

# SEMI E43-0301

## GUIDE FOR MEASURING STATIC CHARGE ON OBJECTS AND SURFACES

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**NOTICE:** This document was completely rewritten in 2001.

### 1 Purpose

1.1 The purpose is to establish a guide for reproducible measurement of electrostatic charge(s) 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 level(s) on objects and surfaces in all environments. Acceptable instrumentation, calibration, and measurement techniques are described in this document. Appendices include background information on the equipment specified and calibration procedure, as well as information and advice on performing a useful general static survey.

**NOTICE:** 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 or other limitations prior to use.

### 3 Limitations

3.1 Direct measurement of charge usually requires the use of a coulombmeter. Charges on an isolated conductor can be measured by transferring the charge into the coulombmeter by contacting the isolated conductor with the coulombmeter 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 coulombmeter. 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. In these instances, charge is indirectly evaluated by detecting the electrostatic field from a charged surface using an electrostatic fieldmeter or an electrostatic voltmeter.

3.3 This guide does not describe instrumentation and techniques capable of making highly precise measurement of electrostatic charge. It is not suitable for measurement of electrostatic charge on small objects, such as packaged devices (i.e., reading(s) obtained are indicative/general area and not precise/minute). No methods of preconditioning the surface prior to measurements and no methods of characterizing the basic electrostatic performance of materials, such as tribocharging, resistance, and decay rate are a part of this document. Measurements made using this guide 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 None.

### 5 Terminology

5.1 *electrostatic discharge (ESD)* — the rapid spontaneous transfer of electrostatic charge induced by a high electrostatic field.

5.2 *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.

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

## 6 Safety

6.1 *Measurements of Very High Static Potentials (>30,000 Volts)* — Measurements of very high static potentials (>30,000 V) may need to be done at larger distances to avoid exceeding the measurement range of the meter and/or an ESD event to the meter.

6.2 *Measurements on Moving Objects or Surfaces* — 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.

6.3 *Measurements Using Electrostatic Voltmeters* — Avoid handling electrostatic voltmeter probes during operation as their surfaces may be at elevated potentials that represent a shock hazard to the operator.

## 7 Equipment and Performance Verification Methods

### 7.1 Equipment

7.1.1 *Electrostatic Locator/Field Sensor/Field Meter* — An electrostatic fieldmeter measures the value of the electrostatic field at its sensor. 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 potentials (*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 potentials or when high spatial resolution of the surface potential is needed.

7.1.1.1 The electrostatic locator/field sensor/field meter will henceforth be referred to as “the fieldmeter.” Note that for measurements to be taken in the presence of air ionization, a chopper stabilized fieldmeter is required. The fieldmeter must be capable of making field measurements at a distance of 2.54 centimeters (cm) = 1 inch or less, from the field source to the sensor for this guide, as written. However, see § 7.2.5 for fieldmeters that are operated at fixed distance(s), and adjust values in this document where applicable.

7.1.2 *Electrostatic Voltmeter* — An electrostatic voltmeter nulls the electrostatic field at its sensor (probe). An electrostatic voltmeter indicates the presence and approximate level of the charge(s) creating the electrostatic field. Under appropriate conditions, electrostatic voltmeters provide a better approximation of the charge level as compared to electrostatic fieldmeters. Electrostatic voltmeters are relatively free of drift and more environmentally stable as compared to fieldmeters.

7.1.2.1 Electrostatic voltmeters are well suited for fixed installation in equipment. Electrostatic voltmeters exhibit a high degree of accuracy that is independent of the distance from the charge. 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.

7.1.2.2 Electrostatic voltmeters are best suited for making measurements of surfaces at potentials below 20kV, or when a calibrated or fixed distance from the probe to the surface cannot be maintained. They are also best suited for measuring low surface potentials, or when it is desired to resolve a small area on the surface. Electrostatic voltmeters are unsuitable for measuring surfaces at very high potentials, such as above 20kV.

7.1.2.3 The electrostatic voltmeter will henceforth be referred to as “the voltmeter.”

7.1.3 *Electrometer* — An electrometer is a contact voltmeter with a very high input impedance. Ideally, this input impedance would be infinite. In practice, it is limited by intrinsic physical materials properties of insulators and by stray leakage paths between the input terminals. Low voltage electrometers (below 200 Volt) have typical input resistances of  $10^{14}$  ohms, accuracies better than 0.1%, and can resolve microVolt type potentials. High voltage electrometers (Kilovolts) usually rely on resistive voltage dividers and have typical input resistances in the  $10^{11}$  ohms 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 voltage potentials on very small charged structures.

7.1.4 *Charged Plate Monitor* — A charged plate monitor is an instrument typically used to monitor the performance of air ionization equipment. Monitoring is done with an electrically isolated 15 cm × 15 cm (6 inches × 6 inches) metal plate, henceforth referred to as “the plate.” The instrument typically provides a means to charge the plate to a known voltage (1000 or 5000 volts of either polarity), a plate sensor to determine the voltage on the plate, and timing circuitry to determine the time required to discharge the plate to a percentage of its initial charge. For the

purposes of this guide, the charged plate monitor, or a separate isolated plate assembly, can be used for performance verification purposes as explained in § 7.2.

## 7.2 Equipment Performance Verification (Confidence Test)

### 7.2.1 Performance Verification of a Coulombmeter — Refer to Figure 1.

7.2.1.1 Zero the coulombmeter prior to each measurement.

7.2.1.2 Maintain a reference calibration capacitor. It should be a polystyrene or polypropylene 10 nF capacitor (Mallory SX-110 or equivalent). Measure the value of the capacitor to better than 1%. It is important to handle the reference calibration capacitor very carefully. Do not 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 coulombmeter.

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

7.2.1.4 Disconnect the charging source from the capacitor.

7.2.1.5 Connect the coulombmeter input probe to the capacitor and discharge the capacitor into the coulombmeter. The coulombmeter should indicate the calculated value.

### 7.2.2 Performance Verification of Fieldmeters and Voltmeters — Refer to Figure 2.

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

**Table 1 Test Voltages**

| <i>Field of Concern</i>                                    | <i>Test Voltage</i> |
|------------------------------------------------------------|---------------------|
| Under 4,000 volts/meter or<br>100 volts/2.5 cm             | 100 volts           |
| Under 40,000 volts/meter or<br>1000 volts/2.5 cm           | 1,000 volts         |
| Over 200,000 volts/meter or<br>5,000 volts/2.5 cm (See #1) | 5,000 volts         |

#1 If fieldmeter or voltmeter performance verification is needed above 5,000 volts, it is left to the user to select values using the table as guide.

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

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

7.2.2.4 *Directing or Pointing the Sense Head* — Direct or point the sense head of the fieldmeter or voltmeter at the center and parallel to the surface of the plate at a distance at least twice the manufacturer's recommended measurement. Slowly move the sense head toward the center of the charged plate until a reading equal to the voltage applied to the plate in § 7.2.2.1 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 § 7.2.2.1 above and the recorded distance, compute the field strength for the fieldmeter. See Figure 2, Fieldmeter and Voltmeter Verification Check.

7.2.2.5 *Alternative to § 7.2.2.4* — Take measurements at a specified/fixed distance per manufacturer's instructions. Locate the sense head of the fieldmeter or voltmeter as in § 7.2.2.4, but, at specified distance; reading displayed (on meter) should be within 5% of applied voltage to plate.

NOTE 1: § 7.2.2.4 or 7.2.2.5 should be applicable to most meters. However, in every case, the electrostatic fieldmeter or voltmeter manufacturer's instructions should be read, understood, and followed.

7.2.2.6 *Other Desired Test Voltages* — Repeat § 7.2.2.4 and § 7.2.2.5 for any other desired test voltages.

7.2.3 *Performance Verification of an Electrometer* — 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.

7.2.4 *Meter Stability* — All measurement devices should be turned on and pre-conditioned for as long a warm-up period as recommended by the manufacturer

7.2.4.1 Reset (zero) the coulombmeter prior to each measurement.

7.2.4.2 Check the zero on the fieldmeter or voltmeter 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.

7.2.4.3 *Zeroing an Electrometer* — 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 (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.

7.2.4.4 See Related Information 1 for notes on equipment accuracy and limitations.

## 8 Sampling

8.1 Sampling methods for this guide should be determined by the requirements of the user's application. Electrostatic surveys can be repeated at different times to make them more representative of actual static charge conditions in the surveyed area. The results will vary due to environment (e.g., humidity) and workstation setup/conditions. However, any measurement that is in excess of a (user) defined maximum or that is a benchmark value, should be repeated more than once, after performing a zero check of the measuring equipment. This is to validate previous reading(s) and/or establish a range/bounds in the case of varying-moving fields on previous reading(s).

## 9 Test Methods and Measurements

### 9.1 *Coulombmeter Measurements*

9.1.1 *Verifying the Coulombmeter* — Verify the performance of the coulombmeter as in § 7 above. Check/reset the zero before each measurement and/or per manufacturer's instructions. Assure that the coulombmeter and operator are grounded.

9.1.2 *Equipment Selection* — Use a coulombmeter for direct measurement of charge. A feedback-type coulombmeter is recommended for charge measurements for the most complete transfer of charge. Shunt-type coulombmeters do not completely transfer charge and are not as straightforward to use as feedback-type coulombmeters. When using a Faraday enclosure, the Faraday enclosure must 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.

9.1.3 *Measurements* — 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.

9.1.3.1 *Isolated Conductors* — To measure the charge on an isolated conductor, touch the lead from the coulombmeter to the isolated conductor.

9.1.3.2 *Faraday Enclosure Measurements* — Refer to Figure 3. 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.

9.1.4 *Limitations* — Do not attempt to measure charges of magnitudes that are below the drift rate of the coulombmeter.

## 9.2 *Electrostatic Fieldmeter Measurements*

9.2.1 *Verifying the Fieldmeter* — Verify the performance of the fieldmeter as in § 7 above. Check/reset the zero periodically and/or per manufacturer's instructions. Assure that the fieldmeter and operator are grounded.

9.2.2 *Measurements* — Measurements made to this guide should be taken/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 volts/inch or volts at a fixed distance in inch(es) and in these cases, raw data are reported/listed directly. The international community specifies that units shall be in SI (Standard International) Metric units and the SI conversion factor in § 7.1.1.1 will apply. However, by definition, electric field is expressed in volts per meter, and thus would be expressed according to Table 2.

9.2.2.1 For instance, when using a meter calibrated only at 100 volts, measurements under 4,000 volts/m would be expressed to the nearest 400 volts/m. Measurements over 4,000 volts/m would be expressed as >4,000 volts/m. For a meter calibrated to all three voltages, measurements under 4,000 volts/m would be expressed to the nearest 400 volts/m, measurements between 4,000 and 40,000 volts/m would be expressed to the nearest 4,000 volts/m, and measurements over 40,000 volts/m would be expressed to the nearest 40,000 volts/m.

**Table 2 Measurement Units**

| <i>Test Voltage</i> | <i>For Readings of</i> | <i>Express in Multiples of</i> | <i>For Readings of</i> | <i>Express as</i>        |
|---------------------|------------------------|--------------------------------|------------------------|--------------------------|
| 100 V               | <4,000 V/m             | 400 V/m                        | >4,000 V/m             | >4,000 V/m               |
| 1,000 V             | <40,000 V/m            | 4,000 V/m                      | >40,000 V/m            | >40,000 V/m              |
| 5,000 V             | <200,000 V/m           | 20,000 V/m                     | >200,000 V/m           | multiples of 200,000 V/m |

#1 Measurements above 1000 volts/2.54 cm may be made based on verification of the meter at 1000 volts where less precision is acceptable due to safety concerns with verification equipment/setup or availability of such equipment.

9.2.3 *Measurement Limitations* — Measurements made to this guide 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 § 9.2.2. See Figure 4, Example of a Survey of a Carrier of Semiconductor Wafers. See Related Information 2 for notes on test methods environment and measurements.

## 9.3 *Electrostatic Voltmeter Measurements* — Refer to Figure 4.

9.3.1 *Verifying the Voltmeter* — Verify the performance of the voltmeter as in § 7 above. Check/reset the zero periodically per manufacturer's instructions. Assure that the voltmeter and operator are grounded.

9.3.2 *Selecting the Voltmeter* — Select an electrostatic voltmeter with a measurement range consistent with the anticipated levels of 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 (saturation).

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

9.3.2.2 Select a side- or end-viewing probe for the electrostatic voltmeter as is best suited to view the target object or surface when the probe is installed in an apparatus.

9.3.3 *Measurements* — Position the probe in front of the surface to be measured. Best results are obtained when the probe is placed less than two (probe) aperture diameters from the object or surface to be measured. At these closer spacings, the effects of extraneous fields are minimized.

9.3.3.1 To resolve a small surface area, the distance between the probe and the surface-under-measurement must be less than 1/5<sup>th</sup> of the diameter of the surface area to be measured. At wider spacings the surface area resolved by the probe will exceed the surface area of interest, and measurement accuracy may be reduced together with the possibility of introducing effects of extraneous fields to the measurement.

9.3.4 *Measurement Limitations* — 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.

9.4 *Electrometer Measurements* — Measuring with an Electrometer is very similar to measuring with any other voltmeter or multimeter.

9.4.1 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.

9.4.2 The major difference between the ordinary voltmeter and the electrometer is the orders of magnitude higher input impedance of the electrometer. An electrometer will therefore pick up voltage signals produced by stray electric fields, potentials associated with noise currents, and artifacts caused by intentional or unintentional ionization of the ambient air when measuring high voltages. An electrometer can, for example, be used to measure the triboelectric and the piezoelectric properties of a piece of coaxial cable: connect the cable under test to the electrometer, and flex it or tap on it with a finger. The voltages induced on the center conductor can be measured by the electrometer.

## 10 Certification

10.1 Certification to survey areas to this guide is for the person doing the certification (certifier) to assure that the person being certified (certifyee) can calibrate the meter and make acceptable measurement of known static field(s) per § 7 and applicable example(s) per § 9. The certifier shall be someone qualified by education and/or training to calibrate and make measurements with the equipment called out in this guide or someone previously certified. The ESD Association conducts such training programs and the National Association of Radio and Television Engineers (NARTE) administers an ESD Engineer and ESD technician certification program.

10.2 *Demonstrating Ability to Verify the Performance of the Meter Against Known Source* — The certifyee shall charge the test plate, zero the meter, and perform the measurement a minimum of two times per § 7; record values per § 11. Readings obtained shall be within 5% of expected values.

10.3 *Demonstrating Ability to Measure Example Item(s) Acceptably* — The certifier will have charged/uncharged example(s) of items/objects for measurement of static field(s) by certifyee(s) a minimum of two times per § 9; record values per § 11.

10.4 *Certifying* — Readings obtained per § 10.2 shall be within 12% of expected values and methodology of obtaining readings shall be acceptable per certifier observation(s). A permanent record of certification is realized by certifyee when certifier signs record sheet(s) for file in personnel records and/or when certifier issues a certificate. Refer to § R1-3.

## 11 Documentation

11.1 Meter calibration check(s), benchmark or laboratory measurements, items/areas surveys, and/or any other electrostatic field measurements should be recorded in permanent records. Recorded are initial reading, second/validation reading, and any subsequent readings taken to acceptable range/bound levels observed. Record sheet(s) should show meter used, area (name), location, date, and items listed opposite readings, name of person who took readings, and space for comments.