

SEMI E135-0918

TEST METHOD FOR RF GENERATORS TO DETERMINE TRANSIENT RESPONSE FOR RF POWER DELIVERY SYSTEMS USED IN SEMICONDUCTOR PROCESSING EQUIPMENT

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NOTICE: This Document was completely rewritten in 2018.

1 Purpose

1.1 The purpose of this Document is to define a test method used to determine the transient response for a radio frequency (RF) generator used in RF power delivery systems for semiconductor processing equipment to support SEMI E113.

2 Scope

2.1 This Document specifies the testing procedures and test equipment required for determining the transient response of an RF generator resulting from a requested change in output power. The response is determined for the RF generator operating into a nominal, high- and low-impedance load.

NOTE 1: The intention of testing into a high- and low-impedance load is to simulate plasma ignition conditions. The requested change in output power can be a change in set point, a request to turn RF on or off, a change in a repetitive power pattern (e.g., changing a power level in a multilevel pulse waveform), or any other requested change that results in a change in output power.

2.2 This Standard is applicable to RF generators that are designed to deliver power to 50- Ω as well as non-50 Ω -loads.

2.3 The primary focus for this Document is semiconductor processing equipment including, but not limited to, the following equipment types:

- Dry etch equipment,
- Film deposition equipment (chemical vapor deposition [CVD] and physical vapor deposition [PVD]).

NOTICE: SEMI Standards and Safety Guidelines do not purport to address all safety issues associated with their use. It is the responsibility of the users of the Documents to establish appropriate safety and health practices, and determine the applicability of regulatory or other limitations prior to use.

3 Limitations

3.1 This Standard addresses RF generators used in RF systems that primarily operate in the frequency range of 0.2 to 100 MHz. It does not address higher frequency RF systems or microwave systems.

4 Referenced Standards and Documents

4.1 *SEMI Standards and Safety Guidelines*

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

NOTICE: Unless otherwise indicated, all documents cited shall be the latest published versions.

5 Terminology

5.1 *Abbreviations and Acronyms*

5.1.1 *AC* — alternating current

5.1.2 *CVD* — chemical vapor deposition

5.1.3 *CW* — continuous wave

- 5.1.4 *DC* — direct current
- 5.1.5 *DUT* — device under test
- 5.1.6 *IEEE* — Institute of Electrical and Electronics Engineers
- 5.1.7 *MIL* — United States Military Standards
- 5.1.8 *NIST* — National Institute of Standards and Technology
- 5.1.9 *PVD* — physical vapor deposition
- 5.1.10 *RF* — radio frequency
- 5.1.11 *VSWR* — voltage standing wave ratio

5.2 Definitions

- 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. [SEMI E113]
- 5.2.2 *device under test (DUT)* — the RF generator to be tested.
- 5.2.3 *high-impedance load* — an impedance with a load-reflection coefficient calculated with respect to the nominal generator load impedance having a magnitude greater than 0.95 and an angle between -10° and 10° .
- 5.2.4 *low-impedance load* — an impedance with a load reflection coefficient calculated with respect to the nominal RF generator load impedance having a magnitude greater than 0.95 and an angle between 170° and 190° .
- 5.2.5 *load impedance* — the load impedance is the impedance to which an RF generator is attached.
- 5.2.6 *nominal generator load impedance* — the impedance into which the RF generator is designed to deliver power.

NOTE 2: For most generators, this impedance is 50 Ω and the RF generator is expected to deliver full power into this load and less power as the load-reflection-coefficient magnitude of a load calculated with respect to this impedance increases. This impedance is typically also the impedance with respect to which forward and reflected power is calculated.

- 5.2.7 *transient response* — (1) a change in the steady-state of a parameter. (2) that part of a change in a variable, such as current, voltage, or speed which may be initiated by a change in steady-state conditions or an outside influence that decays or disappears following its appearance. [SEMI E151]

5.3 Symbols

- 5.3.1 *dB* — decibels
- 5.3.2 Ω — ohm

6 Test Apparatus

- 6.1 *Digital Oscilloscope* — The digital oscilloscope is used to measure the requested change in output power and the RF power output signal.

- 6.1.1 The digital oscilloscope shall have a digitization rate of at least 500 megasamples per second per channel.
- 6.1.2 The digital oscilloscope shall have an up-to-date calibration per the manufacturer's recommended method and time cycle.

- 6.2 *RF Rectifier/Diode Detector* — An RF rectifier/diode detector is a device that converts an RF signal into a direct current (DC) signal that is used to measure a signal related to the output power of the RF generator. The input RF signal is produced by the RF signal sampler. The output DC signal goes to the digital oscilloscope. The use of a rectifier/diode detector is optional since the signal from the RF signal sampler can be sampled by the oscilloscope and the envelope of the RF extracted directly from the sampled signal.

- 6.3 *RF Signal Sampler* — An RF signal sampler is a device that produces a reduced-level RF signal proportional to RF voltage, current, or a linear combination of voltage and current. Using the forward component of a directional coupler is preferred since the forward component does not vanish into high voltage standing wave ratio (VSWR) loads (e.g., current vanishes into an open circuit, voltage into a short circuit, or reflected component into a matched load). The reduced-level signal produced by the sampler is typically -40 to -50 dB below the RF signal being detected.

6.4 Analog Signal Generator — An analog signal generator is a device that will produce the necessary analog signals to cause a requested change in output power. This analog signal generator is not necessary if communication with the RF generator is through digital means.

6.5 Digital Communications Generator — A digital communications generator is the equipment necessary to digitally communicate with the RF generator. This digital communications generator is not necessary if communication with the RF generator is through analog means.

6.6 Digital Communications Monitor — If communication to the RF generator is through digital means, a means shall be provided to monitor the digital communications to determine when a command to request a change in output power has been sent. This monitor can be as simple as a means to access a signal in a digital communications channel so it can be captured on the digital oscilloscope and as complex as dedicated hardware and software to monitor the communication to the RF generator and provide a signal on which the digital oscilloscope can be triggered.

6.6.1 If the digital communications monitor introduces any uncertainty about the timing of digital commands, this uncertainty shall be documented.

6.7 RF Power Meter — An RF power meter is a device that will measure the output power of the RF generator that is used.

6.7.1 For 50- Ω systems, it shall have an absolute power accuracy (traceable to National Measurement Institutes such as the National Institute of Standards and Technology [NIST] or equivalent) of $\pm 3\%$ when measuring power delivered to a 50- Ω load.

6.8 RF Cables, Adapters, and Terminations — Various adapters may be necessary to convert between different types of coaxial connectors (e.g., type N to type HN adapters). All adapters used shall have appropriate impedance, power, voltage, and current ratings at the operating frequency of the RF generator. Typically connectors, cables, and adaptors are coaxial connectors designed for 50- Ω systems. For some measurements, additional coaxial cable assemblies are used. These cable assemblies also shall have appropriate characteristics; typically using 50- Ω coaxial cables, connectors, adaptors, and terminations.

6.9 High-Power RF Dummy Load — A high-power RF dummy load is used to absorb the power produced by the RF generator. The RF dummy load shall have a power-handling capability that is compatible with the RF generator being tested.

6.10 Matched Load Simulator — A matched load simulator is a device that transforms the impedance of the high-power RF dummy load to the nominal RF generator load impedance at the RF generator output connector at the RF generator output frequency when all of the other test equipment is connected as required to perform the test.

6.10.1 If the nominal RF generator load impedance is the same as the impedance of the high-power RF dummy load, the matched load simulator may not be required.

6.11 Mismatched Load Simulator — A mismatched load simulator is a variable load or two fixed loads that can create a high-impedance and a low-impedance load.

6.11.1 The high-impedance load creates a load at the RF generator output connector and at the RF generator output frequency that has a load reflection coefficient calculated with respect the nominal RF generator load impedance having a magnitude greater than 0.95 and an angle between -10° and 10° when all test equipment (e.g., RF signal sampler, cables, and connectors) is installed as is necessary to conduct the test.

NOTE 3: The objective is to measure a magnitude of at least 0.95. Typical uncertainty for network analyzers into this load is a circular uncertainty of 0.03 so that the actual load reflection coefficient magnitude is at least 0.92 and since 0.98 is readily achievable a measurement of 0.95 is readily achievable. For a nominal load impedance of 50 Ω , a load reflection coefficient of 0.92 and angle between -10° and 10° ensures that the magnitude of the impedance is larger than 500 Ω .

6.11.2 The low-impedance load creates a load at the RF generator output connector and at the RF generator output frequency that has a load-reflection coefficient calculated with respect to the nominal RF generator load impedance having a magnitude greater than 0.95 and an angle between 170° and 190° when all test equipment (e.g., RF signal sampler, cables, and connectors) is installed as is necessary to conduct the test.

NOTE 4: The objective is to measure a magnitude of at least 0.95. Typical uncertainty for network analyzers into this load is a circular uncertainty of 0.03 so that the actual load reflection coefficient magnitude is at least 0.92 and since 0.98 is readily

achievable a measurement of 0.95 is readily achievable. For a nominal load impedance of $50\ \Omega$, a load reflection coefficient of 0.92 and angle between 170° and 190° ensures that the magnitude of the impedance is less than $5\ \Omega$.

6.11.3 The load(s) shall have power-, voltage-, and current-handling capabilities compatible with the RF generator being tested.

6.12 *Network Analyzer* — A network analyzer is required to verify that the load and mismatched load simulator(s) provide the requisite impedance at the RF generator output (i.e., at the RF generator output connector and at the RF generator output frequency).

6.13 *Computer Equipment* — Computer equipment may be used to communicate to the RF generator (i.e., device under test [DUT]) and equipment used in the test as well as to capture and process captured data.

7 Safety Precautions

7.1 Work should be conducted in accordance with local safety requirements and test device manufacturer recommended safety procedures.

7.2 The area immediately surrounding the test setup shall be kept free and clear of unnecessary equipment and materials.

8 Test Setup

8.1 The test setup for measuring the transient response of the RF generator (i.e., the DUT) consists of the equipment necessary to request a change in RF generator output power (i.e., analog signal generator(s) and/or digital communications generator), digital communications monitor (if required), a digital oscilloscope, the DUT itself, an RF signal sampler, an RF rectifier/diode detector (if used), an RF power meter, a high-power dummy load, matched load simulator (if needed), and mismatched load simulator(s). An example schematic of the test setup is shown in Figure 1. In Figure 1, (a) shows verification of the nominal load, (b) shows verification of the mismatched loads, (c) shows the setup for measurement of the transient response(s) into a nominal load, and (d) shows the setup for measurement of the transient response(s) into the mismatched loads.

8.2 Prior to performing any measurements, use the network analyzer to verify that the impedance provided by the high-power dummy load to the DUT at the DUT output connector at the DUT output frequency:

8.2.1 Differs from the ‘nominal generator load impedance’ by less than 0.1 in terms of the load reflection coefficient magnitude calculated with respect to the ‘nominal generator load impedance’ (i.e., $-20\ \text{dB}$ return loss) and

8.2.2 That the impedance provided by the mismatched load simulator(s) meets the requirements of § 6.11.

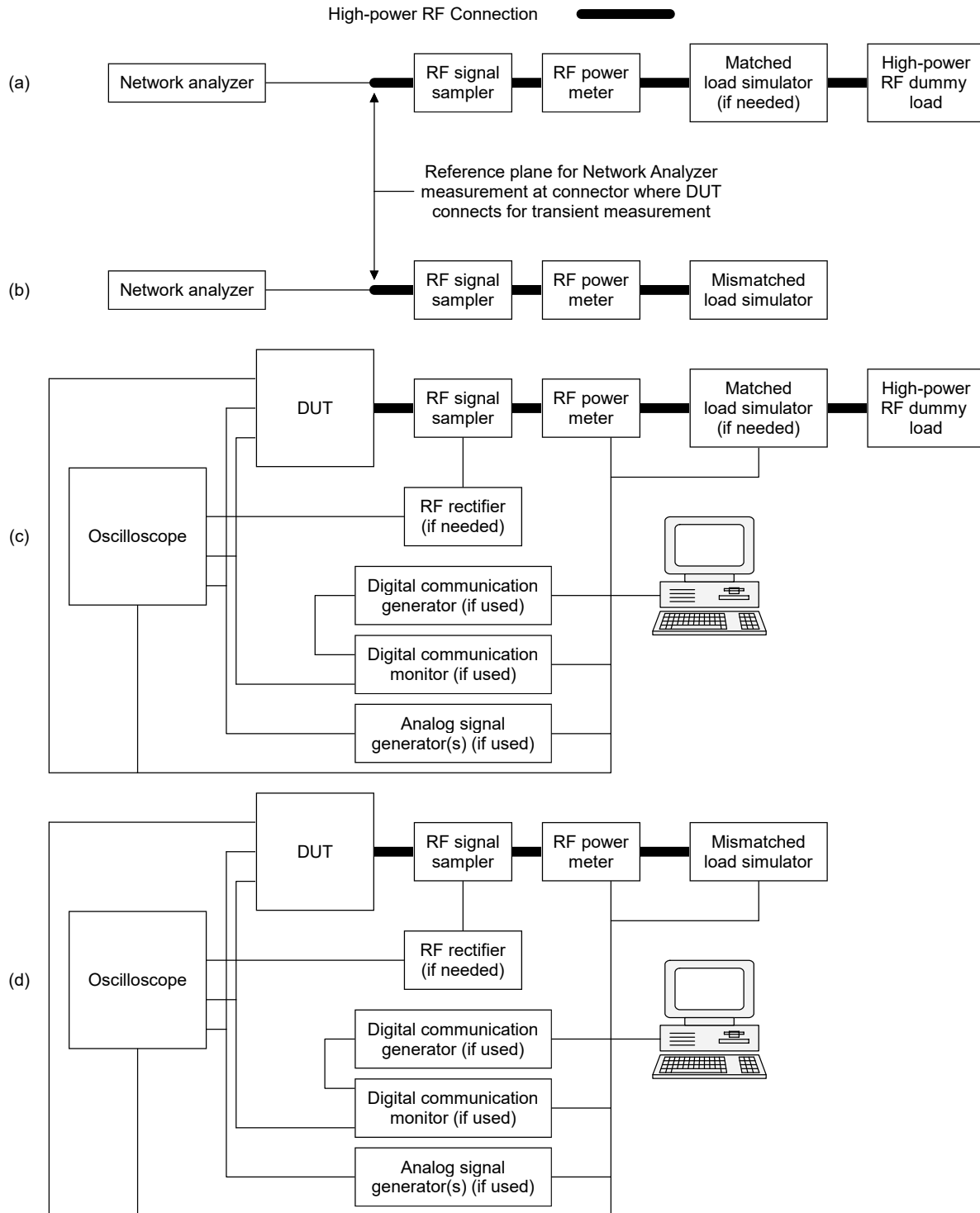


Figure 1
Schematic of the Test Setup for Measuring the Transient Response of the
RF Generator (DUT) Resulting from a Requested Change in Output Power

9 Test Procedure

9.1 The test procedure described below records the transient response of a DUT resulting from a requested change in output power.

9.1.1 Connect the RF signal sampler, RF power meter, matched load simulator (if used), and high-power RF dummy load as shown in Figure 1 (a).

NOTE 5: It is important that the connections are made in exactly the same way for performing the network analyzer load verification and for performing the actual test. One should be able to disconnect the network analyzer cable with adaptors as described in ¶ 9.1.14 and replace it with the DUT without any other changes to the setup.

9.1.1.1 If any coaxial cable assemblies or adapters are used to make any of the connections between the output of the DUT and the high-power RF dummy load, they shall have voltage, current, and power-handling capability that is consistent with the maximum output voltage, current, and power of the DUT.

9.1.2 Prior to making any measurements, the digital oscilloscope and other electronic test equipment shall be turned on and allowed to warm up per the manufacturer's guidelines before the testing is to take place. This time will allow for electronics to come to a stable operating condition for the measurements.

9.1.3 Calibrate the network analyzer over the frequency range where the DUT will be tested using the manufacturer's calibration procedure.

9.1.4 Connect adaptors to the network analyzer cable so that the final connector is the same type as the DUT output connector.

9.1.5 Set up the network analyzer so that the measurement reference plane is at the reference plane of the output connector (see Figure 1 (a) and (b)).

9.1.5.1 If no reference plane is defined for the particular connector, set up the network analyzer so that an open circuit is measured with the connector open.

9.1.6 Verify that the load presented to the DUT is within the requirements of § 8.2.

9.1.7 Replace the matched load simulator (if used) and high-power RF dummy load with the mismatched load simulator(s).

9.1.8 Verify that the high- and low-impedance loads presented to the DUT meet the requirements of § 6.11.

9.1.9 Connect the analog signal generator(s), digital communications generator, and digital communications monitor as needed as shown in Figure 1 (c).

9.1.10 Connect the DUT to the matched load verified in ¶ 9.1.6.

9.1.11 Connect the reduced-level signal output of the RF signal sampler to the input of the RF rectifier/diode detector (if used) or directly to the oscilloscope.

9.1.12 Connect the output of the digital communications monitor (if used) and the output of the RF rectifier/diode detector (if used) to the input channels of the digital oscilloscope.

9.1.13 If analog signals are used to request the change in output power, route these signals to the DUT via a T-connection at the oscilloscope and use a high-impedance input on the oscilloscope.

9.1.13.1 Take care to keep the connection from the T-connection to the oscilloscope short to avoid loading the connection with the stub line.

9.1.13.2 Inspect all connections of the test setup to ensure proper contact.

9.1.13.3 Ensure that the oscilloscope terminations are appropriate (e.g., high impedance or 50 Ω , alternating current [AC] or DC coupled, appropriate filter bandwidth).

9.1.14 Run the DUT in continuous wave (CW) mode over the range of power levels and frequencies over which subsequent tests are to be performed and calibrate the output of the rectifier/detector diode or extracted RF envelope against delivered or forward power as measured by the power meter.

9.1.14.1 The number of calibration points shall be sufficient to convert the level measured on the oscilloscope to the power meter power with an error of less than 3%.

9.1.15 Perform the requested change in output power.

9.1.15.1 The requested change in output power can be a change in set point, a request to turn RF on or off, a change in a repetitive power pattern (e.g., changing a power level in a multilevel pulse waveform), or any other requested change that results in a change in output power.

9.1.15.2 At a minimum, determine the response to a request to turn RF on and RF off in CW mode with set points of 10%, 20%, 50%, and 100% of the DUT's power delivery capability into the particular load into which the generator is being tested.

9.1.15.3 At a minimum, determine the response to a change in power set point between the following power levels (expressed as a percentage of the DUT's power delivery capability into the particular load into which the generator is being tested). Use forward power calculated with respect to a reference impedance (e.g., 50 Ω) for the high- and low-impedance loads using a directional coupler (see ¶ 9.1.18).

9.1.15.3.1 10% and 20%,

9.1.15.3.2 10% and 50%,

9.1.15.3.3 10% and 100%,

9.1.15.3.4 20% and 50%,

9.1.15.3.5 20% and 100%, and

9.1.15.3.6 50% and 100%.

9.1.16 Adjust the oscilloscope triggering and time base so that the requested change in output power and the resulting transient response of the DUT are captured.

9.1.16.1 The transient response shall be captured until the RF output has stabilized at the new level.

9.1.17 Repeat the test defined in § 9.1.16 at least 31 times and record the transient response each time.

9.1.18 Once all of the tests on the matched load are completed, change to the previously verified low- and high-impedance loads.

9.1.19 Calibrate the output of the rectifier/detector diode or extracted RF envelope against forward power as measured by the power meter as in § 9.1.14.

9.1.20 Repeat the test at least 31 times and record the transient response into the high- and low-impedance loads each time (see Figure 1 (d)).

9.1.21 For repetitive waveforms, extract and process the data for each section of the repetitive waveform separately.

9.1.21.1 In this case, the time vs. power data is a series of points (i.e., time, power) sampled in time at the repetition rate of the repetitive waveform. The time for each section can be the mean, start, stop, or other specified time for the section and the power can be the minimum, maximum, mean, or other specified measure of power for that particular section. An example of how data for each section is separated from the captured data is shown in Figure 2.

9.1.22 Record at least one representative transient response in graphical form.

9.1.23 Extract and record the mean and standard deviation of the following five parameters from the data (see Figure 3).

9.1.23.1 *Delay* — Time from completion of requested change in output power to 10% of change in power completed.

9.1.23.2 *Rise Time* — Time from 10% to 90% of change in power.

9.1.23.3 *Settling Time* — Time from when 10% of change in power is completed to where power remains within 10% of final value.

9.1.23.4 *Overshoot* — Maximum overshoot as a decimal fraction of the requested change in power.

9.1.23.5 *Undershoot* — Maximum undershoot as a decimal fraction of the requested change in power.