

SEMI E113-0724

SPECIFICATION FOR RF POWER-DELIVERY SYSTEMS USED IN SEMICONDUCTOR PROCESSING EQUIPMENT

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NOTICE: The section symbol (§) is used to reference a numbered section, paragraph, or header and all subordinate paragraphs, headers, and embedded material (i.e., EXCEPTIONs, lists) therein. The paragraph symbol (§) is used to reference a particular numbered paragraph and embedded material therein. When duplicated (i.e., §§ and §§) the symbols are used to reference more than one section or paragraph, respectively.

NOTICE: Paragraphs entitled ‘NOTE:’ are not an official part of this Standard or Safety Guideline and are not intended to modify or supersede the official Standard or Safety Guideline. These have been supplied by the global technical committee to enhance the usage of the Standard or Safety Guideline.

NOTICE: This Document was completely rewritten in 2024.

1 Purpose

1.1 It is the intent of this Standard to provide radio frequency (RF) power-delivery system specifications for semiconductor processing equipment that leads to improved system and subsystem performance. It outlines performance criteria as well as required documentation to be supplied with the RF power-delivery systems or subsystem components. The goal of the Standard is to provide the specifications needed to produce a well-characterized RF power-delivery system, where stability, repeatability, and important electrical parameters such as delivered power, current/voltage, and the impedance of the system can be determined within the operating space.

2 Scope

2.1 This Standard specifies the minimum performance criteria for RF power-delivery systems used in the semiconductor industry. It does not address specific test methods or procedures for performance verification.

2.2 The primary focus for this Standard is an RF power-delivery system that is incorporated into semiconductor processing equipment including, but not limited to, the following equipment types:

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

2.3 This Standard applies to semiconductor processing equipment RF power-delivery systems whose power is directly used to produce and sustain the plasma or is electrically connected to the plasma (i.e., bias power).

2.4 Although the primary focus of this Standard is RF power-delivery systems used in the semiconductor processing equipment, this Standard can be applied to RF power deliver systems used in similar processing equipment for other high-tech industries (e.g., flat panel display [FPD], high-brightness light emitting diode [HB-LED], microelectromechanical systems/nanoelectromechanical systems [MEMS/NEMS]).

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 power-delivery systems that primarily operate in the frequency range of 0.2 to 100 MHz. It does not address higher frequency RF power-delivery systems or microwave systems.

3.2 This Standard does not address any performance issues of semiconductor processing equipment related to electromagnetic emissions and interference caused by the RF power-delivery systems. Refer to SEMI E33 for more information on semiconductor manufacturing equipment electromagnetic compatibility.

4 Referenced Standards and Documents

4.1 SEMI Standards and Safety Guidelines

SEMI E10 — Specification for Definition and Measurement of Equipment Reliability, Availability, and Maintainability (RAM) and Utilization

SEMI E33 — Guide for Semiconductor Manufacturing Equipment Electromagnetic Compatibility (EMC)

SEMI E89 — Guide for Measurement System Analysis (MSA)

SEMI E114 — Test Method for RF Cable Assemblies Used in Semiconductor Processing Equipment RF Power Delivery Systems

SEMI E115 — Test Method for Determining the Load Impedance and Efficiency of Matching Networks Used in Semiconductor Processing Equipment RF Power Delivery Systems

SEMI E135 — Test Method for RF Generators to Determine Transient Response for RF Power Delivery Systems used in Semiconductor Processing Equipment

SEMI E136 — Test Method for Determining the Output Power of RF Generators Used in Semiconductor Processing Equipment RF Power Delivery Systems

SEMI E143 — Test Method for Measuring Power Variation into a 50 Ω Load and Power Variation and Spectrum into a Load with a VSWR of 2.0 at Any Phase Angle

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 United States Military Standards²

MIL-DTL-17 — General Specification for Cables, Radio Frequency, Flexible and Semi Rigid

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

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

5 Terminology

5.1 Abbreviations and Acronyms

5.1.1 *MNUT* — matching network under the test

5.1.2 *RF* — radio frequency

5.1.3 *VSWR* — voltage standing wave ratio

5.2 Definitions

5.2.1 *electrical length* — the length of an electrical conductor in terms of the phase shift introduced by transmission over that conductor at the operating frequency expressed in terms of degrees, where one wavelength at the nominal operating frequency is equal to 360°.

5.2.2 *harmonic frequency* — the harmonic frequencies are defined as integer multiples of the fundamental frequency.

NOTE 1: For example, the second harmonic of 13.56 MHz is 27.12 MHz.

5.2.3 *matched load* — a load that has a reflection coefficient not greater than 0.032 at any phase angle.

NOTE 2: For example, a matched load for a 50 Ω system has impedance in a magnitude of $50 \pm 3.3 \Omega$.

¹ Institute of Electrical and Electronics Engineers, 3 Park Avenue, 17th Floor, New York, NY 10016-5997, USA; Telephone: +1.212.419.7900, Fax: +1.212.752.4929, <http://www.ieee.org>. IEEE trademark is owned by The Institute of Electrical and Electronics Engineers, Inc.

² United States Military Standards, available as freely downloadable PDF files from the ASSIST Quick Search website at <http://quicksearch.dla.mil>.

5.2.4 *matching network* — the device used to transform the impedance of the load (chamber/chuck) to match the impedance of the generator/cable assembly, which is typically 50 Ω .

5.2.5 *power efficiency* — the power efficiency of a matching network is defined as the power exiting the network (output power) divided by the power entering the network (input power).

5.2.6 *process equipment manufacturer* — the manufacturer of process equipment who integrates the RF delivery system to the process equipment.

5.2.7 *RF cable assembly* — the transmission line between the generator and the matching network. RF cable assembly includes the connector assemblies that terminate the RF power cable.

5.2.8 *RF power-delivery system* — the combination of a generator, a matching network, and RF cable assemblies between the generator and the matching network.

5.2.9 *RF power-delivery system supplier* — the supplier of the RF power-delivery system or its subsystem (e.g., an RF generator, a matching network, a cable assembly).

5.2.10 *tap point* — the position of the switch(es) that connect or disconnect tuning elements in the matching network circuit.

NOTE 3: For some systems, partial tuning of the matching network is achieved by switching in a combination of fixed tuning elements, such as different values of capacitors.

5.2.11 *tuning element position* — the output voltage or output encoder value that corresponds to the position of a variable tuning element in a matching network.

NOTE 4: For example, the voltage from a rotary potentiometer on the rotating shaft of a variable capacitor (the ‘tuning element’) is referred to as the capacitor’s ‘position’. In this example, the position/voltage corresponds to a certain shaft location or position.

5.2.12 *uncertainty* — parameter, associated with a measurement, that characterizes the dispersion of values that can be reasonably attributed to the object being measured. [SEMI E89]

6 Ordering Information

6.1 Semiconductor manufacturers may use this Standard when procuring processing equipment to specify RF power-delivery system performance and documentation. The equipment suppliers may also use this Standard to specify the RF power-delivery system components and subassemblies.

6.2 Orders for RF power-delivery systems in accordance with this Standard shall include:

- The Standard designation number of this Standard including the publication date code (i.e., E113-mm yy).
- Any certification showing passage of qualification tests required to be provided (optional).
- Any test results required to be included in reports to be provided (optional).

NOTE 5: An order of such an RF power-delivery system can be a subpart of an order for the processing equipment.

7 Requirements

7.1 Reliability

7.1.1 The supplier shall provide mutually agreed-upon reliability metrics (e.g., mean time between failures during productive time MTBF_p, as defined in SEMI E10) of the generator, matching network, and the RF power-delivery system as a whole.

7.1.2 The RF power-delivery system supplier shall provide the test method(s) used to determine the reliability metrics.

7.2 RF Cable Assemblies

7.2.1 Many RF power-delivery systems use RF cable assemblies to transfer power from the generator to the input of the matching network.

7.2.2 All cable assemblies shall adhere to industry standards for cables and connectors (e.g., MIL-DTL-17, MIL-PRF-39012, IEEE-STD-383) in terms of rated power/voltage/current, allowed bending radius, expected variation in

characteristic impedance, phase velocity, and attenuation at the expected operating frequency(s) for the specific cable type (e.g., RG217, RG218) per the cable manufacturer's specifications.

7.2.3 The process equipment manufacturer shall use SEMI E114 or an equivalent test method(s) to determine the electrical length, power dissipation (loss), and characteristic impedance of the RF cable assemblies that are intended to be incorporated in its process equipment.

7.2.4 The length of the cable assemblies used to connect portions of the RF power-delivery system shall be specified in terms of electrical length at the nominal operating frequency, in addition to the nominal physical length. The electrical length shall be given in terms of degrees of phase shift.

7.2.5 The process equipment manufacturer shall specify the length of cables used between the matching network and the generator so that the effect of the impedance transformation at the harmonic frequencies (e.g., 10° of phase shift at the 10th harmonic frequency) can be minimized.

7.2.5.1 For frequencies less than or equal to 13.56 MHz, the length shall be within 1.0° of electrical length value

- at the operating frequency for fixed-frequency systems, or,
- at the most frequently used frequency or the midpoint frequency, whichever is practical, for variable-frequency systems,

7.2.5.2 For frequencies above 13.56 MHz, the length shall be a value (in degrees) equal to the frequency in MHz multiplied by 0.074 (e.g., the specification for 60 MHz would be $60 \times 0.074 = 4.44^\circ$).

NOTE 6: For example, at 13.56 MHz, the physical length of typical cable (RG217) corresponding to 1.0° of phase shift (2.0° of reflection-coefficient phase shift) would be approximately 4 cm.

7.2.6 The RF power-delivery system supplier shall provide the expected power dissipation in the RF cable assembly(s) supplied with the system as a function of the operating frequency(s) of the system.

7.2.7 The RF power-delivery system supplier shall provide the amount of power transmitted through the cable assembly in terms of dB (decibels) and percentage. The relationship between dB and percentage is given as:

$$\text{Percentage} = 100 \times 10^{(\text{dB}/10)} \quad (1)$$

NOTE 7: For example, approximately 94.8% (−0.232 dB of loss) of the power at 13.56 MHz is transmitted through a cable assembly made from RG217 cable with a physical length of 15.24 meters (i.e., electrical length of 375.74°). In other words, 5.2% of the power is dissipated in the cable assembly at 13.56 MHz.

7.3 Matching Networks

7.3.1 In an RF power-delivery system incorporated into processing equipment using plasma, matching networks transform the impedance of the plasma load to match the impedance of the generator, which is nominally 50 Ω. The transformation is achieved by the use of various reactive components, such as capacitors and inductors, that 'tune' the matching network by transforming the impedance at the output of the matching network to the input of the matching network. For a given frequency, there is a fixed relationship between the impedance at the input of the matching network and the impedance at the output of the matching network (i.e., the load impedance). In other words, the impedance to which the matching network is matched (i.e., the load impedance) can be determined if the transform properties of the matching network are known for a given frequency. Typically, there are two methods of impedance transformation. The first method uses a fixed-frequency (e.g., 13.56 MHz) and variable-tuning elements, while the second method uses a variable frequency and fixed-tuning elements. Specifications for both methods are given below.

7.3.1.1 For those systems that use fixed-frequency operation, matching networks typically have two variable-tuning elements, which are usually variable capacitors and/or inductors. These variable-tuning elements typically have an output voltage or encoder value that corresponds to a specific value of capacitance or inductance in the matching network.

7.3.1.1.1 To provide information on the operation and performance of the matching network, matching-network supplier shall design the controller of the matching network to indicate the tuning-element positions, such as the output voltage, as outputs.

7.3.1.1.1.1 Optionally, the input impedance (or reflection-coefficient magnitude and phase angle) may be provided based on a supplier-user agreement.