

SEMI E114-0302^E

TEST METHOD FOR RF CABLE ASSEMBLIES USED IN SEMICONDUCTOR PROCESSING EQUIPMENT RF POWER DELIVERY SYSTEMS

This test method was technically approved by the Global Metrics Committee and is the direct responsibility of the North American Metrics Committee. Current edition approved by the North American Regional Standards Committee on March 20, 2002. Initially available at www.semi.org June 2002; to be published July 2002.

^E This document was editorially modified in May 2002. A change was made to Section 1.1.

1 Purpose

1.1 The purpose of this document is to define a test method used to determine the electrical length, power losses, and characteristic impedance variation of RF cable assemblies used in RF power delivery systems for semiconductor processing equipment.

2 Scope

2.1 This document specifies the testing procedures and test equipment required for the following:

- Determining the electrical length of RF cable assemblies at the nominal operating frequency in terms of degrees of phase shift.
- Determining the power dissipation (loss) in the RF cable assembly at the nominal operating frequency.
- Verifying the characteristic impedance of the RF cable assembly.

2.2 The primary focus for this specification is semiconductor processing equipment including, but not limited to, the following tool types:

- Dry etch equipment,
- Film deposition equipment (CVD and PVD).

2.3 This standard does not address any safety or performance issues related to RF emissions or electrical codes (e.g., Underwriter's Laboratory, Inc. (UL), the National Electrical Code (NEC[®]), Federal Communications Commission (FCC)). It is the responsibility of the users of this standard to conform to the appropriate local codes and regulations as applied to this type of equipment, some of which are covered by referenced documents.

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

3 Limitations

3.1 This standard is meant to address RF Cable Assemblies used in RF systems that primarily operate in the frequency range of 0.2–100 MHz. It does not address higher frequency RF systems or microwave systems.

3.2 This standard assumes that the cable assemblies to be tested have a nominal characteristic impedance of 50 ohms. This standard can be used with cable assemblies with a different characteristic impedance if the appropriate standard termination loads are used.

3.3 International, national, and local codes, regulations and laws should be consulted to ensure that the equipment and procedures meet regulatory requirements in each location.

4 Referenced Standards

4.1 SEMI Standards

SEMI E113 — Specification for Semiconductor Processing Equipment RF Power Delivery Systems

4.2 IEEE Standards¹

IEEE-STD-383 — IEEE Standard for Type Test of Class 1E Electrical Cables, Field Splices, and Connections for Nuclear Power Generating Stations

4.3 Military Standards²

MIL-C-17G — General Specification for Cables, Radio Frequency, Flexible and Semirigid

MIL-PRF-39012D — General Specification for Connectors, Coaxial, Radio Frequency

¹ Institute of Electrical and Electronics Engineers, IEEE Operations Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, New Jersey 08855-1331, USA. Telephone: 732.981.0060; Fax: 732.981.1721

² Available through the Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120-5099, USA. Telephone: 215.697.3321

5 Terminology

5.1 Abbreviations and Acronyms

5.1.1 CVD — Chemical Vapor Deposition

5.1.2 PVD — Physical Vapor Deposition

5.1.3 VSWR — Voltage Standing Wave Ratio

5.2 Definitions of Terms

5.2.1 *cable assembly* — the section of cable (transmission line), including the connectors, used to connect various parts of the RF power delivery system.

5.2.2 *device under test (DUT)* — the cable assembly intended to be tested.

5.2.3 *electrical length* — the length of the cable assembly at the operating frequency expressed in terms of degrees, where one wavelength at the nominal operating frequency is equal to 360 degrees.

5.2.4 *half wave resonant frequency* — the frequency of the cable assembly where the electrical length of the assembly is equal to one half (0.5) of a wavelength. For example, the half wave resonant frequency of a cable assembly with an electrical length of 2 meters would be 74.95 MHz ($(c/2\text{-meters})/2$).

5.2.5 *harmonic frequency* — the harmonic frequencies are defined as integer multiples of the fundamental frequency. For example, the second harmonic of 13.56 MHz is 27.12 MHz.

5.2.6 *quarter wavelength* — the length equal to one quarter of the wavelength at a given frequency, where the wavelength is equal to the speed of light divided by the frequency.

5.2.7 *S-parameters* — the scattering matrix used to describe a network. The reflection coefficient is the S11 parameter and the transmission coefficient is the S21 parameter.

5.2.8 *speed of light (c)* — the speed of light in free-space is assumed to be 2.9979×10^8 meters/second.

5.2.9 *velocity of propagation (VP)* — the velocity of propagation, VP, is defined as the ratio of the speed of an electrical signal down a length of cable divided by the speed in free space. It is the reciprocal of the square root of the relative dielectric constant of the dielectric material between the inner and outer conductor of a coaxial assembly. For example, the VP for cable type RG-217 is nominally 0.66.

6 Test Apparatus

6.1 *RF Vector Network Analyzer* — The network analyzer is used to measure the electrical length and can also be used to determine the attenuation (power

losses). The network analyzer requires vector capability so that both the magnitude and phase of the reflection coefficient and transmission coefficient can be measured as a function of frequency. The frequency range shall include the operating frequency and the quarter-wave resonant frequency of the RF cable assembly.

6.2 *Time Domain Reflectometer (TDR)* — The TDR is used to measure and verify the characteristic impedance as a function of distance along the transmission line.

6.3 *RF Adapters and Terminations* — Various adapters may be necessary to convert between different types of coaxial connectors (e.g., type N to type HN adapters, etc.). All adapters used shall have the same nominal characteristic impedance as the cable assembly to be tested (DUT), which is typically 50 ohms. For some measurements, additional coaxial cable assemblies may be necessary. These cable assemblies, which should not be confused with the DUT cable assembly, shall be of the same nominal characteristic impedance as the DUT cable assembly. Standard terminations will also be used, such as shorts, opens, and precision 50-ohm loads.

7 Safety Precautions

7.1 Work should be conducted in accordance with local safety requirements and test device manufacturer recommended safety procedures. The tests described in this document involve using low output power test instrumentation (typically less than 10 milli-Watt).

7.2 The area immediately surrounding the Test Setup should be kept free and clear of unnecessary equipment and materials. Some of the cable assemblies to be tested may be long and can be trip and lift/weight hazards.

8 Test Setup for Electrical Length Test

8.1 The Test Setup for the electrical length test consists of the Network Analyzer, the cable assembly to be tested (DUT), the appropriate adapter (if any) to connect the DUT to the network analyzer, and the appropriate adapter (if any) to connect a coaxial short circuit termination to the output of the DUT. A schematic of the Test Setup is shown in Figure 1. Care should be taken to ensure that the cable assemblies to be tested do not exceed the vendor specified bending radius, which is typically 5 times the outer diameter of the cable.

8.2 Prior to making any measurements, the Network Analyzer shall be turned on and allowed to warm up before the testing is to take place. This time allows for electronics to come to a stable operating condition for the measurements.

9 Test Procedure for Determining Electrical Length

9.1 Two test procedures can be used to determine the electrical length of a cable assembly. One method measures it directly at the operating frequency and the other measures the half-wave resonant frequency to determine the electrical length. Each method has advantages, depending on the length of the cable assembly. Prior to choosing a method, the equivalent free-space length of the DUT shall be estimated in units of distance (i.e., meters). This length can be estimated by dividing the physical length of the DUT by the velocity of propagation for the particular type of cable. For example, a DUT made from RG-217 cable with a physical length of 20 meters and a velocity of propagation of 0.66 would have an equivalent free-space length of 30.303 meters ($20/0.66 = 30.303$). A flow chart showing the steps for choosing which test method to use is shown in Figure 2.

9.2 The equivalent free-space length of the DUT shall be compared with the wavelength of the nominal operating frequency. Test Method 1 (Section 9.3) shall be used if the equivalent free-space length is less than a quarter wavelength of the nominal operating frequency. Test Method 2 shall be used if it is equal to or greater than a quarter wavelength of the nominal operating frequency. For example, if the estimated free-space length is 3 meters and the nominal operating frequency is 13.56 MHz (quarter wavelength = $0.25 \times c/13.56 \times 10^6 = 5.527$ meters), then Test Method 1 is recommended. If the estimated free-space length is 25 meters, then Test Method 2 is recommended.

9.3 Test Method 1 for Determining Electrical Length

9.3.1 This test method measures the phase angle of the reflection coefficient at the nominal operating frequency of the DUT when the DUT is terminated by a short circuit.

9.3.2 Calibrate the Network Analyzer at the desired operating frequency (e.g., 13.56 MHz). If adapters are to be used to connect the DUT to the Network Analyzer and/or to the short circuit termination, then the calibration shall be made with the adapters in place. The Network Analyzer shall be calibrated for measuring the reflection coefficient at test Port 1 (see Figure 1) using the calibration kit provided with the Network Analyzer. This measurement is equivalent to measuring the S11 S-parameter. The calibration shall be performed at fixed frequency (continuous-wave operation) using the lowest bandwidth possible (typically 10 Hz).

9.3.3 After calibration, the cable assembly to be tested (DUT) shall be attached to Port 1 on the Network Analyzer. The other end of the DUT shall be

terminated with a short circuit. After all connections have been visually inspected to ensure proper contact and the Network Analyzer measurement has stabilized, the value of the reflection coefficient phase angle shall be recorded.

9.3.4 If the indicated phase angle of the reflection coefficient is positive, then the electrical length of the DUT is equal to one half of the value of the difference between 180 and the measured phase angle. For example, if the measure reflection coefficient phase angle is 120 degrees, then the electrical length is 30 degrees $((180-120)/2)$.

9.3.5 If the indicated phase angle of the reflection coefficient is negative, then the electrical length of the DUT is greater than a quarter wavelength. For this case, the electrical length is equal to one half of the absolute value of the measured value of the reflection coefficient phase angle plus 90. For example, if the measure reflection coefficient phase angle is -10 degrees, then the electrical length is 95 degrees $(90 + 10/2)$.

9.4 Test Method 2 for Determining Electrical Length

9.4.1 This test method determines the electrical length of the cable assembly DUT by measuring the half wave resonant frequency when the DUT is terminated by a short circuit. For this measurement, the frequency of the network analyzer is swept. The frequency range of the sweep is determined from the estimated free-space length of the DUT.

9.4.2 Estimate the half wave resonant frequency of the DUT. This frequency is equal to one half of the ratio of the speed of light divided by the estimated free space length determined in Section 9.2. For example, if the estimated free space length of the DUT is 25 meters, then the estimated half wave resonant frequency is 5.996 MHz $(0.5 \times c/25)$.

9.4.3 Calibrate the Network Analyzer. If adapters are to be used to connect the DUT to the Network Analyzer and/or to the short circuit termination, then the calibration shall be made with the adapters in place. The center frequency of the frequency sweep shall be at the estimated half wave resonant frequency calculated in Section 9.4.2, and the frequency span of the sweep shall be no greater than 10% of the estimated frequency. For example, if the estimated half wave resonant frequency is 6.0 MHz, then the frequency span shall be no greater than 0.6 MHz. The Network Analyzer shall be calibrated for measuring the reflection coefficient at test Port 1 (see Figure 1) using the calibration kit provided with the Network Analyzer. This measurement is equivalent to measuring the S11 S-parameter. The calibration shall be performed using the lowest bandwidth possible (typically 10 Hz).