loss
ISO	isolation
RF	radio frequency
R/L	return loss

5.2. Definitions

Definitions of terms used in this document are provided in this section. Defined terms that have specific meanings are capitalized. When the capitalized term is used in this document, the term has the specific meaning as defined in this section.

bandwidth	1) The amount of spectrum, measured in units of hertz, that an electromagnetic signal significantly occupies. 2) The operating passband of a device or system, typically expressed in units of hertz.
flatness	The maximum peak to valley excursion of the transmission response over the specified bandwidth. The flatness can be derived numerically from the forward transmission data. Flatness is defined with respect to an ideal response. The ideal response could have no slope, could have linear slope, or could have inverse cable equivalent slope.
frequency response	The variation of the power amplitude of the gain or signal level at each frequency of the intended frequency range. Frequency response does not include slope or tilt.
insertion gain	Insertion gain is the ratio between the power level of a signal exiting a port of a device to the power level of a signal entering a port of a device. Note that a positive insertion gain means <i>more</i> signal power out than signal power in.
insertion loss	Insertion loss is the ratio between the power level of a signal entering a port of a device to the power level of a signal exiting a port of a device. A positive insertion loss means <i>less</i> signal power out than signal power in.
isolation	The insertion loss response through a secondary path of a device typically having a higher attenuation than the primary path. For example, the path through two outputs of a splitter or the output and the coupled tap port of a symmetrical directional coupler has greater loss than the primary path from input to output. In the case of an amplifier, the insertion loss response from output to input is the secondary path. The insertion loss response through this path is called reverse isolation.
return loss	The ratio of incident signal to reflected signal, expressed in dB. Return loss is a one-port measurement.
scattering parameters (S-parameters)	Voltage transmission coefficients and voltage transmission coefficients that can be used to characterize N-port networks (components, devices, etc.). S-parameters describe the electrical behavior of linear N-port networks when those networks undergo steady-state stimuli by electrical signals.
slope	A measure of the monotonic frequency response of the network from low to high frequency. Slope is positive, or upward going, if the gain increases as the response is swept from low frequency to high frequency. Note that slope does not include the small variations in

	amplitudes of the gain or loss of a device that are included in the frequency response. Slope could be flat (the same at all frequencies), linear (increasing or decreasing linearly across the frequency range) or cable equivalent (increasing or decreasing across the frequency range in a manner that matches the loss characteristics of coaxial cable).
tilt	The variation in level across the operating range of the network. Positive tilt is defined to occur if the signals at lower frequencies are lower in amplitude than those at higher frequencies. Note that tilt does not include the small variations in amplitudes of the signals that are included in the frequency response. Tilt could be flat (the same at all frequencies), linear (increasing or increasing linearly across the frequency range) or cable equivalent (increasing or decreasing across the frequency range in a manner that matches the loss characteristics of coaxial cable).

6. Discussion

Transmission and reflection measurements can provide much useful information about a device such as components, subsystems, passive devices and amplifiers. The measurements can be used to determine gain or loss, slope and flatness (frequency response). The measured results can be used to verify manufacturer published product specifications and certificates of compliance (when available). They can also be used to predict overall performance when the measured devices are incorporated into a subsystem or network.

It is recommended that measurements be made with a vector network analyzer. Vector network analyzers are capable of measuring both the magnitude and phase of the transmission and reflection characteristics of a device under test (DUT).¹

6.1. A Review of S-parameters

Vector network analyzers typically measure S-parameters. Scattering parameters or S-parameters are a way to characterize the steady state response of an N-port device to signals incident at any of the ports. S-parameters are always a ratio of two complex voltage quantities. S-parameter notation identifies these quantities using the numbering convention S_{xy} where x refers to the device port the signal is emerging from, and y refers to the device port where the signal is incident. For example, the s-parameter S_{21} identifies the measurement as the complex ratio of the voltage emerging at device port 2 to the incident voltage at device port 1.

Figure 1 and Table 1 show the relationship between voltages at the ports of a two port device and the s-parameters for that device. In the illustration, “a” represents the voltage entering the device and “b” represents the voltage emerging. Note that in general a and b are complex quantities. Note also that s-parameters may vary as a function of frequency.

¹ Manufacturers of vector network analyzers include Keysight Technologies (Agilent), Anritsu (Wiltron), Advantest, and Rhode & Schwarz.

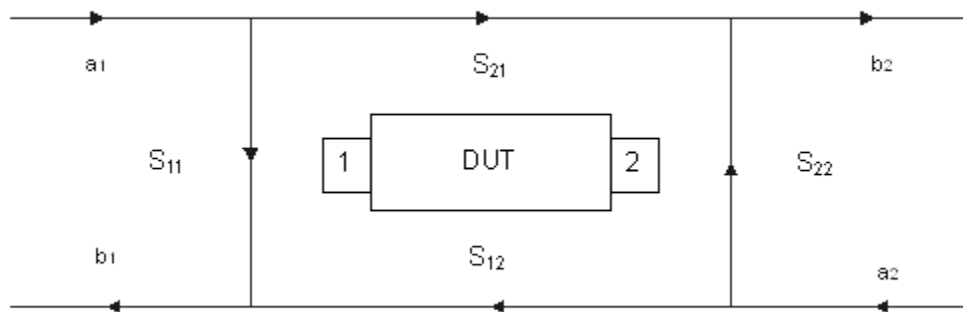


Figure 1 - S-Parameter Diagram For A 2-Port Device

Table 1 - Test Measurements To Characterize A 2-Port Device

S-Parameter	Definition	Description	Direction
S_{11}	b_1/a_1 $a_2=0$	Input Reflection	FWD
S_{21}	b_2/a_1 $a_2=0$	Forward Transmission	FWD
S_{12}	b_1/a_2 $a_1=0$	Reverse Transmission	REV
S_{22}	b_2/a_2 $a_1=0$	Output Reflection	REV

The concept of s-parameters can be extended to devices with more than two ports. This is described in Appendix A and Appendix B.

6.1.1. Transmission

S-parameters can be used to describe the forward and reverse characteristics of a device. Note that most devices are specified using the magnitude of the transmission characteristics in units of decibels. These transmission characteristics can be determined from the S-parameters using the relationships

$$\text{Forward Transmission(dB)} = 20 \text{ Log}_{10}(|S_{21}|)$$

$$\text{Reverse Transmission(dB)} = 20 \text{ Log}_{10}(|S_{12}|)$$

Note that in general S_{21} and S_{12} are complex quantities, hence the magnitude of S_{21} , $|S_{21}|$, and the magnitude of S_{12} , $|S_{12}|$.

Appendix C contains several examples of gain measurements for devices with various gain and slope tolerances. These examples illustrate trade-offs between the measured gain, slope, and frequency response. Such trade-offs may be necessary to ensure that an equitable compromise has been reached to make sure that all parameters are within their specified tolerances. Note that in general this is not as simple as defining slope by fitting to the measured transmission values at the frequency endpoints. A best trade-off typically requires iterative adjustment of gain and slope tolerances until a best compromise is reached.