

What is static electricity, and why are we concerned about it?

Static electricity is the charge that builds up on dissimilar materials when they are brought together then separated. We've all experienced static electricity in our houses during the winter, when walking on the carpet causes static to build up on our bodies. Touching another object will cause a static shock. The shock is created by the difference in electrical potential of the two materials being equalized (i.e. electron movement between the two materials). Notice that neither material is assumed to be grounded - all that is required is a difference of electrical potential.

Charges collect on all materials including insulators, partial conductors, and conductors. The amount of time that the charge remains on the material is dependent on the conductivity of the material, and the impedance to ground. Insulators collect the highest levels of static charge, since both conductors and partial conductors dissipate the static charges faster. When the stored static charge is quickly transferred to another material (or to ground) it is called an "electrostatic discharge", or ESD event.

The reason that ESD events are catastrophic to semiconductor devices is because the energy contained in an ESD event is concentrated into a short time period. Several thousand volts at currents of many amps are common in an ESD event, and the event is over in less than a hundred nanoseconds. When this energy is applied to a semiconductor circuit it is likely to cause immediate device failure. It can also weaken the internal structure of the device causing a higher probability of failure in the future.

How does static charge build up?

Triboelectric charging is the term describing how static charges build on the surface of dissimilar materials when they are brought into close contact with one another, then separated. The charge is caused by a movement of electrons from one material to the other. The triboelectric series (shown in appendix "B") shows some common material types, ranked in order of their affinity to collect positive or negative charges. Depending on what the two materials are and their relative location within the triboelectric series it can be shown which of the two materials will become more positively charged, and which will become more negatively charged. Even identical materials (i.e. plastic storage trays) can become charged when stacked and unstacked due to the presence of

impurities on their surface. Dirt, moisture, contamination or other surface impurities can cause identical objects to appear in different positions within the triboelectric series.

Environmental variables also contribute to the amount of charge built up on an item, and the amount of time it takes for the charge to be dissipated in free air. Charge buildup is a greater problem in the wintertime, when dry heat removes moisture from the air and static charges are not dissipated. Using humidifiers to increase the level of free air humidity (to a minimum of 40% R.H.) is one of the simplest things that can be done to help reduce the amount of static charge buildup.

If static charges are present a deionizer should be installed to flood the air with positive and negative ions. The ions that are of opposite polarity to the static charge will be attracted to them and neutralize them. There must be an adequate number of free ions available and they must be located in close proximity to the static charges that have built up for the neutralization to take place.

What does an ESD waveform look like?

ESD pulses have been modelled in several ways over the last several decades. The common modelling methods are called the Human Body Model (HBM), Machine Model (MM), Charge Device Model (CDM) and EURONORM model. These four models represent different types of static discharge events, and should be used in combination to model ESD events that may occur. Table 1 shows the four ESD models, and the type of ESD discharge each represents.

The HBM and CDM are currently thought to be the best models to use for representing an ESD event. When components are connected via wiring harnesses to other subassemblies the EURONORM model is also applicable. Some details of each of the representative models are documented in the following sections.

Table 1:

ESD Model:	Represents:
Human Body (HBM)	The charge from a human being, resistively discharged to a device.
Machine (MM)	The charge stored on handheld tools & mechanical test equipment. Similar to the HBM, but the discharge is through a zero ohm resistor.
Charged Device (CDM)	The charge carried by an integrated circuit as it moves through integrated circuit manufacturing, test, symbolization, or packaging equipment.
EURONORM (IEC 1000-4-2)	The charge buildup on multi-conductor cables when the cable insulation is rubbed together.

Human Body Model (HBM)

The Human Body Model was initially developed to simulate the charge stored on a person, then discharged through a device. Electrically the circuit can be represented as shown in Figure 1.

The representative charge on a human body is collected on capacitor C1, when the switch is in position 1. When the switch is moved to position 2, the energy stored in the capacitor is discharged through the R1 resistor and the device under test (DUT). The short and resistor R2 are only used during equipment qualification, and switch S2 is used at the end of a test to remove any residual charges from the device.

One of the most prevalent problems with the HBM in the past was determining what value to use for C1 and R1. Correlations between testers was nearly impossible because many values were used for the resistor and capacitor, and everybody thought their

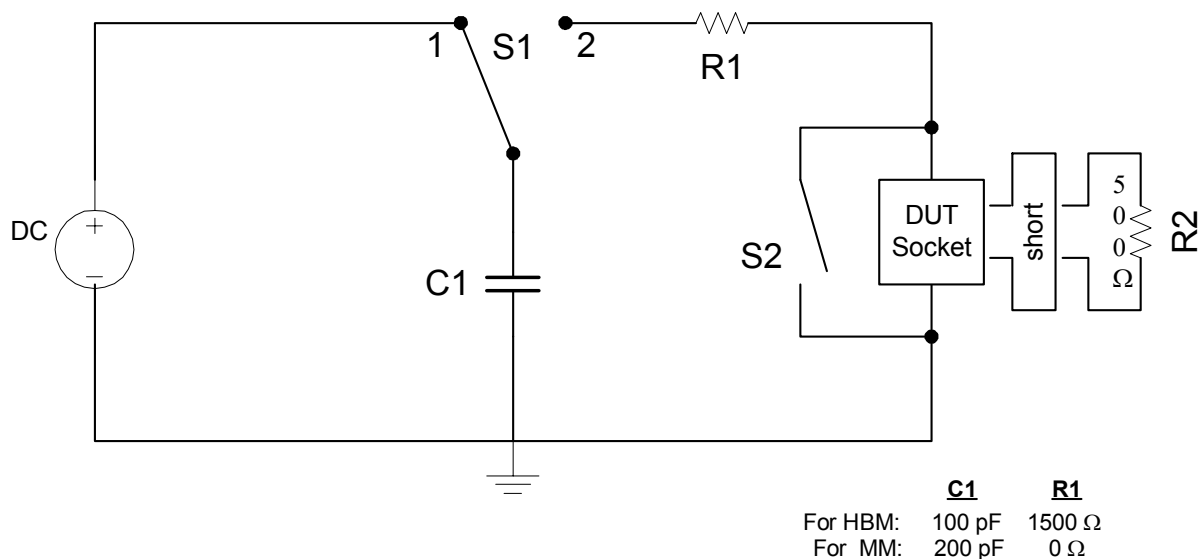
values modelled a human body discharge the best. The US military resolved the problem when they documented MIL-STD-883 Method 3015 in 1979. They specified the values shown (1500 ohms, 100 pF) for use in the HBM ESD test.

Even with the capacitor set to 100 pF, and the resistor at 1500 ohms there is still no consensus that this test accurately models an ESD charge from a human body. However, the HBM gave everyone a benchmark test that could be performed, allowing devices to be compared using standardized test procedures.

When performing HBM testing the voltage across capacitor C1 is selectively increased until the device under test (DUT) fails. Voltages as high as 8KV can be used in this test. Semiconductor materials are classified into categories based on the voltage at which point the device fails. The classification table is shown in Table 2:

Table 2: HBM ESDS Classification (JEDEC JESD22-A114-B)

HBM Class	Failure Criteria
Class 0:	Fails at 250 volts or less.
Class 1A:	Passes 250 volts but fails at 500 volts.
Class 1B:	Passes 500 volts but fails at 1000 volts.
Class 1C:	Passes 1000 volts but fails at 2000 volts.
Class 2:	Passes 2000 volts but fails at 4000 volts.
Class 3A:	Passes 4000 volts but fails at 8000 volts.
Class 3B:	Passes 8000 volts.

Figure 1- HBM & MM Electrical Equivalent


Machine Model (MM)

The machine model is equivalent to the human body model (Figure 1), although the value of R1 is zero (0) ohms and capacitor C1 is 200 pF. The currents seen in the machine model are very high, since there is no current limiting resistor (R1) present in the discharge path. This model emulates the discharge of static electricity from the tip of a handheld tool. It also emulates the static charge generated by equipment in an automated assembly area, such as improperly grounded pick & place machines, mechanical transports, or testers. It has fallen out of favor because stray impedances (due to bond wires) and resistances have a significant effect on the resulting discharge waveform.

Charged Device Model (CDM)

Both the machine model and the HBM assume that the charge is carried by an external presence, which is then discharged through a grounded device. Studies of semiconductor fabrication facilities has proved that more often charge is collected on the surface of the device as it is handled and moved from location to location, and the discharging happens when the device is placed into contact with a grounded piece of equipment. Devices sliding through tubes or handlers collect static charges, and an ESD event is triggered

when it hits a grounded mechanical stop or socket somewhere along the line. The CDM is a good model to use for replicating ESD events that happen in an assembly line, both at the manufacturers site and also at a board assembly area.

The most common CDM model used is called the Field Induced CDM. A device passing through, or sufficiently close to an electrostatic field ends up with a static charge on it. The change in field strength as the device moves through the field will cause a current flow to be generated in the device. Either this current flows to ground through some path, or static builds up on the device.

The testing procedure has been documented by JEDEC as JESD22-C101-A.

Table 3 shows the ratings for devices that have undergone CDM testing. Notice that the classification is different than the standards used in the HBM tests.

Table 3: CDM ESDS Classification (JEDEC JESD22-C101-A)

CDM Class	Failure Criteria
Class I:	Fails at 200 volts or less.
Class II:	Passes 200 volts but fails below 500 volts.
Class III:	Passes 500 volts but fails below 1000 volts.
Class IV:	Passes 1000 volts.

Comparisons of ESD sensitivity ratings

The tables shown (Table 2 and Table 3) identify which classification category a device falls into when performing a HBM or CDM test. For HBM testing, the charge is stored on an external capacitor (C1 in Figure 1), then discharged through the DUT through an external resistor. In the CDM test the charge is stored in the capacitance associated with the DUT itself, then the ESD event is triggered by touching a device pin to ground through a 1 ohm resistor. Variations in capacitance and resistance used in these tests will affect the resulting ESD waveform that is presented to the device, making ESD testing correlation a difficult task to achieve.

The use of a classification category (i.e. passing at 500 volts, but failing at 1000 volts) allows devices to be tested and placed into a grouping with similar parts. If manufacturers were to specify their ESD sensitivity with finer resolution they would need to be much more careful to identify the exact set of test conditions being used to achieve their rated level. Environmental factors such as relative humidity would need to be disclosed, and all stray parasitic elements (inductances, capacitances, and resistances) would also need to be measured and disclosed. The classification grouping provides an easier system for users interested in comparing the robustness of the ESD protection provided by designers on their devices.

What handling procedures should be followed?

So what can be done to reduce the accumulation and dissipation of static electricity on semiconductor devices? The list below shows things that should be done as standard operating procedure whenever static sensitive devices are being transported or used:

- Operators should wear conductive ESD wrist straps, connected to a good earth ground. Straps

should be worn snugly, and conductive lubricant can be used to ensure a good contact with the skin. The resistivity of the wrist straps should be between 500 KW and 10 MW. Continuous monitoring alarms are recommended.

- Flooring - ESD protective flooring or floor mats are required when floor grounded devices (ESD protective footwear, or mobile ESD protected workstations) are used. Flooring or floor mats should be connected directly to an ESD ground.
- ESD ground connections should be made using firm fitting electrical connections like metallic crimp connectors, snaps, or banana plugs. Using alligator clips to achieve ground is not recommended.
- ESD smocks should be fully buttoned when worn. Cleaning instructions provided with the smocks should be adhered to.
- Workbenches should be well connected to ground.
- Portable equipment should be well connected to ground after being positioned.
- All ESD sensitive devices received in ESD protective packaging must not be opened anywhere except at an ESD protected area.
- All ESD sensitive devices should be packed in ESD protective packaging when not at an ESD protected area or workbench.
- When antistatic tubes, trays, magazines or carriers are used as transport containers the container should also be placed inside a static shielded bag.
- Applying or removing labelling tape from a package container should not be done with devices inside.

- Relative humidity should be maintained at 40% minimum R.H. at all times.
- Air ionizers will reduce/eliminate static charges if used properly. There should be an unrestricted path between the ionizer and the unprotected devices. Instructions provided with the ionizers should be followed to achieve the proper dispersion of ions.
- Desoldering tools should be purchased that are made of antistatic plastics. Although triboelectric charging will still take place, the charge will be dissipated away from the nozzle more rapidly, reducing the chance of damage to components.
- Soldering stations should be purchased that have good electrical grounding, including the tip of the soldering iron. Handheld testers should be used to verify that static charges are not building up on the tip of the device.
- Appliances provided with three terminal electrical plugs should be plugged into three terminal electrical outlets. Three wire to two wire adapters should not be used.

they may not handle a lot of power, they are fast enough to respond to the onset of the ESD pulse. A low capacitance TVS array is also shown, and may prove useful at low frequencies. The following parts could be considered to help protect the RF amplifier:

- Agilent -- HSMS-8101, or HSMS-8202
- Agilent -- HSMP-482x (RF Limiter diode)
- ON Semi / Philips / Zetex -- BAV-99
- ProTek Devices -- GBLCxx (TVS diodes)

Evaluation of circuit performance with ESD protection diodes needs to be done using the actual PCB layout, board material, input signal sources, and components specified in the bill of materials to ensure that RF performance is not compromised. The addition of a few picofarads of capacitance or a few nanohenries of inductance can be significant at RF frequencies. At lower frequencies the additional capacitance and inductance of the protection diodes may not impact the RF performance very much, but there is always a point (as frequency is increased) where the parasitics will cause the amplifier match or tuning to become poor. When this happens the amplifier gain and/or return loss becomes inadequate, and the protective diodes cannot be used.

Circuit Design Options

Designers may be able to add protective devices (Schottky diodes are generally used) to shunt an ESD event to ground, or clamp it non-destructively to a supply rail. The diodes need to be connected between the ESD entry point, and the pin of the semiconductor device. Some possible alternatives are shown in Figures 2 - 4 below.

The diodes used need to have a very low capacitance associated with them. RF Schottky, mixer, pin, detector, and limiter diodes all have very low capacitance. While

Summary & Closure

This document has given a brief overview of what static electricity is, described how static charges are generated, mentioned the four most common modelling techniques used to generate ESD waveforms that emulate a real-world ESD event, presented some handling procedures that should be used when handling, shipping, or transporting ESD sensitive electronic devices, and described some possible external protection networks that might be evaluated.

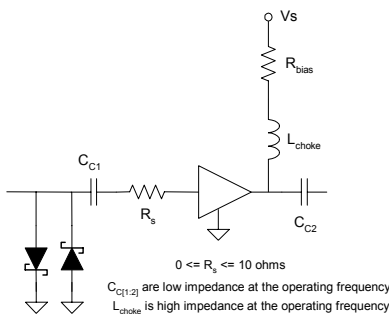


Figure 2

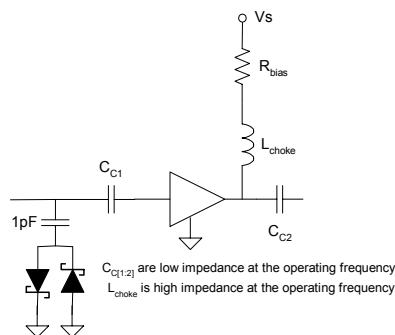


Figure 3

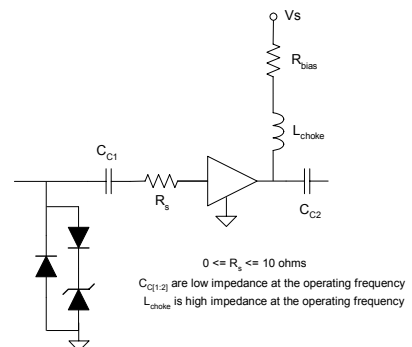


Figure 4

Since static charges are not detectable by the five human senses (sight, sound, taste, smell, or touch) we are often oblivious to their presence until an ESD discharge happens, and by then it may be too late if a sensitive electronic component is being handled. Smaller ESD events may not even be noticed by a person if they are distracted or if the static shock is not very large. Unfortunately, even a "small" ESD event can have enough concentrated energy to destroy a sensitive electronic component.

Meters are commercially available to show the amount of static charge present, and these should be used regularly to detect a buildup of static electricity. They are not expensive (\$350 - \$700 will buy a decent one), and only need to be held within an inch of the material being tested for static buildup. The level of static charge is generally displayed on an LCD screen.

Although we are not recommending any of the following manufacturers specifically, the following companies make static meters:

- **ACL Inc.**
(847) 981-9212
(800) 782-8420
- **Desco Industries**
(909) 627-8178
- **Electrostatics Inc**
(888) 782-8427
- **Exair**
(800) 903-3322
- **Ion**
(510) 548-3640
(800) 367-2452
- **Kernco Instruments**
(800) 325-3875
- **Lemke Diagnostics GmbH**
(+49) 35207 863-0
- **Simco**
(215) 997-0590
(800) 538-0750
- **SPI/Westek**
(800) 508-6594

- **3M**
(800) 328-1368
- **TREK**
(716) 798-3140
(800) 367-8735

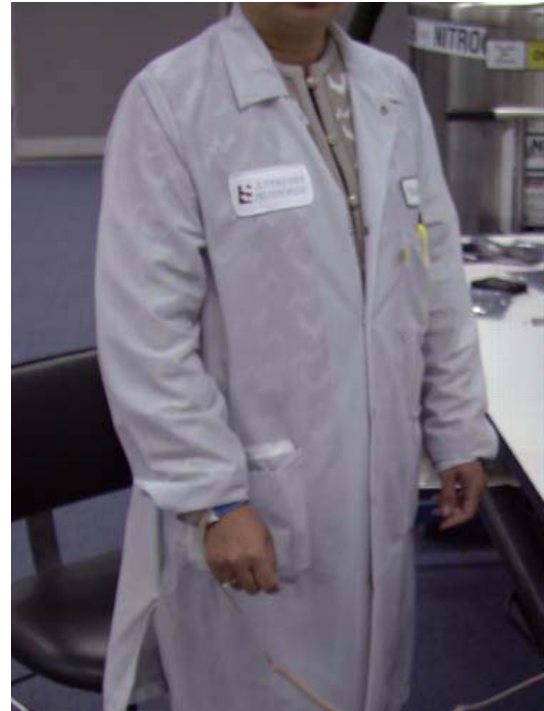
If a static problem is detected, good control of humidity levels and proper grounding of all equipment is essential to help dissipate the static charge. Ionizers can also be used to neutralize the static charges. Preventing the triboelectric charge from ever building up in the first place is the best form of ESD protection you can have!

Appendix A - ESD Example

The photos below contain illustrations showing both proper and improper usage of items that are generally found in areas using ESD sensitive devices. Proper ESD wrist-strap usage and ESD smock wearing are two things that can be done to help reduce the accumulation of static charges.



Proper buttoning of smock. Notice that the top button is being used, and that the operators shirtsleeves are covered by the smock material.



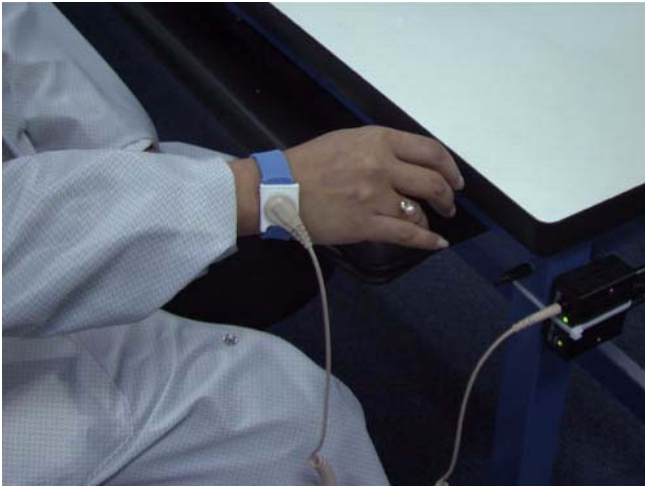
Improper use of smock. The top button is not being used, and the users garment being worn underneath is exposed.



Proper buttoning of smock. The bottom button (although a little hard to see) is buttoned.



Improper buttoning of smock. The bottom button is not being used.



Proper smock garment covering. No part of the users clothing is exposed.



Improper coverage of personal clothing. Notice the exposed sleeve visible due to improper smock sizing or operator error.

Packaging Materials:

The following pictures show some examples of packaging materials that are common in the industry. With plastics and styrofoam being so inexpensive and commonplace it is not unusual to see them being used to hold static sensitive devices, but these are some of the worst materials to use and are definitely NOT recommended. Static shielded bags (typically silver in color) are the only acceptable flexible bag that static sensitive devices should be handled in. Electrically conductive chip trays are also an acceptable container to place devices into. Examples of both are shown below.



Static shielded bags are typically dark silver in color, and may (or may not) have the ziplock mechanism on them. They should be marked as "static shielded" somewhere on the surface of the bag. These are highly recommended for transporting static sensitive devices.



Electrically conductive chip trays are good for storing or transporting static sensitive materials when used with shielding bags. The conductive surface acts like a Faraday cage, so static charges are conducted around the outside of the tray and dissipated to ground without going through the devices.



Styrofoam peanuts are not a good material to use when shipping static sensitive parts. Styrofoam is an insulator, and will retain static charges for a long period of time.



Plastic bubble wrap is also not a good packaging material. It is also an insulator, and will retain static charges for a long period of time.



Transparent tape (i.e. "Scotch Tape") generates large amounts of static charge as it is unwound from the roll. The meter shows the high level of static charge carried on the surface of the tape, which is then discharged through the item being taped.

Appendix B

Triboelectric series:

Asbestos - Will end up more positive

Leather

Rabbit Fur

Glass

Human Hair

Nylon

Wool

Fur

Lead

Silk

Aluminum

Paper

Cotton

Steel (neutral)

Wood

Amber

Sealing Wax

Hard Rubber

Mylar

Nickel

Copper

Silver

UV Resist

Brass, Stainless Steel

Gold, Platinum

Sulfur

Styrene (Styrofoam)

Saran Wrap

Polyurethane

Polyester

Polyethylene (scotch tape)

Polypropylene Vinyl (PVC)

Silicon

Teflon

Silicon Rubber - Will end up more negative