

SEMI E43-0813 (Reapproved 1019) GUIDE FOR ELECTROSTATIC MEASUREMENTS ON OBJECTS AND SURFACES

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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.

1 Purpose

1.1 This Standard provides guidance for reproducible electrostatic measurements on any surface or object, consistent with the scope and limitations set forth below.

2 Scope

2.1 The measurement methods described herein can be applied to characterize the general electrostatic charge, voltage, field level(s), and electrostatic discharge (ESD) on objects and surfaces in semiconductor manufacturing environments. Acceptable equipment, calibration, and measurement techniques are described in this Standard. Appendices include background information on the equipment specified and calibration procedures, as well as information and advice on performing a useful general electrostatic survey.

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 Direct measurement of charge requires the use of a Coulomb meter. Charges on an isolated conductor can be measured by transferring the charge into the Coulomb meter by contacting the isolated conductor with the Coulomb meter input probe. Charges on isolated conductors and insulators can be measured by transferring the charged object into a Faraday enclosure that is connected to the Coulomb meter. These measurements can be relatively precise if care is taken in the transfer process to avoid changing the charge level when making the measurements.

3.2 Direct measurement of charge is often impractical, due to the object size or difficulties in moving the charged object from its location to the Faraday enclosure. In these instances, charge is indirectly evaluated by measurement of the electrostatic field or the electrostatic potential of a charged surface using an electrostatic fieldmeter, electrostatic voltmeter, electrometer in the voltage-measurement mode, or a high-impedance contacting digital voltmeter (HIDVM).

3.3 This Standard does not describe equipment and techniques capable of making highly precise measurement of electrostatic charge. No methods of preconditioning the surface prior to measurements and no methods of characterizing the basic electrostatic performance of materials, such as tribocharging, resistance/resistivity, and decay rate are a part of this Standard. Measurements made using this Standard on the same surface or object may differ due to differences in the environment or history of the surface or object between the times any two measurements are made.

4 Referenced Standards and Documents

4.1 SEMI Standards and Safety Guidelines

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

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

5 Terminology

5.1 Abbreviations and Acronyms

- 5.1.1 *CDM* — charged device model
- 5.1.2 *DC* — direct current
- 5.1.3 *EED* — ESD event detector
- 5.1.4 *EMC* — electromagnetic compatibility
- 5.1.5 *EMI* — electromagnetic interference
- 5.1.6 *ESD* — electrostatic discharge
- 5.1.7 *ESVM* — electrostatic voltmeter
- 5.1.8 *HBM* — human body model
- 5.1.9 *HIDVM* — high-impedance contacting digital voltmeter
- 5.1.10 *IC* — integrated circuit
- 5.1.11 *LSR* — low series resistance
- 5.1.12 *MM* — machine model

5.2 Definitions

5.2.1 *electromagnetic compatibility (EMC)* — the ability of electronic equipment to function properly with respect to environmental electromagnetic interference (EMI). [SEMI E33]

5.2.2 *electromagnetic interference (EMI)* — the degradation of the performance of an equipment, transmission channel, or system caused by an electromagnetic disturbance. [SEMI E33]

5.2.3 *electrostatic discharge (ESD)* — the rapid spontaneous transfer of electrostatic charge induced by a high electrostatic field. [SEMI E78]

NOTE 1: ESD may also be referred to as an ‘ESD event’.

5.2.4 *ground* — a conducting connection between an object, electrical equipment, and earth, such as the portion of an electrical circuit of the same electrical potential as earth.

5.2.5 *grounded* — connected to earth or some other conducting body that serves in the place of earth.

6 Safety Precautions

6.1 Measurements of Very High Electrostatic Potentials ($>30,000$ V)

6.2 Measurements of very high electrostatic potentials ($>30,000$ V) may need to be done at larger distances than the commonly used 2.54 cm (1 in.) or less to avoid exceeding the measurement range of the meter and/or an ESD event to the meter.

6.3 Measurements on Moving Objects or Surfaces

6.3.1 Care should be taken, when attempting to read electrostatic charges on moving objects or surfaces, to maintain correct distance and avoid any contact; this is to assure ‘good’ readings with no mechanical damage or personal injury.

6.4 Measurements Using Electrostatic Voltmeters

6.4.1 Avoid touching electrostatic voltmeter probes during operation as their surfaces may be at elevated potentials that represent a shock hazard to the operator.

7 Equipment

7.1 *Electrometer (Direct Measurement of Electric Charge or Voltage)*

7.1.1 An electrometer is an electrical instrument for measuring electric charge, electric current, and/or electrical potential difference (i.e., voltage). Measurements of electric current with an electrometer are not discussed in this Document. An electrometer that measures electric charge only is called a Coulomb meter.

7.1.2 One of the typical features of an electrometer used in the charge or the voltage measurement mode is very high input impedance. That high impedance is needed to prevent or to minimize the transfer of electric charges between the measured object and electrometer. Ideally, the input impedance would be infinite. In practice, it is limited by intrinsic, physical material properties of insulators and by stray leakage paths between the input terminals. Low-voltage electrometers (below 200 V) have typical input resistances of $10^{14} \Omega$ or higher and accuracies better than 0.1%. In the voltmeter mode, an electrometer can resolve microvolt potentials. High-voltage electrometers (kilovolts range) usually rely on resistive voltage dividers and have typical input resistances in the $10^{11} \Omega$ range with accuracies in the 1% range. It is important to evaluate and understand the burden that the input impedance of an electrometer represents when measuring charge or voltage on charged objects.

7.2 *Fieldmeter/Field Sensor*

7.2.1 An electrostatic fieldmeter measures the value of the electrostatic field created by an object under test. Electrostatic fieldmeters are calibrated and recommended for use at a particular distance from the charged object. Fieldmeters are best suited for making general surveys or audits, for making measurements of surfaces at very high electric potentials (i.e., charge levels), and for making measurements when long-term stability is not important. They are not well suited for measurements of surfaces with very low charge levels or when high spatial resolution of the surface charge is needed. The fieldmeter modifies the electric field that is being measured.

7.2.1.1 The fieldmeter/electrostatic locator/field sensor will henceforth be referred to as ‘fieldmeter’. For measurements in the presence of air ionization, a chopper-stabilized fieldmeter is required. The fieldmeter is typically capable of making field measurements at a distance of 2.54 cm (1 in.) or less, from the field source to the fieldmeter sensor for this Standard, as written. However, refer to § 9.2.4 for fieldmeters that are operated at fixed distance(s), and adjust values in this Standard where applicable. The handheld fieldmeter is practical as an electrostatic locator only because precise measurements need a fixed distance between the fieldmeter sensor and the object under test.

7.3 *Electrostatic Voltmeter (ESVM)*

7.3.1 An ESVM measures an electric potential of an object under test. An ESVM indicates the presence and allows for calculation of the charge(s) creating the electrostatic field. Under appropriate conditions, ESVMs provide a better approximation of the charge level as compared to fieldmeters. ESVMs are relatively free of drift and more environmentally stable as compared to fieldmeters.

7.3.1.1 ESVMs exhibit a high degree of accuracy that is independent of the distance from the object under test. Thus, they are considered better suited for making more accurate and repeatable measurements as compared to fieldmeters. The probe can be located very close to a charged surface without arc-over, and, under appropriate conditions, can resolve a small spatial area on a surface.

7.4 *High-Impedance Contacting Digital Voltmeter (HIDVM)*

7.4.1 An HIDVM is capable of making direct contact measurements of electrical potentials on small objects under test (e.g., integrated circuit [IC] pins). An HIDVM should have both a high input resistance and low capacitance (i.e., high impedance). This is necessary to avoid removing the charge from the object under test by discharging it through the input resistance or transferring it to the capacitance of the HIDVM.

7.4.1.1 For the purpose of making voltage measurements on IC pins, or similar-sized objects, the HIDVM should have an input resistance greater than $10^{14} \Omega$ and an input capacitance less than 10^{-2} pF. In any case, testing should be done with known voltages on the object under test to establish the effect of the measurement instrument.

7.5 *Meter Stability*

7.5.1 All previously mentioned measurement instruments should be turned on and preconditioned for as long a warm-up period as recommended by the manufacturer.

NOTE 2: Refer to Related Information 1 for notes on equipment accuracy and limitations.

7.6 ESD Event Detection

7.6.1 An electrostatic discharge, also commonly referred to as an ESD event, is a source of damage to the devices and reticles. Measurements of ESD events are the only direct way of assessing the actual ESD exposure. ESD events can be measured directly or indirectly. Direct measurements are possible by inserting a current probe into the discharge path and measuring the discharge current. Such measurements, though providing the maximum accuracy, are largely limited to laboratories as it is impractical to make them in an operating factory. A practical and sensitive way of identifying ESD events is by detecting a specific electromagnetic field transient that is generated by an ESD event. Though this method is a qualitative technique that does not offer the precision of the current probe measurements, it does offer a practical way of assessing ESD exposure in situ.

8 Sufficient Number of Measurements

8.1 The number of independent measurements should be determined by the user. Tests can be repeated to make them more representative of actual electrostatic charge conditions in the surveyed area. The results may vary due to environment (e.g., humidity) and workstation setup/conditions. However, any measurement that is outside of user-defined limits or different than a benchmark value should be repeated more than once after performing a zero check of the measurement equipment. This is to validate previous reading(s) and/or establish range/bounds in the case of varying results on previous reading(s).

9 Test Methods, Measurements, and Performance Verification Methods

9.1 Coulomb Meter Measurements

9.1.1 Equipment Selection

9.1.1.1 Use a Coulomb meter for direct measurement of charge. A feedback-type Coulomb meter is recommended for charge measurements for the most complete transfer of charge. Shunt-type Coulomb meters do not completely transfer charge and are not as straightforward to use as feedback-type Coulomb meters. When using a Faraday enclosure, the Faraday enclosure should be large enough to hold the objects to be measured. The Faraday enclosure is used to measure charge on insulating materials as well as on conductors.

9.1.2 *Performance Verification of a Coulomb Meter (or an Electrometer Used in the Charge Measurement Mode)* — Refer to Figure 1.

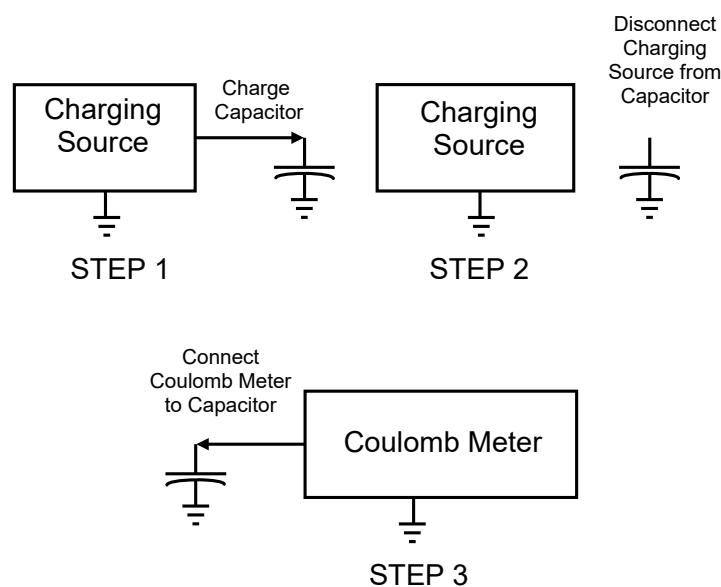


Figure 1
Verifying Performance of the Coulomb Meter

9.1.2.1 Reset (zero) the instrument prior to each measurement.

9.1.2.2 Maintain a reference calibration capacitor. It should be a polystyrene or polypropylene 10 nF capacitor (e.g., class C0G, low series resistance [LSR]). Measure the value of the capacitor to better than 1%. It is important to handle the reference calibration capacitor very carefully. Do not touch or hold the capacitor by its body or discharge it by touching both leads with the fingers. Hold the capacitor by one lead only. Use a clip lead connected between ground and this lead of the capacitor to maneuver the other lead of the capacitor between the ‘hot’ side of the charging source and the input terminal of the Coulomb meter.

9.1.2.3 Charge the reference calibration capacitor to 1 V with a charging source (i.e., power supply). Calculate the amount of charge on the capacitor by multiplying the voltage by the value of the capacitor. Example: $1\text{ V} \times 10\text{ nF} = 10\text{ nC}$ of charge.

9.1.2.4 Disconnect the charging source from the capacitor.

9.1.2.5 Connect the Coulomb meter input probe to the capacitor and discharge the capacitor into the Coulomb meter. The Coulomb meter should indicate the calculated value.

9.1.3 Measurements

9.1.3.1 Best results are achieved when all surfaces surrounding the measurement area are grounded (to minimize the effects of stray fields on the measurement) and when a consistent, systematic handling method is used during the measurement process. The operator should be grounded using a grounded wrist strap.

9.1.3.2 *Isolated Conductors* — To measure the charge on an isolated conductor, touch the lead from the Coulomb meter to the isolated conductor.

9.1.3.3 *Faraday Enclosure Measurements* — Refer to Figure 2. To measure the charge on an object, carefully pick up the object with an insulated tool and place the charged object into the Faraday enclosure. Special handling considerations: Be careful not to add or subtract any charge in the process of moving the charged object into the Faraday enclosure. Don’t let the charged object rub or slide against any other surface, as this may add or subtract charge from the object.

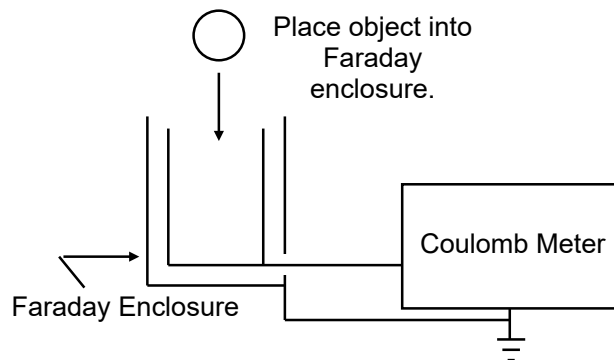


Figure 2
Measurement with a Coulomb Meter and Faraday Enclosure

9.1.4 Limitations

9.1.4.1 Do not attempt to measure charges of magnitudes that are below the drift rate of the Coulomb meter.

9.2 Voltage Measurements with Electrometer

9.2.1 Equipment Selection

9.2.1.1 Measuring with an electrometer working in the voltage mode is very similar to measuring with any other voltmeter or multimeter. The major differences between the ordinary voltmeter and the electrometer are that the input impedance of the electrometer is orders of magnitude higher, and grounded objects near the measurement location can affect the reading.

9.2.2 Performance Verification of an Electrometer Used in the Voltage Mode

9.2.2.1 It is good practice to occasionally check the performance of the electrometer by connecting it to a known voltage source, and comparing its readings with readings taken by another reference voltmeter.

9.2.3 Zeroing an Electrometer Used in the Voltage Mode

9.2.3.1 Except on some older analog models, there are usually no provisions to zero an electrometer. Some electrometers with analog or digital read-outs do allow offsetting of a reading, as well as relative (i.e., delta) measurements. However, the electronic zero of the electrometer is usually set by the manufacturer, and should be part of the normal calibration. It is good practice to occasionally check the zero by shorting the input terminals together and verifying that the zero reading is within the manufacturer's specifications.

9.2.4 Measurement

9.2.4.1 Connect the 'common' terminal of the electrometer through a test lead to the reference plane or ground. Connect the 'hot' or signal lead to the object or test point of interest. Some electrometer measurements will use a separate wire or shield connected to the electrical ground or a guard ring. Connect this as recommended by the manufacturer of the equipment.

9.3 Electrostatic Fieldmeter and ESVM Measurements

9.3.1 Performance Verification of Fieldmeters and ESVMs — Refer to Figure 3.

9.3.1.1 *Choosing Test Voltage(s)* — Choose one or more test voltage(s) from Table 1, based upon the electrostatic field/voltage level of concern:

Table 1 Test Voltages

<i>Field of Concern</i>	<i>Test Voltage</i>
Under 4 kV/m or 100 V/2.5 cm	100 V
Under 40 kV/m or 1 kV/2.5 cm	1 kV
Over 200 kV/m or 5 kV/2.5 cm ^{#1}	5 kV

#1 If fieldmeter or ESVM performance verification is needed above 5 kV/2.5 cm, it is left to the user to select values using this table as a guide.

9.3.1.2 *Equipment Performance Verification* — Charge a conductive, isolated test plate to the desired verification voltage. Use of a suitable power supply or a charged plate monitor for test purposes is recommended.

9.3.1.3 *Assuring Meters and Operator Are Grounded* — Assure that the fieldmeter, ESVM, and operator are grounded. Turn on the meter and zero it as required according to manufacturer's instructions.

9.3.1.4 *Directing or Pointing the Sense Head* — Direct or point the sense head of the fieldmeter or ESVM at the center and parallel to the surface of the plate at a distance at least twice of that recommended by the manufacturer. Slowly move the sense head toward the surface of the charged plate until a reading equal to the voltage applied to the plate in ¶ 9.3.1.1 above is displayed by the meter. Measure and record the distance from the sense head to the surface to the plate. Using the plate voltage from ¶ 9.3.1.1 above and the recorded distance, compute the field strength for the fieldmeter. See Figure 3.

9.3.1.5 *Alternative to ¶ 9.3.1.2* — Take measurements at a specified/fixed distance per manufacturer's instructions. Locate the sense head of the fieldmeter or ESVM as in ¶ 9.3.1.4, but, at specified distance; reading displayed (on meter) should be within 5% of applied voltage to plate.

NOTE 3: ¶ 9.3.1.4 or ¶ 9.3.1.5 should be applicable to most meters. However, in every case, the electrostatic fieldmeter or ESVM manufacturer's instructions should be read, understood, and followed.

9.3.1.6 *Other Desired Test Voltages* — Repeat ¶ 9.3.1.4 and ¶ 9.3.1.5 for any other desired test voltages.

9.3.2 Check the zero on the fieldmeter or ESVM as specified by the manufacturer. Usually this is done while the probe is positioned to view a grounded surface. If the zero of the meter has drifted by more than 5% of the test voltage for any range contained in Table 1, the meter is not suitable for use for measurements over that range. It may be

suitable for use over other ranges contained in Table 1, using other test voltages. Reverify the meter's calibration at the selected test voltage.

9.3.3 Measurements with a Fieldmeter

9.3.3.1 Measurements made to this Standard should be taken and reported in units that conform to the customer specifications. Most common fieldmeters manufactured to date have operating instructions that reflect the user doing calibration and taking measurements in English units of V/inch or V at a fixed distance in inch(es) and in these cases, raw data are reported/listed directly. The international community and SEMI Standards program regulations specify that units shall be in International System of Units (SI) units.

9.3.4 Measurement Limitations

9.3.4.1 Measurements made to this Document are only valid for surfaces that are flat to a radius of 1.5 times the measurement distance from a point directly below the sensor head. For surfaces that are not flat, measurements should be made by moving the sensor over the surface such that the specified measurement distance is maintained as closely as possible. These measurements may only be stated as a range, with rounding as applicable to the meter's measurement range according to ¶ 9.3.1.1. Refer to Figure 4.

NOTE 4: Refer to Related Information 2 for notes on test methods environment and measurements.

9.3.5 Measurements with an Electrostatic Voltmeter (ESVM)

NOTE 5: Refer to Figure 3.

- A) Connect meter and charged plate directly to the same ground reference.
- B) Hold the meter so that the sense head is approximately 2.54 cm away from the charged plate.
- C) The meter reading should be within 5% of the voltage applied to the charged plate.
- D) Assure that both the operator and the meter are properly grounded.

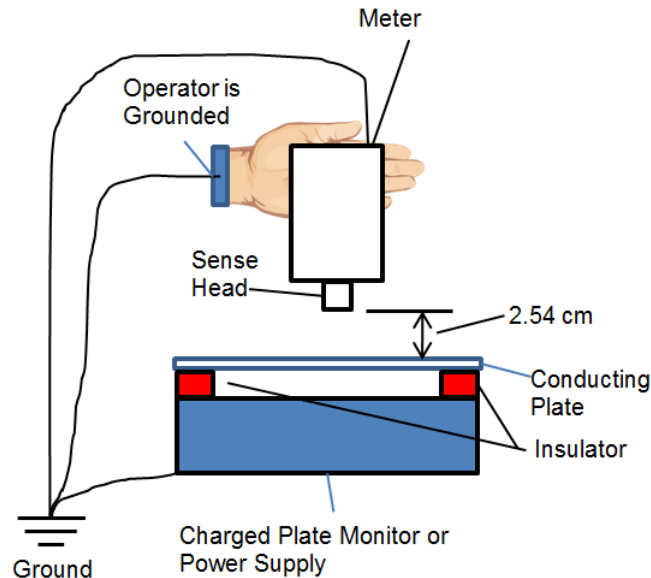


Figure 3
Fieldmeter and ESVM Verification Check

- A) Make sure meter is properly grounded according to manufacturer's instructions.
- B) Scan approximately 2.54 cm along both sides and ends of carrier.
- C) Scan approximately 2.54 cm length of carrier and top-center of wafers with meter.
- D) Note high-low values for B) & C).
- E) Assure that the operator is properly grounded.

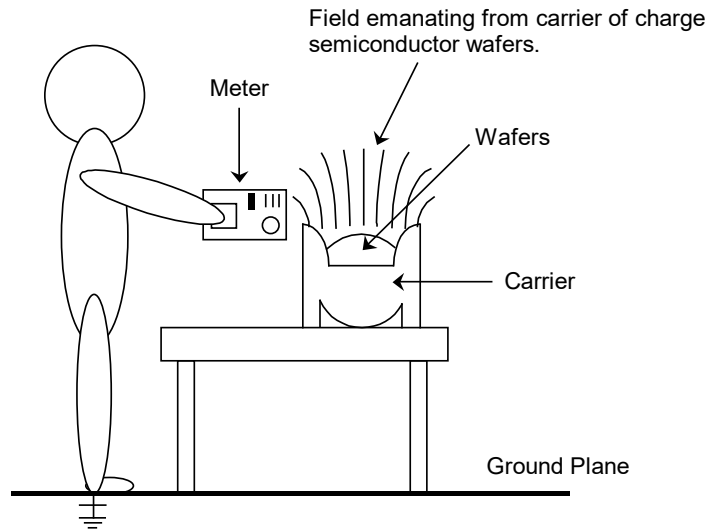


Figure 4
Example of a Survey of a Carrier of Semiconductor Wafers

9.3.6 Selecting the ESVM

9.3.6.1 Select an ESVM with a measurement range consistent with the anticipated levels of electrostatic potentials/charge on the objects to be measured. The selection of too high a measurement range will sacrifice voltage resolution, while selection of too low a range will cause out-of-range operation (i.e., saturation).

9.3.6.2 To measure moving objects, select an ESVM with a speed of response fast enough to detect the objects when they are moving past the electrostatic voltmeter probe at the highest anticipated velocity.

9.3.6.3 Select a side- or end-viewing probe for the ESVM as is best suited to view the target object or surface when the probe is installed in equipment.

9.3.7 Measurements

9.3.7.1 Position the probe in front of the surface to be measured. Best results are obtained when the probe is placed at the distance recommended by the manufacturer.

9.3.8 Measurement Limitations

9.3.8.1 Voltage levels on isolated conductors can be measured. Insulators do not have a uniform surface charge distribution. Therefore, it is considered that voltage levels measured on insulators indicate an electrostatic field strength in a particular area. Under certain conditions, a surface charge on the insulator can be calculated from the electrostatic potential reading provided by the ESVM.

NOTE 6: SEMI has published an ESD Guide (SEMI AUX021) to complement this Document. Refer to this ESD Guide for additional information on measurements of charge on insulators.