



Electrostatic Discharge Overview

Background/Overview:

If you've ever been "shocked" after walking across a new carpet you've witnessed the creation of electrostatic charge and the effects of electrostatic discharge (ESD). For two kids trying to "shock" each other this can be great fun, but for modern electronics and semiconductors the same effects can cause severe damage. When left unchecked electrostatic charge accumulation and ESD can damage electronic devices, contaminate manufacturing areas, increase development time, reduce product yields, affect product reliability and have significant detrimental cost impact ranging from a few cents for a single damaged device to billions of dollars per year industry wide.

This application note provides a brief introduction to the basic principles of ESD, the models used to evaluate and characterize electronic devices sensitive to ESD and some precautions for preventing ESD damage. Also included is a bibliography and reference listing informational resources for more in-depth study. This is an informative overview and it is highly recommended that additional, more detailed resources be considered before dealing with ESD and related issues.

Description of Electrostatic Charge:

Static charging is a natural, physical phenomenon that occurs in many ways. An imbalance of electrons on the surface of a material produces static electricity: a measurable electric field capable of affecting both objects it contacts and objects at a distance. An electrostatic charge is considered to be an electric field; however, it is most commonly referred to as a voltage level. ESD is the transfer of charge between two bodies of unequal electrical potentials. The drive for higher speed and increasing performance is resulting in ever-smaller electronic devices thus causing today's state-of-the-art semiconductors to be increasingly more sensitive to the damaging effects of ESD. ESD can cause both catastrophic affects with immediate impact and latent damage resulting in reduced performance over time. ESD damage is often difficult to identify, frustrating to isolate and costly to fix.

Electrostatic charge is most commonly caused by the physical contact and separation of two materials. This physical contact can be rubbing, sliding, banging or other similar, intimate contact interaction. The contact and separation process transfers negatively-charged surface electrons from one material to the other thereby creating a negative charge on one surface and a positive charge on the other. This is called triboelectric charging and can occur with virtually any type of material—even water and dirt. Figure 1 lists some of the most common materials in the triboelectric series and their tendency toward charge polarizations.

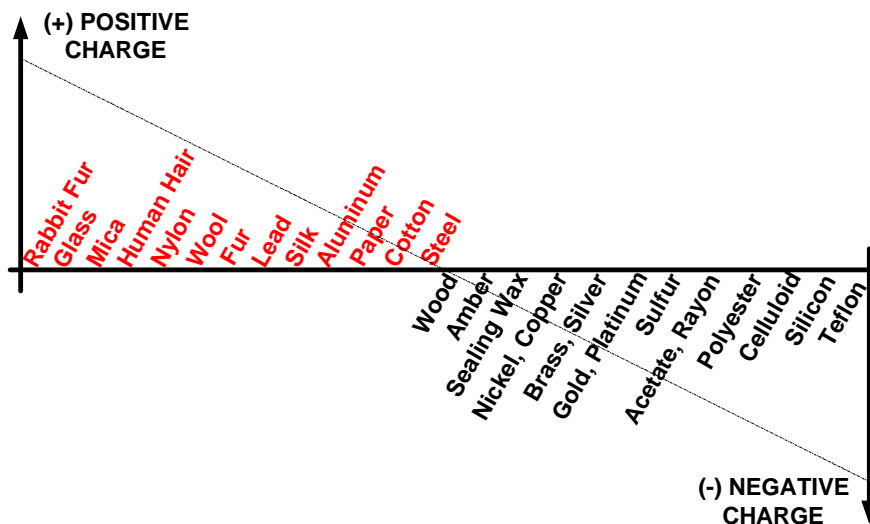


FIGURE 1: Triboelectric Series Examples



The charge level (magnitude and polarization), charge storage characteristics and discharge properties depend on the material properties, the physical environment (moisture level, temperature, etc.) and many other factors. Insulative materials have high electrical resistance (surface and volume resistivity), are capable of storing large surface charge levels and can even sustain localized positive and negative surface charges simultaneously. Electrical charge does not readily flow through insulators, so charge can be stored for long periods of time. Conductive materials' low electrical resistance properties enable efficient charge flow through the material. Electrons flow easily through conductive materials and readily travel between materials when two conductors come in physical contact. Accumulated charge is uniformly distributed through the conductive material and readily dissipated when connected to an earth grounding point. Earth grounding a conductor "neutralizes" electrostatic charges. Static dissipative materials' electrical resistance values are typically higher than conductors and lower than insulators.

Since electrostatic charge is an electrical field phenomena, charged materials have field lines in space that can affect other materials in the field through induction. Conductive and dissipative materials brought within the influence of an electric field can become polarized while in the field. While the overall charge of the material does not physically change, surface polarization occurs. If the polarized material then exits the electrical field, it returns to its original polarization. However, if the material touches ground or other materials charge can transfer and the polarized material will have a new overall charge.

ESD and ESD Models:

ESD is the transfer of electrostatic charge from one material to another. This occurs when the two materials are of unequal charge levels. ESD events can occur when two materials come into physical contact or under the influence of electric fields: field induction. Electronic devices susceptible to the damaging effects of ESD are called electrostatic discharge sensitive (ESDS) devices. Charge can be discharged to the ESDS device or from the ESDS device. There are three main models used to understand, characterize and categorize ESDS devices.

A system of measuring and classifying ESDS devices enables people handling devices to better understand the susceptibility of each part to ESD damage, and it's a convenient means of classification. Please note that the models described herein are generally accepted as the standardized baseline. However, like any model they are an attempt to simulate real world scenarios and may not be exact.

Probably the most common cause of electrostatic damage is the transfer of charge from the human body or a charged material directly to the ESDS device. This is simulated using the human body model (HBM). Figure 2 shows the basic test schematic for the HBM with the detailed testing procedure being outlined in MIL-STD 883 Method 3015 and the ESD Association's ESD STM5.1. If the charged material is conductive then the machine model (MM) is used. The machine model is intended to simulate improperly grounded equipment and is not especially relevant. Figure 3 shows the basic test schematic for the MM with the detailed testing procedure is outlined in the ESD Association's ESD STM5.2. It is important to note that the MM test circuit is similar to the HBM circuit; however, the MM is considered to be a more rigorous test since the charge is delivered directly to the device under test and not through a 1.5 KΩ resistor.

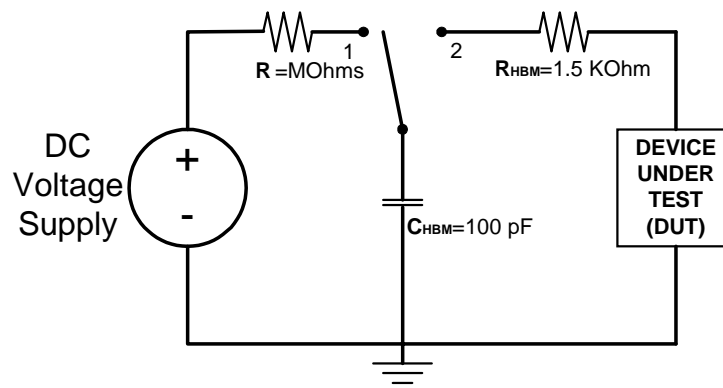


FIGURE 2: Human Body Model (HBM) ESDS Device Sensitivity Test Circuit

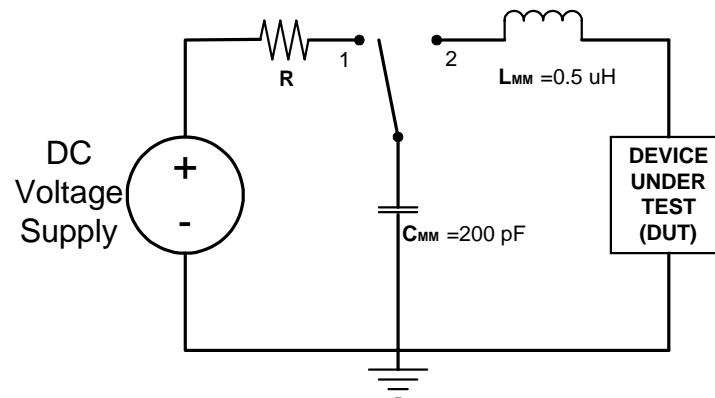


FIGURE 3: Machine Model (MM) ESDS Device Sensitivity Test Circuit

Charge can also accumulate on the ESDS device itself—through handling or contact with packaging materials and work surfaces for example—and then transfer via an ESD event to something else. For example a charged device coming off a surface mount reel feeding an automated placement machine could dissipate its charge upon contact with a machine surface connected to earth ground. This phenomenon is simulated using the charged device model (CDM). Also, if an ESDS device is grounded while polarized by the influence of an electrical field the flow of charge is an ESD event characterized by the CDM model. Figure 4 shows the basic test apparatus for the CDM with the detailed testing procedure being outlined in JESD22-C101-A.

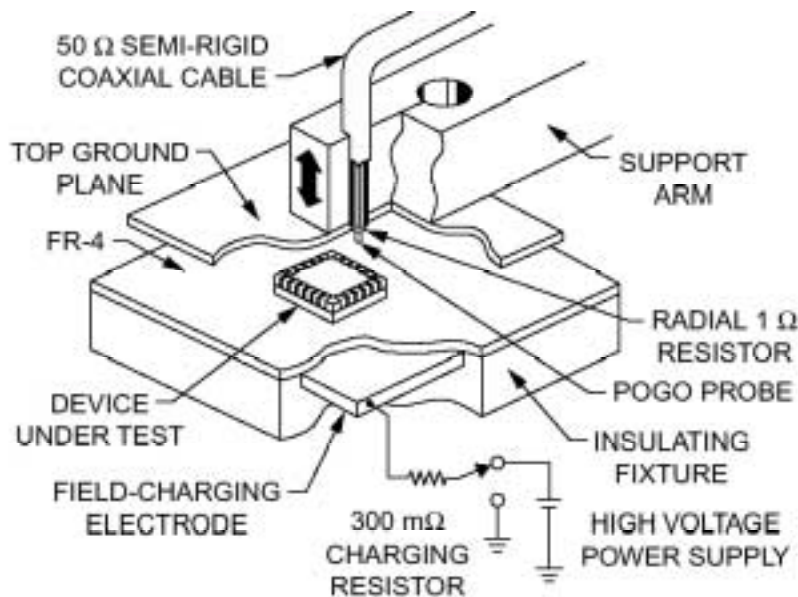


FIGURE 4: Charged Device Model (CDM) ESDS Device Sensitivity Test Circuit

Table 1 lists the ESDS device classifications and voltage levels criteria associated with the three ESD models. The specific test set-up and conditions are beyond the scope of this introductory application note. For further detail please refer to the reference lists at the end of this document.



TABLE 1: ESDS Device Model Classifications, Criteria & Reference Documents

ESD SIMULATION MODEL	CLASSIFICATION LEVEL	CRITERIA
Human Body Model (HBM) Ref. ESD STM5.1-1988	Class 0	< 250 volts
	Class 1A	≥ 250 to < 500 volts
	Class 1B	≥ 500 to < 1,000 volts
	Class 1C	≥ 1,000 to < 2,000 volts
	Class 2	≥ 2,000 to < 4,000 volts
	Class 3A	≥ 4,000 to < 8,000 volts
	Class 3B	≥ 8,000 volts
Machine Model (MM) Ref. ESD STM5.2-1999	Class M1	< 100 volts
	Class M2	≥ 100 to < 200 volts
	Class M3	≥ 200 to < 400 volts
	Class M4	≥ 400 volts
Charged Device Model (CDM) Ref. JESD22-C101-A	Class I	< 200 volts
	Class II	≥ 200 to < 500 volts
	Class III	≥ 500 to < 1,000 volts
	Class IV	≥ 1,000 volts

ESD events of all types can be potentially damaging to ESDS devices. An individual ESDS device may be at ESD risk from any or all three of the simulated ESD event model types (HBM, MM and CDM) during the normal course of unpacking, loading into an assembly machine, assembling, inspecting and packaging. In today's often-outsourced, automated-assembly environment it is important to ensure all levels of the supply chain—from device suppliers to contract assembly manufacturers to consumers—are aware of ESD issues and have proper procedures in place to prevent or minimize ESD damage. The charged device model is especially applicable to automated surface-mount assembly lines utilizing a high level of machine automation with a minimal level of physical human contact of individual piece parts. Even so, packaging, handling, proper machine grounding and many other issues can come into play.

WJ does sensitivity testing and classification for both HBM and CDM. Knowing the ESD sensitivities of WJ parts enables customers to design, handle and use parts in a manner that maximizes production yields, ensures long-term reliability and reduces manufacturing costs. Table 2 lists examples of WJ devices and their corresponding ESD classification levels.

TABLE 2: A Sampling of WJ Devices and the Corresponding ESD Model Classifications

WJ DEVICE	HUMAN BODY MODEL (HBM)	CHARGED DEVICE MODEL (CDM)
AH1	Class 1B	Class IV
AH11	Class 1B	Class IV
AH2	Class 1B	Class IV
AH22	Class 1B	Class IV
AH3	Class 1B	Class IV
AH101	Class 1C	Class IV
AH102	Class 1C	Class IV
AM1	Class 1B	Class IV
AG101	Class 1B	Class IV
HMJ7	Class 2	Class IV
MH1	Class 1B	Class III
MH101	Class 1B	Class III
MH102	Class 1B	Class III



ESD Control:

Understanding the properties of electrostatic charge and ESD is the first step in preventing or minimizing ESD damage. There are two main approaches to preventing damage: changing the sensitivity of the ESDS device and changing the environment around the ESDS device.

One of the most effective means of reducing ESD damage is to modify the ESDS device to reduce its sensitivity level. This often entails adding ESD protection on and/or across various input and output ports of the device. This protection doesn't come for free, and there is usually a performance trade-off that is made. Furthermore, as technology advances and device geometries get smaller, they generally become increasingly more sensitive to ESD damage. As such, providing ESD protection is ever more challenging.

The other main approach to minimizing the effects of ESD damage is to change the environment around the ESDS device. This is part of a greater ESD control program that includes analyzing the environment, identifying and defining electrostatic protected areas, defining processes for dissipating and neutralizing static charges and protecting products during handling. Additionally, an encompassing ESD control program should also include documentation, training, testing and auditing elements to validate the overall effectiveness of the program on a periodic or continual basis.

Electrostatic protected areas typically include but are not limited to receiving, inspection, storage, assembly, test, in-process inspection, packaging, shipping, engineering and R&D labs, clean rooms and service/repair areas. It is important to identify any area handling or using ESDS devices as an electrostatic protected area and then to take appropriate steps to dissipate and neutralize electrostatic charge. The specific, detailed requirements for ESD protected areas is beyond the scope of this document but well documented in some of the references listed at the end of this document. However, some of the most common elements are summarized as follows:

Wrist Straps – Since people naturally generate static charge it is important to bleed of that charge before handling ESDS devices. Wrist straps connect people to ground to dissipate this charge and must be worn in a proper manner making skin contact. Additionally, wrist straps must be monitored regularly for proper operation (daily testing is recommended).

Floor, Floor Mats & Floor Finishes – Special floors and floor finishes can also be used to provide grounding of personnel. To do so the conductive floor must be connected to ground. When personnel using foot straps or special footwear contact the floor any accumulated charge is dissipated. Flooring not only dissipates static charge, but by its very nature it helps to reduce some triboelectric charge creation. Furthermore, it can help to reduce charge accumulation of carts, chairs and other objects in physical contact with the floor.

ESD Clothing – Special clothing is often used for cleanliness purposes in clean rooms (so called “bunny suits”) but can also be used to reduce electrostatic charge creation and induced fields common with typical clothing. Special smocks covering all personal garments above the waist except for the neck area are very common and effective. For full effectiveness it is important that the smocks fit properly, are kept clean, are closed at the cuffs and cover all clothing above the waist and up to the neck.

Workstations and Work Surfaces – A workstation is any place where ESDS devices are handled or processed. It is important that all workstations be properly grounded. This can include both a common ground for the workstation and a connection to earth ground. Where both are used they should be connected together at a common point. Proper grounding reduces the accumulation of charge and enables the neutralization of any charges that do exist. Work surfaces are typically covered with special mats or finishes that are conductive and allow the dissipation of charges to ground. It is important that workstation surfaces be kept clean and free of food or personal items. It is also important to note that workstations may be used in conjunction with wrist straps or other additional items for maximum effectiveness. Some items often used in manufacturing—like paper and transparent tape—can accumulate large static charges. It is a good practice to only use these items at workstations when absolutely necessary.



Equipment Grounding – It is absolutely critical that all equipment handling ESDS devices be properly grounded. All AC power connections should be grounded in accordance with appropriate city, state and national electrical codes.

Ionizers and Antistats – It is not always possible to ground insulative materials. Air ionizers can be used to produce a localized charge of opposite polarity to dissipate charge accumulated on insulative materials. Topical antistats sprays may be another option for items that are particularly difficult to ground. In general these items do not replace the need for proper and effective grounding.

Handling & Packaging – ESDS devices need to be handled and packaged in a manner that is not damaging. Special tote boxes and parts trays are made of static dissipative material to reduce accumulated charges and the potential for damage. Conductive surfaces act like a Faraday cage by dissipating surface charges to ground (not to the ESDS devices). Special packaging materials also made of conductive materials are available. Typical packaging materials like polystyrene plastic peanuts and plastic bubble wrap are insulators and should not be used with ESDS devices without other ESD packaging protection (such as shielded bags, totes and trays). All packaging materials and containers should be marked with ESD warning signs and placards (see the next paragraph).

Signs and Placards – It is very important to identify ESDS devices in an easily recognizable fashion. Figure 5 shows the ESD susceptibility symbol that should be used to identify ESDS devices that need to be handled appropriately. This should be used on shipping and packaging materials. Figure 6 shows the ESD protective symbol which is applied to ESD protective materials. Figure 7 shows examples of other common ESD markings.

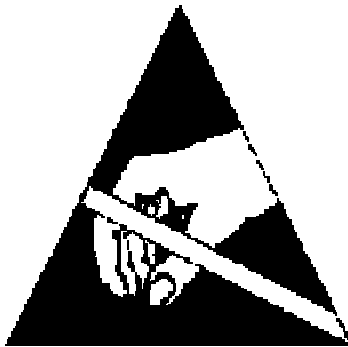


FIGURE 5: ESD Susceptibility Symbol



FIGURE 6: ESD Protective Symbol



FIGURE 7: Common ESD Markings

Any ESD control plan should include periodic testing to verify efficacy. Testing specifications and intervals are defined in numerous documents. An effective plan should include training of all personnel handling parts including management. Periodic audits are one method for validating if an ESD control plan is being adhered to, and also help identify areas needing improvement.



Summary:

Electrostatic charge accumulation and the damaging effects it can have on modern electronics is important to understand. Understanding is the first step in analyzing part susceptibility and taking steps to reduce damage.

It is important to note that this application note is intended as an introductory overview only. It is strongly suggested that any reader interested in the subjects discussed herein conduct further, in-depth research. Standards evolve over time and any of the above information could become antiquated at any time. A thorough listing of references is appended to this document to help aid further research in the important, complex and often-misunderstood subject of electrostatic discharge.

Bibliography:

Field-Induced Charged-Device Model Test Method for Electrostatic-Discharge-Withstand Thresholds of Microelectronic Components, JEDEC Standard JESD22-C101-A (Revision of JESD22-C101), June 2000.

Fundamentals of ESD, Electrostatic Discharge Association, <http://www.esda.org/>.

MIL-STD 883E, Test Method 3015.7, 22 March 1989.

Protection of Electrical and Electronic Parts, Assemblies, and Equipment (Excluding Electrically Initiated Explosive Devices), ANSI/ESD 20.20-1999, Approved August 4 1999.

Requirements for handling Electrostatic-Discharge-Sensitive (ESDS) Devices, JEDEC Standard JESD625-A (revision of EIA-625), December 1999.

References:

ANSI/ESD S6.1-1991: Grounding—Recommended Practice.

ANSI/ESD S7.1: Floor Materials -- Resistive Characterization.

ANSI/ESD S8.1-ESD Awareness Symbols.

ANSI/ESD S20.20-1999--Standard for the Development of an ESD Control Program

ASTM-257-DC Resistance or Conductance of Insulating Materials.

Compliance Engineering Magazine online. <http://www.ce-mag.com/ARG/toc.html>.

EIA 541: Packaging Material Standards for ESD-Sensitive Items.

EIA 625: Requirements for Handling ESD-Sensitive Devices.

EN100015 - Protection of Electrostatic Sensitive Devices.

ESD ADV1.0-1994: Glossary of Terms.

ESD ADV2.0-1994: ESD Handbook.

ESD ADV53.1-1995: ESD Protective Workstations.

ESD Association, 7900 Turin Road, Building 3, Rome, NY 13440, Phone: 315-339-6937. Fax: 315-339-6793,

<http://www.esda.org>.

ESD S1.1-1998: Evaluation, Acceptance, and Functional Testing of Wrist Straps.

ESD S11.11 for Shielding Bags.

ESD STM2.1-1997: Resistance Test Method for Electrostatic Discharge Protective Garments.

ESD STM5.1-1998 Revised: Electrostatic Discharge Sensitivity Testing -- Human Body Model.

ESD STM5.2-1999 (Revised): Electrostatic Discharge Sensitivity Testing -- Machine Model.

ESD STM5.3-1999: Electrostatic Discharge Sensitivity Testing - Charged Device Model.

MIL-B-81705: Barrier Materials, Flexible, Electrostatic Protective, Heat Sealable.

MIL-HBDK-263B: Electrostatic Discharge Control Handbook for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices).

MIL-PRF 87893-Workstation, Electrostatic Discharge (ESD) Control.

MIL-STD-129-Marking for Shipment and Storage.

MIL-STD-1686C: Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices).