SEMI E78-0998
ELECTROSTATIC COMPATIBILITY - GUIDE TO ASSESS AND CONTROL ELECTROSTATIC DISCHARGE (ESD) AND ELECTROSTATIC ATTRACTION (ESA) FOR EQUIPMENT

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1 Purpose

1.1 The purpose of this document is to minimize the negative impact on productivity caused by static charge in semiconductor manufacturing environments. It is a guide for establishing electrostatic compatibility of equipment used in semiconductor manufacturing.

1.2 Electrostatic surface charge causes a number of undesirable effects in semiconductor manufacturing environments. Electrostatic discharge (ESD) damages both products and reticles. ESD events also cause electromagnetic interference (EMI), resulting in equipment malfunctions. Charged wafer and reticle surfaces attract particles (electrostatic attraction or ESA) and increase the defect rate. Charge on products can also result in equipment malfunction or product breakage. Operating problems and additional product defects due to static charge can have a negative impact on the cost of ownership of semiconductor manufacturing equipment (refer to SEMI E35).

1.3 An increasing amount of semiconductor production is done in minienvironments or within the production equipment. The majority of static related problems occur while the product is in its carriers, or being transferred from them, by the production equipment.

1.4 Static control methods can be incorporated in the equipment design to reduce static charge to acceptable levels. This guide will be used primarily by equipment manufacturers during the design of their equipment. There are test methods available (see Sections 6 and 7 of this guide) to demonstrate the effectiveness of the static control methods. The end user will be able to use the same test methods to verify compliance with an equipment purchase specification.

2 Scope

2.1 The scope of this document is limited to methods of measurement and a guide for the maximum recommended level of static charge on:

— Product or reticles

— Carriers

— Parts of the input/exit ports of equipment and minienvironments

2.2 This document presents a matrix of maximum recommended levels of static charge on products, reticles, carriers, and the input and exit ports of production equipment or minienvironments. The purpose is to:

— Reduce product, reticle, and equipment damage due to ESD

— Reduce equipment lock-up problems due to ESD events.

— Reduce the attraction of particles to charged surfaces.

2.3 This document references SEMI E43 and other methods of measuring static charge. Related Information 1 of this document contains a theoretical investigation of electrostatic particle attraction, as well as case histories from users and equipment manufacturers as to the static charge problems encountered and how they were solved. A bibliography of related technical papers is also included. Related Information 2 describes static control methods commonly used in semiconductor manufacturing.

3 Limitations

3.1 *Static Measurements* — Measurements of electrostatic quantities such as charge, electric field, and voltage are difficult to make. The nature of the object (insulator or conductor), its geometry, its surroundings, and the measuring equipment itself, are only a few of the factors affecting the accuracy of an electrostatic measurement.

3.1.1 Similarly, it is difficult to relate the measurement of an electrostatic quantity to its effect on products or equipment. For example, an ESD simulator produces a standardized discharge waveform when a capacitor is discharged at a known voltage. This device is used to establish the ESD damage threshold for semiconductor products, or the effect of ESD on equipment. While the amount of charge transferred is known ($q = CV$), the maximum current that results is not. There is no guarantee that the same amount of charge would produce the same results if different values of capacitance and voltage were used.

3.2 *Location* — The test methods and maximum recommended levels of static charge on product, reticles, and carriers are meant to be applied at the input/exit ports of production equipment, and when possible within the equipment. This document is not

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meant to be applied in any way that affects the process within the equipment.

3.3 *Test Methods* — The test methods referenced in this document do not guarantee precise measurements of static charge levels. The maximum static charge levels recommended in this document have large tolerances. (See Section 15.1.)

3.4 *Static Charge Control* — There are a variety of static related issues in a semiconductor manufacturing environment. The issues are complex due to the wide range of electrostatic problems, and device or equipment sensitivities to these problems. This guide contains general recommendations. Users of this document are cautioned that specific static related problems may require or allow different levels of static charge than are recommended in this document.

4 Referenced Documents

NOTE: As listed or revised, all documents cited shall be the latest publications of adopted standards.

4.1 *SEMI Standards*

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

SEMI E33 — Specification for Semiconductor Manufacturing Facility Electromagnetic Compatibility

SEMI E35 — Cost of Ownership for Semiconductor Manufacturing Equipment Metrics

SEMI E43 — Recommended Practice for Measuring Static Charge on Objects and Surfaces

4.2 *ESD Association Standards and Advisories*[1]

ANSI EOS/ESD S5.1 — Standard for Electrostatic Discharge (ESD) Testing - Human Body Model (HBM) - Component Level

EOS/ESD ADV 1.0 — Advisory for Electrostatic Discharge Terminology - Glossary

EOS/ESD ADV 2.0 — Advisory for Protection and Sensitivity Testing of Electrostatic Discharge Susceptible Items - Handbook

EOS/ESD DS5.3 — Draft Standard for Electrostatic Discharge (ESD) Testing - Charged Device Model (CDM) - Component Level

EOS/ESD S5.2 — Standard for Electrostatic Discharge (ESD) Testing - Machine Model (MM) - Component Level

4.3 *Other Documents*

IEC 1000-4-2 — Transient Immunity Standard, International Electrotechnical Commission

89/336/EEC — European Union Directive on Electromagnetic Compatibility

5 Terminology

5.1 *Definitions*

5.1.1 *deposition velocity* — Particle flux to a surface (number of particles deposited per unit area per unit time) divided by the particle concentration adjacent to the surface boundary layer.

5.1.2 *electromagnetic interference (EMI)* — Any electrical signal in the non-ionizing (sub-optical) portion of the electromagnetic spectrum with the potential to cause an undesired response in electronic equipment.

5.1.3 *electrostatic attraction (ESA)* — The force between two or more oppositely charged objects. The result is increased deposition rate of particles onto charged surfaces, or movement of charged materials.

5.1.4 *electrostatic compatibility* — Charge control adequate for interequipment transfer of products, reticles, and carriers without electrostatic problems.

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

NOTE: Usually the charge flows in a spark between two objects at different electrostatic potentials.

5.1.6 *equipment interrupt* — Any variance from the specifications of equipment operation, whether or not the equipment recovers automatically. Interrupts include, but are not limited to, equipment stoppage, equipment data errors, and physical mishandling of products (reference SEMI E10).

5.1.7 *ESD simulator* — An instrument providing a specified electrostatic discharge current waveform when discharged directly to a product or equipment part.

5.1.8 *input and exit ports* — The locations where product and/or product carriers are placed to allow the equipment to process them, or where they are removed from the equipment after processing.

5.1.9 *minienvironments* — A localized environment created by an enclosure to isolate the product from contamination and people.

5.1.10 *product* — Any unit intended to become a functional semiconductor device.

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5.1.11 *sensitivity level 1* — Product, reticles, and equipment are extremely vulnerable to damage and/or problems from static charge.

5.1.12 *sensitivity level 2* — Product, reticles, and equipment are highly vulnerable to damage and/or problems from static charge.

5.1.13 *sensitivity level 3* — Product, reticles, and equipment have nominal vulnerability to damage and/or problems from static charge.

5.1.14 *sensitivity level 4* — Product, reticles, and equipment have negligible vulnerability to damage and/or problems from static charge.

5.2 *Description of Terms Specific to this Standard*

5.2.1 *carrier* — A device for holding wafers, dies, packaged integrated circuits, or reticles for various processing steps in semiconductor manufacturing.

6 Requirements

6.1 *Measurement Methods and Instrumentation* — No single method of testing for static charge can determine a "safe" level. The amount of static charge, the distribution of static charge on an object, and the nature of the static discharge will all interact to determine if the charge level is safe. It will be difficult to determine levels that ***guarantee*** static related problems are totally eliminated. The goal of this guide is to assist the user in identifying static charge levels likely to cause problems in process equipment. This guide should provide the user with enough insight to define a test methodology for each static problem and understand its limitations.

6.2 *ESD Damage*

6.2.1 When considering direct ESD damage to an object (product, reticle, or equipment), the important parameter is the current accompanying the charge transfer to or from the object. Under a fixed set of test parameters, the damaging amount of current due to the charge transfer to or from the object can be determined. Established test methods exist for determining the threshold of damage to a particular object. ESD simulators of various types are used for this purpose. Refer to EOS/ESD Association Standards listed in Section 4 for further information concerning device testing.

6.2.2 The end user should determine what is damaging current level due to charge transfer to product or reticles that will be handled in a particular piece of production equipment.

6.2.3 In the context of production equipment, it appears important to know the charge on the product, its carriers, and any other objects that might directly contact the product. Charge is measured in coulombs, or more conveniently in nanocoulombs (10^{-9} coulombs) for this purpose. The measurement is made with instrumentation known as a Faraday Cup, as shown in Section 7, Figure 1.

6.2.4 A charged object, like an integrated circuit, is placed in the Faraday Cup and a reading is taken of the charge on it. It will be necessary to obtain an instrument with a large enough "cup" for wafers, cassettes, and other equipment parts. It will also be necessary to get the objects into the cup without altering their charge levels. Further information on making these measurements should be available from the manufacturers of the measuring equipment.

6.2.5 The user should determine with an ESD simulator what levels of ESD cause product, or reticle damage. The equipment manufacturer will need to determine with an ESD simulator what levels of static charge cause equipment damage.

6.2.6 It will be the responsibility of the equipment manufacturer to demonstrate that equipment operation does not generate more than the allowable amount of charge on product, carriers or equipment parts. This is shown in Section 7, Figure 2.

6.3 *Particle Attraction*

6.3.1 Electrostatic attraction (ESA) of particles can occur due to the electrostatic field created by the charge on the surface of an object. Both the field strength and, usually to a lesser degree, the divergence of the field influence the electrostatic contribution to particle deposition velocity. Electrostatic particle deposition velocity also depends on particle size and particle electrical charge. Unfortunately, even under controlled laboratory conditions, accurate measurements of electric field strength, particle size distribution, and, especially, particle charge, are difficult. Of these three parameters, electric field measurements are the most likely to be available.

6.3.2 Measurements of electrostatic field can be made with a commonly available electrostatic fieldmeter. The units of electrostatic field are volts/cm (volts/inch). Precise measurements will be difficult as the presence of the measuring instrument changes the field characteristics and may overstate the actual level of electrostatic field. This is shown in Section 7, Figure 3. SEMI E43 describes measurement techniques using an electrostatic fieldmeter.

6.3.3 Electrostatic deposition velocity depends only on electric field, particle size and particle charge. However, the concentration of particles deposited on a surface also depends on the particle concentration in the equipment area and the length of the exposure time during which particle deposition occurs. Mechanisms

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other than electrostatic deposition, such as gravitational settling and diffusion, can also contribute to particle deposition. The concentration of particles deposited by these non-electrostatic mechanisms will also vary with particle concentration in the equipment ambient and exposure time.

6.3.4 Comparisons of the electrostatic deposition velocity with the deposition velocities associated with these other deposition mechanisms is the key for determining threshold values of allowed electrostatic field from the viewpoint of particle deposition. Such comparisons are the basis for estimating the allowed values of electrostatic field presented in Appendix A1-2.2 and Related Information R1-2. Users and equipment manufacturers should determine and agree on ambient particle sizes and concentrations, and product exposure times.

6.4 *Equipment ESD*

6.4.1 Equipment ESD immunity is being addressed in general through a number of international standards including IEC 1000-4-2 and EN50082-2 for European CE compliance. Measurements are made using an ESD simulator which is described in these standards.

6.4.2 The ESD simulator is used to create both a direct discharge to the surface of the equipment and an air discharge to a surface 10 cm (4 inches) away from the equipment. The ESD simulator charges a 150 picofarad capacitor (C) to a known voltage (V) and then discharges it to produce a standardized discharge waveform. Knowing the voltage and capacitance involved in this test means the total charge can be calculated by the equation q = CV. For example, a 4000 volt discharge (IEC 1000-4-2 test level) transfers a charge, q = 600 nanocoulombs.

6.4.3 The value of the capacitor (C) in the ESD simulator is specified in the international standards. It should not be assumed that a different value of capacitance and voltage that produce the same charge transfer of 600 nanocoulombs would have the same affect on a specific piece of equipment. Discharge currents will vary with the impedance of the discharge path and with the voltage. It is, however, impractical to test all possible combinations. For the purposes of this guide, the parameters of the ESD simulator specified in the standards for equipment ESD immunity will be used.

6.4.4 For true ESD immunity, an ESD event in equipment must not disturb either the equipment it occurs in, or another nearby piece of equipment. Charge on product or carriers transferred from one piece of equipment must not disturb the operation of subsequent equipment. It will be a systems issue to make sure that **all** equipment in a facility meets the required ESD immunity standards.

6.4.5 The range of reactions in equipment to an ESD event runs from *transient errors* that are automatically corrected, to *hard errors* that cannot be corrected without manual intervention or damage the equipment. While small numbers of transient errors may be acceptable from the point of view of equipment operation, they may still cause unacceptable product losses.

6.4.6 The user and manufacturer must determine with an ESD simulator what levels of ESD cause equipment interruptions. The user must determine if any of these equipment interruptions caused by ESD are acceptable.

6.4.7 In setting a level to provide ESD immunity for an individual piece of equipment from static charge on products and carriers, the charge on these items should be kept below the levels determined by ESD simulator testing.

6.4.8 The Faraday Cup measurement can be used for this purpose. If equipment has been tested for ESD immunity and passes a 4000 volt test, then total charge on product and carriers leaving this equipment should be kept below 600 nanocoulombs. Any product transferred at this level should not be handled by other equipment with a lower ESD immunity. A possible implementation of this test method is shown in Section 7, Figure 4.

7 Apparatus

7.1 *ESD Damage* — The apparatus for determining the ESD damage thresholds for products will depend on the test methods used. See Section 4 for additional information. For measuring the charge generated on product, reticles, or carriers, the Faraday Cup test method is shown in Figure 1.

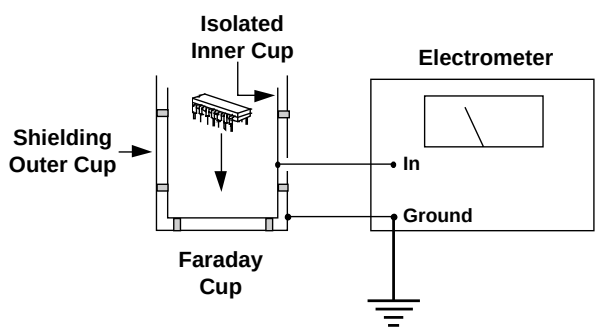

Figure 1
Faraday Cup Charge Measurement

7.1.1 The relationship between ESD simulator testing for product damage and charge measurements using the Faraday cup is shown in Figure 2.

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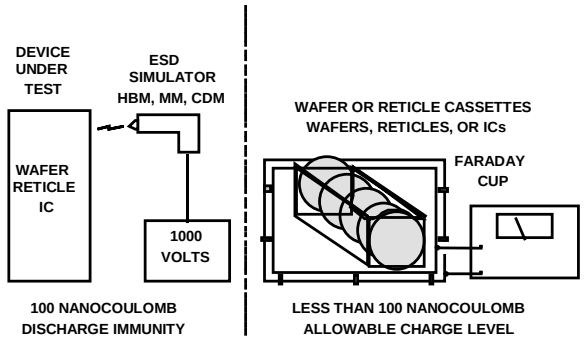

Figure 2
ESD Damage Testing

7.2 The instrument used for making electrostatic field measurements is known as an electrostatic fieldmeter. Instructions concerning its use should be obtained from the instrument manufacturer and SEMI E43. The measurement configuration shown in Figure 3 illustrates the effect of the instrument on the measurement. In most cases the presence of the fieldmeter will increase both the flux from the charged surface and the divergence of the electric field lines. The fieldmeter will generally indicate a higher value of electric field than would be present without the fieldmeter.

7.3 The instrumentation and test methods for determining the ESD sensitivity of equipment are described by IEC 1000-4-2 or other acceptable test methods. The amount of static charge determined by this test method is to be compared with the charge measured on products and carriers with the Faraday Cup test method. Figure 4 illustrates the two methods.

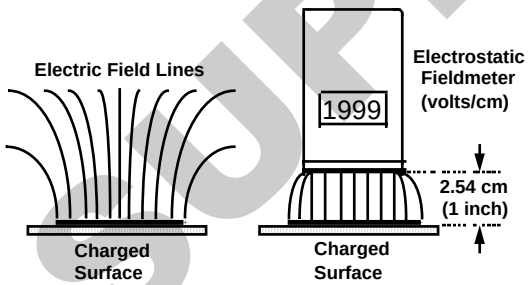

Figure 3
Electrostatic Field Measurement

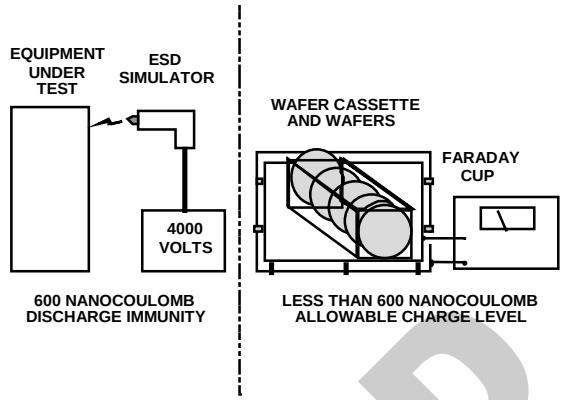

Figure 4
ESD Immunity Testing

8 Safety Precautions

8.1 *Personnel* — Static charges can create safety hazards during some semiconductor production processes. ESA or ESD events that result in the jamming or breakage of product in high speed equipment may create a personnel hazard. ESD events that produce sparks must be prevented in areas that use flammable or explosive chemicals or gases. ESD events to personnel are usually not harmful, but they may result in an unwanted reflex, or "startle" reaction. This reflex may create a personnel hazard, particularly in the vicinity of moving equipment or where caustic chemicals are in use. It may be necessary to use additional static charge control methods, beyond those used inside the equipment, to minimize these personnel hazards.

8.2 *Measurement Safety* — Users should exercise caution while making static charge measurements in the vicinity of moving parts of production equipment, or in areas where static potentials on ungrounded conductors may exceed 30,000 volts. Refer to SEMI E43 for additional measurement safety considerations.

9 Test Specimen

9.1 The user and equipment manufacturer will need to agree on:

— The type(s) of testing to be performed.

— Who will do the testing.

— The number and type of test samples.

— The number of measurements.

— Acceptable test results.

9.2 The operating history of the equipment prior to, or during testing (e.g., warm-up time, type of carrier, number of products processed, operating speed), and all appropriate environmental conditions (e.g.,

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temperature, humidity, airflow) should be agreed upon and documented.

10 Preparation of Apparatus

10.1 Depending on the type of testing to be done, consult the appropriate testing document for apparatus preparation. See Sections 4 and 16 for additional information.

11 Calibration and Standardization

11.1 Depending on the type of testing to be done, consult the appropriate testing document for apparatus calibration and verification. See Sections 4 and 16 for additional information.

12 Procedures

12.1 Refer to Sections 6 and 7 and the appropriate test methods of Sections 4 and 16.

12.2 *ESD Damage*

12.2.1 Users shall establish product damage thresholds for their products. Measurement methods for integrated circuits are described in the documents contained in Sections 4 and 16. Appropriate measurement methods for ESD damage to wafers, reticles, and other items may be adapted from the instrumentation used in these test methods. Appendix A1-2.1 and Related Information R1-1 contain additional information to select an appropriate sensitivity level to reduce ESD damage.

12.2.2 Measurement of ESD damage thresholds are made in units of nanocoulombs (nC = 10^{-9} coulombs).

12.2.3 The Faraday Cup method is used to determine the static charge levels on products, product carriers and equipment parts. Each item shall be transported to the Faraday cup in a way that does not alter its charge level. Consult the measurement equipment manufacturer's instructions for recommendations on how to achieve this.

12.2.4 Measurements should be made of products, carriers, and materials in the equipment input/exit ports after significant amounts of product have been handled under normal manufacturing conditions. Measurements should be made of products and their carriers after they have undergone normal processing in the equipment under test. Typically five measurements of products and/or carriers should be sufficient to demonstrate compliance with the selected Sensitivity Level.

12.2.5 Measurements should be made on each of three successive days after equipment has stabilized in its normal operating mode (e.g., after two hours).

12.3 *Particle Attraction*

12.3.1 Users should work with equipment manufacturers to determine ambient particle levels and product exposure times during processing. Appendix A1-2.2 and Related Information R1-2 contain information to select an appropriate Sensitivity Level to reduce electrostatic attraction of particles.

12.3.2 Electrostatic field measurements on products, product carriers, and equipment surfaces should be made in at least three different locations on any item. Locations should be separated by approximately three times the distance between the measuring instrument and the measurement location. For most electrostatic fieldmeters measuring at 25.4 mm (1 inch), the measurement locations will be 76.2 mm (3 inches) apart. Refer to SEMI E43 for additional measurement considerations. Measurements of electrostatic field are expressed in volts/cm or volts/inch.

12.3.3 Measurements should be made on products, carriers, and materials in the equipment input/exit ports after significant amounts of product have been handled under normal manufacturing conditions. Measurements should be made of products and their carriers after they have undergone normal processing in the equipment under test. Typically five measurements of products and/or carriers should be sufficient to demonstrate compliance with the selected Sensitivity Level.

12.3.4 Measurements should be made on each of three successive days after equipment has stabilized in its normal operating mode (e.g., after two hours).

12.4 *Equipment ESD*

12.4.1 Equipment manufacturers should determine the effects of ESD on their equipment using an ESD Simulator and the appropriate test methods (IEC 1000-4-2 or others). Users should agree on the types of equipment interrupts that are acceptable (if any). Appendix A1-2.3 and Related Information R1-3 contain additional information to select an appropriate sensitivity level to reduce ESD-related equipment interruptions.

12.4.2 Compliance with the desired Sensitivity Level may be demonstrated using the Faraday Cup method described in Sections 6.4 and 7.3.

12.4.3 Measurements should be made on products, carriers, and materials in the equipment input/exit ports after significant amounts of product have been handled under normal manufacturing conditions. Measurements should be made of products and their carriers after they have undergone normal processing in the equipment under test. Typically, five measurements of products and/or carriers should be sufficient to demonstrate compliance with the selected Sensitivity Level.

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12.5 Equipment used in semiconductor manufacturing should meet the following levels shown in Table 1 for protection from problems caused by static charge.

Table 1 Recommended Sensitivity Levels

	Electrostatic Discharge (Nanocoulombs)	*Particle Attraction (Volts/cm)*	*Equipment Malfunction (Nanocoulombs)*
Level 4	100	4000	1200
Level 3	50	400	600
Level 2	10	200	300
Level 1	1	100	150

12.5.1 Sensitivity Level 4 compliance means that products, reticles, and carriers can leave the equipment with up to the recommended amounts of static charge or electrostatic field measured on them according to the test method used. This level essentially states that the equipment is used in a process that has no significant problems handling charged product, nor are there issues associated with contamination or ESD damage.

12.5.2 At levels 1, 2, or 3 a decision should be made as to what is the most serious static charge problem. The Sensitivity Level and test methods are chosen accordingly. The lower the level of static charge allowed, the more static control measures the equipment manufacturer may need to install.

12.5.3 Level 1 may be used primarily by manufacturers of specialized components such as: gallium arsenide semiconductors or magneto-resistive (MR) disk drive read heads; those experiencing significant losses due to contamination; or those using specialized equipment with low immunity to ESD or EMI.

12.6 The levels listed in Table 1 have been determined as the result of analysis of working conditions, or experiments done in operating semiconductor facilities. Justifications for these levels are found in Appendix 1. The actual levels to be used for any piece of production equipment may be decided by agreement between the user and manufacturer of the equipment.

12.7 Other levels may be appropriate under specific equipment conditions and for specific devices.

13 Calculations

13.1 A series of five measurements should be made. The average of the five measurements should not exceed the recommended level.

14 Reporting Results

14.1 Data records should contain the following information:

— Description of equipment under test including model and serial numbers.

— Description of the equipment operating conditions and environment.

— Measurement equipment and last calibration date.

— Description of objects measured and measurement locations.

— Humidity and temperature at measurement location when measurements were made.

— Results of measurements.

— Personnel making the measurements.

— Any other relevant comments.

15 Precision and Accuracy

15.1 *Accuracy of Test Methods* — The test methods referenced in this document do not guarantee precise measurements of static charge levels. Similarly, maximum static charge levels recommended in this document are not stated as precise requirements. Accuracy of approximately ± 20% is acceptable in all measuring instrumentation. At low static charge levels or for more accurate measurements, alternative instrumentation and test methods may need to be used.

16 Related Documents

16.1 *EIA/JEDEC Standards*

EIA/JESD22-A114 — Electrostatic Discharge (ESD) Sensitivity Testing Human Body Model (HBM)

EIA/JESD22-A115 — Electrostatic Discharge (ESD) Sensitivity Testing Machine Model (MM)

Test Method C101 — Field-Induced Charged-Device Model Test Method for Electrostatic Discharge Withstand Thresholds of Microelectronic Components

16.2 *Other Documents*

EN 50082 — Generic Immunity Standard for CE Compliance, CENELEC European Union

MIL-STD 883C — Notice 8 – Method 3015.7 – Electrostatic Discharge Sensitivity Classification

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