

ESD TR20.20-2016

ESD Association Technical Report

ESD TR20.20-2016

Revision of ESD TR20.20-2008

***For the Protection of Electrostatic
Discharge Susceptible Items***

***Handbook for the Development
of an Electrostatic Discharge
Control Program for the Protection of
Electronic Parts, Assemblies,
and Equipment***



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the Protection of Electrostatic Discharge
Susceptible Items***

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of an Electrostatic Discharge
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Assemblies, and Equipment***

EOS/ESD Association, Inc.



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TABLE OF CONTENTS

1.0 INTRODUCTION	1
1.1 OVERVIEW	1
2.0 BASICS OF STATIC ELECTRICITY	1
2.1 INTRODUCTION	1
2.2 HISTORY	2
2.3 NATURE OF STATIC ELECTRICITY	2
2.4 SOURCES OF STATIC ELECTRICITY	6
2.5 MATERIAL ELECTRICAL CHARACTERISTICS: INSULATIVE, CONDUCTIVE AND DISSIPATIVE	7
2.6 MATERIAL TEST PRINCIPLES	9
2.7 ESD CONTROL PRINCIPLES	10
2.8 FOR FURTHER REFERENCE	11
3.0 DEVICE DAMAGE, THREAT CATEGORIES, AND MODELS	12
3.1 EFFECTS OF ESD ON DEVICES	12
3.2 ESD THREAT CATEGORIES AND MODELS	12
3.3 DEVICE SENSITIVITY	14
3.4 DETERMINING ESD SENSITIVITY THROUGH DEVICE TESTING	14
3.5 SUMMARY	17
3.6 FOR FURTHER REFERENCE	17
4.0 PERSONNEL SAFETY	17
4.1 OVERVIEW	17
4.2 GROUND POTENTIAL OF ELECTRICAL EQUIPMENT AND POWER TOOLS	17
4.3 CONDUCTIVE WORKSURFACE CONSIDERATIONS	18
4.4 GROUNDING TRADE-OFFS	18
5.0 ESD CONTROL PROGRAM PLAN - ADMINISTRATIVE REQUIREMENTS	18
5.1 DEVELOPING AN ESD CONTROL PROGRAM PLAN	18
5.2 DEVELOPING A TRAINING PLAN	20
5.3 DEVELOPING A PRODUCT QUALIFICATION PLAN	21
5.4 DEVELOPING A COMPLIANCE VERIFICATION PLAN	22
6.0 ESD CONTROL PROGRAM PLAN—OVERVIEW	26
6.1 MEASUREMENT CONSIDERATIONS	26
6.2 HUMIDITY	27
7.0 GROUNDING / EQUIPOTENTIAL BONDING SYSTEMS	28
7.1 INTRODUCTION	28
8.0 PERSONNEL GROUNDING	30
8.1 SYSTEM REQUIREMENTS	31

8.2	WRIST STRAP SYSTEM.....	31
8.3	FOOTWEAR/FLOORING SYSTEM.....	32
9.0	ESD PROTECTED AREAS	32
9.1	IDENTIFICATION.....	32
9.2	INSULATORS	33
9.3	ISOLATED CONDUCTORS	34
10.0	WORKSURFACES	34
10.1	INTRODUCTION	34
10.2	FACTORS IN SELECTING WORKSURFACES.....	35
10.3	TYPES OF DISSIPATIVE WORKSURFACE MATERIALS.....	36
10.4	TESTING.....	37
10.5	MAINTENANCE	38
10.6	FOR FURTHER REFERENCE	38
11.0	WRIST STRAPS	38
11.1	INTRODUCTION	38
11.2	DESCRIPTION OF A WRIST STRAP	39
11.3	WRIST STRAP USE AND SELECTION.....	40
11.4	WRIST STRAP TESTING	40
11.5	CONTINUOUS WRIST STRAP MONITORS	42
11.6	CURRENT LIMITING	42
11.7	SUMMARY.....	42
11.8	FOR FURTHER REFERENCE	43
12.0	FOOTWEAR.....	43
12.1	INTRODUCTION	43
12.2	TYPES OF FOOTWEAR	44
12.3	PROPER USAGE.....	44
12.4	TESTING.....	45
12.5	COMMON TESTING PROBLEMS.....	45
12.6	FOR FURTHER REFERENCE	45
13.0	STATIC PROTECTIVE FLOOR MATERIALS.....	45
13.1	INTRODUCTION	45
13.2	FUNCTION OF STATIC PROTECTIVE FLOOR MATERIALS	46
13.3	RELATIONSHIP BETWEEN FLOORS AND FOOTWEAR	46
13.4	BENEFITS OF FLOOR MATERIALS	46
13.5	LIMITATIONS OF FLOOR MATERIALS	46
13.6	APPLICATIONS OF FLOOR MATERIALS	47
13.7	TYPES OF FLOOR MATERIALS	47
13.8	TEST METHODS	50
13.9	HAZARDS	52
13.10	CLEANROOM CONSIDERATIONS.....	52
13.11	TEST METHODS, STANDARDS, AND SPECIFICATIONS – ELECTRICAL RESISTANCE	54

13.12 FOR FURTHER REFERENCE	55
14.0 STATIC PROTECTIVE SEATING	56
14.1 INTRODUCTION	56
14.2 RELATIONSHIP BETWEEN CHAIRS, FLOORING, AND THE USER	56
14.3 BENEFITS	56
14.4 TYPES AND SELECTION	56
14.5 TESTING.....	57
14.6 CLEANING.....	57
14.7 FOR FURTHER REFERENCE	57
15.0 IONIZATION	57
15.1 INTRODUCTION	57
15.2 STATIC CHARGE CONTROL	58
15.3 WHAT IS AIR IONIZATION	59
15.4 MEASUREMENT OF AIR IONIZATION	60
15.5 PURPOSE OF IONIZATION.....	61
15.6 TYPES, USE, SELECTION, AND INSTALLATION OF AIR IONIZERS.....	61
15.7 TESTING OF AIR IONIZERS	67
15.8 MAINTENANCE/CLEANING.....	69
15.9 ENVIRONMENTAL/HUMIDITY IONIZATION CONSIDERATIONS.....	69
15.10 OTHER CONSIDERATIONS	70
15.11 FOR FURTHER REFERENCE	71
16.0 SHELVING	72
16.1 WORKSTATION SHELVING.....	72
16.2 STORAGE AREA SHELVING (I.E., WAREHOUSE, KITTING, ETC.).....	72
17.0 MOBILE EQUIPMENT	72
18.0 CONTINUOUS MONITORS	73
18.1 INTRODUCTION	73
18.2 WRIST STRAP CHECKERS	73
18.3 TYPES OF CONTINUOUS MONITORS	74
18.4 CONTINUOUS MONITOR FEATURES	75
18.5 PERIODIC VERIFICATION TESTING	75
18.6 SUMMARY.....	76
18.7 FOR FURTHER REFERENCE	76
19.0 GARMENTS	76
19.1 INTRODUCTION	76
19.2 TYPES AND SELECTION	76
19.3 APPLICATION	77
19.4 PROPER USE.....	78
19.5 TESTING AND QUALIFICATION	78
19.6 MAINTENANCE AND CLEANING	79

19.7 ENVIRONMENTAL/HUMIDITY	80
19.8 OTHER CONSIDERATIONS.....	80
19.9 FOR FURTHER REFERENCE	80
20.0 PACKAGING ELECTRONIC PRODUCTS FOR SHIPMENT AND STORAGE.....	80
20.1 INTRODUCTION	80
20.2 ITEM SENSITIVITY TO ESD.....	81
20.3 ESD THREAT EXPOSURE	81
20.4 PROTECTIVE PROPERTIES OF ESD PACKAGING	81
20.5 SELECTING A PACKAGE	82
20.6 FOR FURTHER REFERENCE	83
21.0 MARKING.....	83
21.1 MARKING OF ASSEMBLIES AND EQUIPMENT	83
21.2 MARKING OF PACKAGING	83
21.3 OTHER CONSIDERATIONS.....	84
21.4 FOR FURTHER REFERENCE	84
22.0 ESD GLOVES AND FINGER COTS.....	85
22.1 INTRODUCTION	85
22.2 GLOVES AND FINGER COT MATERIAL ISSUES	85
22.3 INTRINSIC RESISTANCE OF ESD GLOVES AND FINGER COTS	85
22.4 IN-USE RESISTANCE OF ESD GLOVES OR FINGER COTS	85
22.5 CHARGE GENERATION OF ESD GLOVES AND FINGER COTS.....	85
22.6 TEST METHODS TO MEASURE CHARGE GENERATION AND ACCUMULATION OF ESD GLOVES AND FINGER COTS	86
22.7 PERSONNEL GROUNDING	86
22.8 SELECTION OF THE APPROPRIATE ESD GLOVE/FINGER COT	86
22.9 FOR FURTHER REFERENCE	86
23.0 EQUIPMENT	87
23.1 INTRODUCTION	87
23.2 EQUIPMENT TYPES	87
23.3 TESTING - QUALIFICATION/PERIODIC VERIFICATION	88
23.4 EQUIPMENT - CAUSED ELECTRICAL OVERSTRESS (EOS)	89
23.5 TRIBOCHARGING.....	89
23.6 FOR FURTHER REFERENCE	89

FIGURES

Figure 1: Triboelectric Charge Materials Make Intimate Contact.....	4
Figure 2: Triboelectric Charge – Separation	4
Figure 3: Simplified HBM Simulator Circuit.....	15
Figure 4: HBM Current Waveform Through a Shorting Wire Indicating Decay Time and Peak Current.....	15
Figure 5: Schematic of the CDM Test Setup from ANSI/ESDA/JEDEC JS-002.....	16
Figure 6: Typical CDM ESD Waveform using a Single-Shot 8 Gigahertz Bandwidth Oscilloscope and Indicating Peak Current and Full Width Half Maximum (FWHM) .	16
Figure 7: Common Point Ground Symbol	28
Figure 8: Typical ESD Protective Workstation	29
Figure 9: Relationship between Body Voltage and Resistance to Ground	31
Figure 10: Example of an EPA Caution Sign	33
Figure 11: Process Required Insulators	34
Figure 12: Ionization by Alpha and X-ray Radiation.....	59
Figure 13: Corona Ionization – Positive	60
Figure 14: Corona Ionization – Negative.....	60
Figure 15: ESD Sensitive Part or Assembly.....	83
Figure 16: ESD Protective Material Marking	84

TABLES

Table 1. Typical Static Electricity Sources	7
Table 2. Distance Rules in ANSI/ESD S20.20	34
Table 3. Comparison of Selected Properties of ESD Protective Floor Material.....	48
Table 4. Floor Material Evaluation Criteria.....	54
Table 5. Ionizer Selection Checklist	64

ESD Association Technical Report for the Protection of Electrostatic Discharge Susceptible Items - Handbook for the Development of an Electrostatic Discharge Control Program for the Protection of Electronic Parts, Assemblies, and Equipment

1.0 INTRODUCTION**1.1 Overview**

The Electrostatic Discharge Association (ESDA) Standards Committee developed this ESD handbook for individuals and organizations that are faced with controlling ESD. It provides guidance that can be used for developing, implementing, and monitoring an electrostatic discharge control program in accordance with ANSI/ESD S20.20. This handbook applies to activities that include manufacturing, processing, assembling, installing, packaging, labeling, servicing, testing, inspecting, or otherwise handling electrical or electronic parts, assemblies, and equipment susceptible to damage by electrostatic discharges greater than or equal to 100 volts human body model (HBM), 200 volts charged device model (CDM), and exposure to charged isolated conductors.

ANSI/ESD S20.20 is the culmination of ESDA's response to the US Department of Defense's request to write a commercial version of MIL-STD-1686, Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies, and Equipment (Excluding Electrically Initiated Explosive Devices). This handbook is a living document that is periodically updated as new ESD control technology emerges.

The fundamental ESD control principles that form the basis of ANSI/ESD S20.20 are as follows.

All conductive and dissipative items in the environment, including personnel, should be bonded or electrically connected and attached to a known ground or contrived ground (as on shipboard or on aircraft). This attachment creates an equipotential balance between all items and personnel. Electrostatic protection can be maintained at a potential above a "zero" voltage ground potential as long as all items in the system are at the same potential. However, there are times when it is not possible to ground all the conductors that come into contact with electrostatic discharge sensitive (ESDS) items. Some examples include in-circuit testers (ICT), device-level microprobes, or cables that need to be connected for testing purposes. In these cases, the requirement in ANSI/ESD S20.20 is for the isolated conductors to have between - 35 and + 35 volts before contacting the ESDS item.

Insulators in the environment that have been triboelectrically charged cannot lose their electrostatic charge by attachment to ground. Circuit board materials and some device packages are examples of necessary insulators. Properly deployed ionization systems can reduce the residual charge on these necessary insulative items over time. Assessment of the ESD hazard created by electrostatic charge on the necessary insulators in the work place is required to ensure that appropriate actions are implemented, commensurate with risk.

TRANSPORTATION OF ESDS ITEMS OUTSIDE AN ESD-PROTECTED AREA (EPA), REQUIRES ENCLOSURE IN STATIC PROTECTIVE MATERIALS, ALTHOUGH THE TYPE OF MATERIAL DEPENDS ON THE SITUATION AND DESTINATION. INSIDE AN EPA, LOW CHARGING AND DISSIPATIVE MATERIALS MAY PROVIDE ADEQUATE PROTECTION. OUTSIDE AN EPA LOW CHARGING AND STATIC DISCHARGE SHIELDING MATERIALS ARE RECOMMENDED. THE REQUIREMENTS FOR PACKAGING INSIDE THE EPA AND OUTSIDE THE EPA CAN BE FOUND IN ANSI/ESD S541.

2.0 BASICS OF STATIC ELECTRICITY**2.1 INTRODUCTION**

For most people, static electricity is represented by the noise or crackle heard on a radio that interferes with good reception or the shock experienced when touching a metal object after walking across a carpeted room or sliding across a car seat. Static electricity is also observed as static cling when clothes are stuck together after coming out of a clothes' dryer. Most of the time, people observe static electricity when the weather is cold and dry.

The word “electricity” comes from the Greek word “elektron”, which means amber - the fossilized resin from prehistoric trees. When rubbed with silk or wool, amber and other materials can be electrified which results in the ability of those substances to attract or repel lightweight objects. For centuries this was the only meaning of the root words, which today mean “electricity”.

After the properties of flowing electricity were discovered in the 1700s, the term static electricity was used to distinguish between the old and new forms. While many people tend to think of static electricity as being at rest or not moving, static electricity causes the most concern when it ceases to be stationary.

2.2 History

Static electricity has been an industrial problem since man invented black powder and started printing on paper by machine. Early European and Caribbean forts dating back to the 1400s had static control procedures and devices to prevent electrostatic discharge ignition of hazardous stores. In the 1860s paper mills throughout the U.S. employed basic grounding and flame ionization techniques to dissipate static electricity from steam drums and the paper web as it traveled through the drying process.

The evolution of electronic items for military, commercial and consumer applications during the 1960s and 1970s resulted in increased use of ESDS items or devices. The military created specifications for packaging and protection of ESDS items during this time. Electronic items continued to become smaller, faster, and their susceptibility to static damage increased. In the late 1970s and early 1980s the U.S. Navy developed guidelines for controlling ESD in contractors' environments. Ultimately, their concern was that all electronic devices required some form of electrostatic control to assure continued operation and product reliability.

Concurrent with the military's efforts to control ESD, a small group of engineers representing industry and the military met in 1978 to explore various means of exchanging information related to static control. Their initial meeting led to the first EOS/ESD Symposium in September of 1979. With ESD losses in the electronics industry growing, greater interest in controlling ESD resulted in the formation of the EOS/ESD Association to explore these problems in greater depth.

2.3 Nature of Static Electricity

In order to control static electricity, we must have a basic understanding of its cause.

Electrostatic charge is most commonly formed by the contact and separation of two materials. The materials may be similar or dissimilar; where dissimilar materials tend to generate higher levels of static charge. An example is a person walking across the floor. Static electricity is produced when the person's shoe soles make contact then separate from the floor surface. Another example is an electronic device sliding into or out of a bag, magazine, or tube. Here, the device's housing and metal leads make multiple contacts and separations with the surface of the container. While the magnitude of electrostatic charge may be different in these examples, static electricity is indeed formed in each case.

Static electricity is measured in Coulombs, often represented by “Q” or “q”. The charge “q” on an object is related to the object's capacitance (C) and voltage (V) by:

$$q = C V$$

The quantity of charge is difficult for most people to visualize without some reference. As an example, an average person has a capacitance of about 100 pF and can feel a static discharge at their fingertips when the potential difference between their body and a grounded conductive object is about 3,000 volts (3 kilovolts). Thus, the discharge from the person must be from a charge of at least:

$$\begin{aligned} q &= C V = (100 \text{ pF}) \times (3 \text{ kV}) \\ q &= 1 \times 10^{-10} \text{ F} \times 3 \times 10^3 \text{ V} = 300 \text{ nC} \end{aligned}$$

To put this value into some perspective, a very sensitive part may be altered or susceptible to damage when exposed to a discharge of 100 volts or less. At a capacitance of less than 1 pF, the resulting total charge involved to cause damage may be under 0.1 nC.

Other factors, such as resistance of the actual discharge circuit and contact resistance at the interface between contacting surfaces, affect the actual charge that can cause damage (usually the charge must be much larger than predicted by simple arithmetic). It is often important to equate a static discharge to energy E in joules as shown by:

$$E = \frac{1}{2} C V^2$$

Where:

E = Energy in joules (Newton-meter)

C = Capacitance in Farads

V = Potential difference in Volts

The above formula represents the stored energy and not necessarily the amount of energy delivered in a static discharge. To estimate the actual delivered energy, the ratio of the receiving item resistance and the total circuit resistance must be considered in the formula as shown by:

$$E_{\text{delivered}} = \frac{1}{2} C V^2 \left(\frac{R_{\text{item}}}{R_{\text{total}}} \right)$$

As an example, the person described above will have a stored energy E of:

$$E = \frac{1}{2} \times 100 \times 10^{-12} \text{ F} \times (3,000 \text{ volts})^2 =$$

$$E = 450 \times 10^{-6} \text{ joules}$$

The actual delivered energy in a typical situation may be very different. Assume that the skin resistance at their fingertip in touch contact is 500 ohms and they touch a component lead that has an internal resistance of 30 ohms. What is the energy delivered $E_{\text{delivered}}$?

$$E = \frac{1}{2} \times 100 \times 10^{-12} \text{ F} \times (3,000 \text{ volts})^2 \times \frac{30 \text{ ohms}}{(500 + 30) \text{ ohms}}$$

This calculation results in a delivered energy of

$$E_{\text{delivered}} = 25.5 \times 10^{-6} \text{ joules}$$

Thus, there is a considerable difference in stored versus delivered energy in this example.

Another important concept to recognize is the voltage V between an object and ground is influenced by the capacitance of the system C as shown in the formula:

$$V = \frac{q}{C}$$

A change in capacitance will increase or decrease the voltage provided the charge remains constant. Understanding this concept is important in the design of a static safe work environment since the electrical potential can change dramatically (perhaps with catastrophic results) by simply making a change in position of two items in the workplace. For example, a device in an automated handler may experience numerous changes in relative capacitance depending on its proximity to other parts of the equipment. If the capacitance is maintained at a high level (by close contact with a grounded machine part) the apparent voltage may be quite low. If the part then loses contact with the machine and the capacitance decreases to near the free space capacitance of the device, the voltage may be very high. When any conductive contact is made between the device (leads) and the machine or a conductive part is coming close to the charged part, a discharge will take place. Naturally, if no charging takes place there will be no discharge. However, in practical situations it is most difficult to prevent charging completely. Therefore, in machine design it is important to take into account charge generation as well as changes in capacitance that could expose the part to a discharge risk.

The phenomenon of forming an electrostatic charge by contact and separation of materials is known as "triboelectric charging", from the Greek "tribo" meaning "to rub", and "elektron" meaning "amber", as mentioned above. It involves the transfer of electrons between materials.

Triboelectric Charge

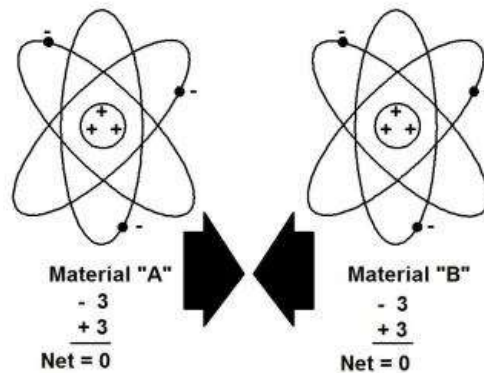


Figure 1: Triboelectric Charge Materials Make Intimate Contact

The atoms of a material with no static charge will have an equal number of positive (+) protons in their nucleus and negative (-) electrons orbiting the nucleus. In Figure 1, Material "A" consists of atoms with equal numbers of protons and electrons and is electrically neutral. Material B also consists of atoms with equal (though perhaps different) numbers of protons and electrons. This material is also electrically neutral. If we were to use an electrostatic field sensing instrument to measure the static charge on either Material "A" or "B", the instrument would indicate that no static charge was present on either material.

When the two materials are placed in contact, negatively charged electrons will transfer from the surface of one material to the other material. Electrons are carried off upon separation of the two materials. Which material loses electrons and which gains electrons will depend on the nature of the two materials. The material that loses electrons becomes positively charged, while the material that gains electrons is negatively charged. This is shown in Figure 2.

Triboelectric Charge

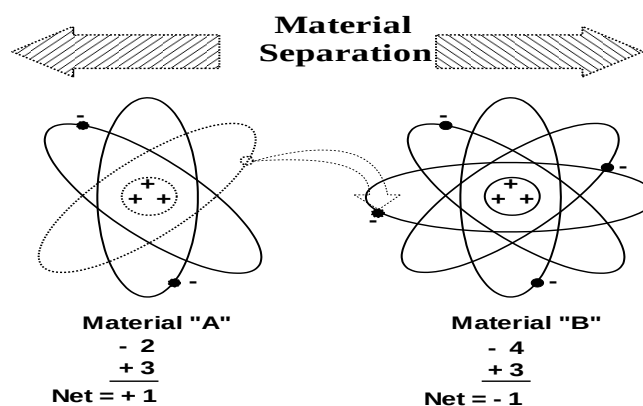


Figure 2: Triboelectric Charge – Separation

An electrostatic field sensing instrument would now indicate an electrical field emanating from the surface of each charged material. If we scanned Material "A" with an electrostatic field meter, the instrument would see a positive (+) field indicating the loss of electrons. The opposite would be true of Material "B" because it gained electrons. The meter would indicate a negative (-) field from

Material "B". However, it should be noted that the process of material contact, electron transfer, and separation is a more complex mechanism than described here. The amount of charge created by triboelectric charging is affected by the area of contact, the speed of separation, relative humidity, material work function, surface energy, and other factors. Once the charge is formed on a material, it becomes an "electrostatic" charge (if it remains on the material). This charge may be transferred from the material to another material, creating an ESD event.

Electrons are free to move from one atom or molecule to another in electrical conductors, but the proton in the nucleus of the atom cannot move unless the atom moves. In solids, only electrons are mobile, but in gases and liquids electrons can move along with the atoms and molecules themselves.

The normal stable structure of the atom shows that unlike charges attract and like charges repel. Therefore, charge resulting from separation will be self-repellent and will reside only on the surface of a charged item. If the item is a perfect insulator or perfectly insulated, an electrostatic charge would remain indefinitely. Since there are no perfect insulators and it is impossible to have perfect isolation, charges tend to leak away to join opposite charges in the immediate environment, thus eventually returning the item to an electrically balanced state. This process of charge balancing is called "electrostatic decay". As discussed later, the rate of electrostatic decay is an important characteristic that will be used in various ways to determine the usefulness of static control materials and equipment.

Taking all of the above into account, static electricity is the set of phenomena associated with electrostatic charge on the surface of an insulator or insulated conductive body. Static electricity is actually "liberated" by the expenditure of mechanical work. The word "generated" is commonly used to describe the formation of static electricity, but this is technically incorrect since electricity is not actually created; its components are found in each and every atom and merely need to be separated. However, for the purposes of this Handbook, the term "generated" will be used interchangeably with liberated. In each generation of a static charge, both positive and negative charges are present in exactly equal amounts, although one of them may be "grounded", suppressed, or otherwise difficult to find.

Whether a material will be charged positively or negatively depends on the material with which it contacts and then separates from. It is important to understand that the amount of charge that accumulates on any given surface is dependent on the contacting material, intimacy of contact, speed of separation, cleanliness of surfaces, and other physical and chemical factors. It has been shown to be difficult to develop material specifications based on charge generation characteristics unless all of the contact influences and environmental conditions can be fully characterized. Triboelectric series tables have been developed over the years to try to show how charge is generated on various materials. While there are similarities among the tables of this type, they should be used with caution. These tables should only be used as a guide because the variables cannot be controlled well enough to ensure repeatability. For instance, a triboelectric series should not be used as a method of trying to design a low charge generating interaction surface without experimentation with the exact materials that will be used in that application.

A typical triboelectric series is as follows:

Positive (+)

Rabbit fur
Glass
Human hair
Nylon
Wool
Silk
Aluminum
Paper
Cotton
Steel

Wood
 Amber
 Hard rubber
 Nickel, Copper
 Brass, Silver
 Gold, Platinum
 Acetate Rayon
 Polyester
 Orlon
 Polyurethane
 Polyethylene
 Polypropylene
 PVC
 Silicon
 Teflon
Negative (-)

The triboelectric series is arranged so that materials higher on the list lose electrons to materials lower on the list when they are brought into contact and then separated.

An electrostatic field and associated lines of force are present around a charged object. Conductive objects brought into the vicinity of this electric field will be polarized by the process known as induction. A negative electric field will repel electrons on the surface of the conducting item that is exposed to the field. A positive electric field will attract electrons to near the surface of the conducting item thus leaving other areas positively charged. No change in charge on the item will occur in polarization. However, if the item is conductive or dissipative and is touched to ground while polarized, charge will flow from or to ground to compensate for the charge imbalance. If the ground contact is disconnected and the electrostatic field is removed, the charge will be trapped on the item. If an insulative object is brought into the electric field, the electrical dipoles will tend to align with the field creating apparent surface charge, hence an insulator cannot be charged by induction. See Section 9.2 for more information.

2.4 Sources of Static Electricity

Theoretically, any two items or materials brought into contact and then separated can generate static electricity. For the purposes of this handbook, the interactions that are important involve people, electronic and electrical components, handling equipment, and packaging materials, as well as any other item or material that may enter the work area.

Once a static charge is generated, a charged surface can influence other items through space at a distance. Induction, as described in the previous section, can result in an ESD event if the conductive/dissipative item is grounded while in the presence of the electric field. This important concept has been shown to cause many difficulties in industry including: explosions, fires, component damage, system disruption, and personnel shock.

An isolated or insulated conductor will share a static charge with another isolated or insulated conductor if they touch through a conductive interface. The shared charge will result in an equal voltage on both conductors, but the actual charge on each will depend on the capacitance of the individual objects.

The main sources of static electricity in a manufacturing environment include those listed in Table 1.

Table 1. Typical Static Electricity Sources

Object or Process	Material or Activity
Worksurfaces	Waxed, painted or varnished surfaces Common vinyl or other plastics
Floors	Sealed concrete Waxed, finished wood Common vinyl tile or sheeting
Clothes	Common cleanroom smocks Common synthetic personal garments Insulative shoes Virgin cotton (under 30% R.H.)
Chairs	Finished wood Vinyl Fiberglass
Packaging and handling	Common plastic – bags, wraps, envelopes Common bubble pack, foam Common plastic trays, plastic tote boxes, vials, plastic parts bins
Assembly, cleaning, test and repair areas	Spray cleaner containers Common plastic solder suckers Soldering irons with ungrounded tips Brushes (animal hair and synthetic bristles) Cleaning or drying by fluid or evaporation Temperature chambers* Cryogenic and low temperature sprays* Heat guns and blowers* Vacuum cleaners* Sand blasting Copy equipment CRT, Cathode Ray Tubes R7, C2*Moving air is not a static electricity source. Particles impinging on a surface from a moving air source may cause charging.

It should be understood that any object, item, material, or person could be a source of static electricity in the work environment. Removal of unnecessary insulators, replacing insulative materials with dissipative or conductive materials, and grounding all conductors are the principle methods of controlling static electricity in the workplace, regardless of the activity.

2.5 Material Electrical Characteristics: Insulative, Conductive, and Dissipative

As discussed in the previous section, electrostatic charge may be generated triboelectrically by the contact and separation of materials. Virtually all materials, including water and dirt particles in the air, can be triboelectrically charged. How much charge is generated, where that charge goes, and how quickly it goes are functions of the material's electrical characteristics. Consequently, a basic understanding of a material's electrical characteristics is required to understand how to control electrostatic charge, dissipation, and ultimately ESD. The terms "resistivity" and "resistance" are often confused and misused. Resistivity is an intrinsic electrical property of a material. Resistivity defines the type of material and determines its electrical classification. Resistivity is analogous to "density" if discussing a physical property. Measurements are expressed in ohm/cm for volume

resistivity and in ohms/square for surface resistivity (although later on in this section you will see that ohms/square is technically incorrect). A resistivity measurement is almost always made on a precisely sized piece of material placed into a specific fixture with a controlled current and voltage applied. Specimen thickness must be known and the electrode configuration is defined by the specific measurement method. Industry standard test methods are defined for resistivity measurements. Manufacturers of ESD control materials, items, and equipment typically use resistivity measurements to validate the raw materials used in production. The finished items manufacturers produce often cannot be measured in the same way that the resistivity measurements are made.

Electrodes and probes are available in the industry to allow electrical resistance measurements of the finished items. These electrodes and probes have specific dimensions and parameters so that consistent measurements can be made by the end users of the ESD control items.

Resistance is the measurement (in ohms) of retardation of electron flow through an item. A resistance value takes into account the resistivity of the material that makes up the item as well as the size and shape (geometry) of the item. Resistance of materials have to be measured with standardized probes to obtain a repeatable and reproducible value; this is how materials are measured in ESDA standards and standard test methods. Resistance is analogous to "mass" if discussing a physical property. Surface resistance is measured on the same side of the material using an electrode designed for the type of item. Most often, the electrode will be a concentric ring or a two-point electrode with defined spacing between the contacting parts of the electrode. Volume resistance is measured through the thickness of the material with one electrode on the top of the item and another counter electrode on the bottom of the item.

Resistance to a groundable point or to ground is a measurement that evaluates the performance of an item (in a practical application sense) if the item is supposed to be electrically bonded to ground.

2.5.1 Insulative Materials

An insulator is a material that prevents or limits the flow of electrons across or through its volume. This type of material has an extremely high electrical resistance, generally greater than 1.0×10^{11} ohms (surface and volume resistance). Few electrons will flow across the surface or through the volume of an insulator.

A considerable amount of charge can be accumulated on the surface of an insulator. An electrostatic field meter indicates the presence of charge by measuring the electrostatic field resulting from an imbalance of electrons on the surface. The charge on the material surface can be measured with a coulombmeter. This instrument measures charge in nanocoulombs.

Because an insulative material does not readily allow the flow of electrons, both positive and negative charge can reside on an insulative surface at the same time, although they would be at different locations on the surface. The excess electrons at the negatively charged spot might be sufficient to satisfy the absence of electrons at the positively charged spot. However, electrons cannot easily flow across the insulative material's surface, and thus charge may remain separated for a long time, only influenced by the environment.

2.5.2 Conductive Materials

A conductive material allows electrons to flow easily across its surface or through its bulk (volume). Conductive materials have low electrical resistance, generally less than 1.0×10^4 ohms (surface and volume resistance). When a conductive material of uniform shape (i.e., sphere) becomes charged, the charge (i.e., the deficiency or excess of electrons) will be uniformly distributed across the surface of the material. For non-uniformly shaped conductive materials, the charge is distributed according to the shape of the object and nearby grounded surfaces or other charged items. If the charged conductive material makes contact with another conductive material, the electrons will transfer between the materials quite easily. If the second conductor is a wire lead attached to an earth grounding point, the electrons will flow to or from ground and the excess charge on the conductor will be "neutralized".

Electrostatic charge can be generated triboelectrically on conductors the same way it is on insulators. The static charge will remain on the conductor as long as the conductor is isolated from other conductors or ground. Its presence can be measured the same as with insulators. Since the conductive material allows easy flow of electrons, the charge will flow to ground or will be shared with another conductive object it contacts. It can flow across the conductive material's surface or through its volume (bulk).

2.5.3 Static Dissipative Materials

Static dissipative (or simply dissipative as used in this document) materials have electrical resistance between insulative and conductive materials ($1.0 \times 10^4 - 1.0 \times 10^{11}$ ohms for surface and volume resistance). Electrons will flow across or through the dissipative material, but the rate is controlled by the surface or volume resistivity of the material. This can be very useful in protecting ESD sensitive devices since limiting the current flow during a discharge event reduces the threat of damage. Since the defined dissipative range involves seven orders of magnitude, there is a very large difference in electron flow from or through materials on the low end of the range compared to materials on the high end of the range. When choosing dissipative materials for any application, the end user is cautioned to determine the suitability of any given material since there is such a large range of performance. If a material is chosen for an application that is too conductive, there exists an increased threat of harmful discharge if an ESD sensitive part has built up a charge. Conversely, if the material is too resistive, the risk is that not all the charge will be drained from the part while it is in contact with the dissipative surface.

As with the other two types of materials, charge can be generated triboelectrically on a dissipative material. However, like the conductive material, the dissipative material will allow the transfer of charge to ground or to other conductive objects. The transfer of charge from a dissipative material will generally take longer than from a conductive material of equivalent size. Charge transfers from dissipative materials are significantly faster than from insulators, and slower than from conductors.

The most obvious difference between insulative, conductive, and dissipative materials is their electrical resistance. As you will see in later sections, the measurement and evaluation of resistance characteristics of items are important in determining the appropriateness of an item in a given application. Measurement of electrostatic fields and charge decay times are also basic elements of ESD control and analysis.

2.6 Material Test Principles

The evaluation methods for insulative, dissipative, and conductive materials and items made from them involve measuring surface resistivity and resistance, volume resistivity and resistance, charge generation, decay rate, and in some cases electric field strength.

2.6.1 Resistance and Resistivity

Many materials – particularly those that are polymer based and used in the control of static electricity – have additives, coatings, or treatments on their surface. Measurement of the electrical characteristics of such materials usually requires placing an electrode of appropriate configuration on the surface and applying a measuring current at some given potential. Depending on the electrode configuration, the results may be interpreted as resistance or resistivity. For surface treated materials, the conventional way to describe the electrical property has been ohms/square.

Homogeneous volume conductive materials may be measured for volume resistivity using test method ASTM D991. A volume resistance measurement is described in ANSI/ESD STM11.12.

Care must be taken in selecting the appropriate resistance or resistivity test method for any given application or material/item. Choosing the correct test method also requires an understanding of the function of the material/item in an application. Many static control items are formed from laminations of dissimilar materials. Resistance or resistivity tests may not be completely appropriate for such items, since the actual function of the item may not be predicted. A simple surface resistance measurement may not be enough to understand a static control item's performance

attributes. For example, installed static control items, such as worksurfaces and flooring materials, are properly evaluated for in-use performance by measuring resistance to ground from points on their surface. Measuring methods are described in ESDA standards and standard test methods.

2.6.2 Charge Generation (Liberation)

Measurement of charge generation has been a subject of controversy for many years. It has been recognized, in at least some standards development groups, that there is no reliable or practical measurement method for determining an intrinsic charge generation property for a material. Charge generation is controlled by the properties of the two (or more) contacting and separating materials. Therefore, any test to determine the charging characteristics of one material would require contacting that material with samples of all other materials it may contact in the predicted environment. This of course is impractical. Some of the methods of measuring charge generation of materials that have been used in the industry are described in ESD ADV11.2. Measuring the charge accumulation on personnel while walking on a floor is described in ANSI/ESD STM97.2.

2.6.3 Decay Rate

Decay rate measurements are typically used to evaluate the performance of ionizer equipment. An instrument called a charged plate monitor (CPM) was designed for this purpose. The measurement techniques and instrumentation are described in ANSI/ESD STM3.1.

Test methods also exist for measuring the decay of a fixed charge on materials but these have been shown to be valid only for homogeneous materials. In the case of laminated (multi-layered) materials, the most conductive layer in the structure controls the discharge rate in decay testing.

Fundamentally, the measurement of decay rate is simply a matter of charging an item or material by direct current, triboelectric interaction, or by exposure to a corona charging system, then grounding the item and recording the time for the charge to reach some preset level (typically 10% of initial charging level). This type of evaluation is done frequently by practitioners in the static control field. However, the methods have been shown to be difficult to standardize due to poor repeatability and lack of lab-to-lab correlation and reproducibility.

2.6.4 Electric Field

Many different instruments are available that provide measurements from a simple indication of the presence of an electric field all the way to a precise measure of electric field strength in volts/meter. Determining the presence of an electric field – or more importantly the absence of any electric field – is a common measurement technique used in maintaining an EPA. In choosing instruments of this type, it is important to understand the limitations of the instrument, proper use as specified by the manufacturer, and how to interpret the information provided in the measurement.

2.6.5 Summary

Virtually all materials will generate an electrostatic charge. Depending on the properties of the material, they may have different abilities to store or dissipate the charge.

Electrostatic fields are associated with charged objects.

2.7 ESD Control Principles

- Define the control level needed to protect parts. For example, ANSI/ESD S20.20 provides adequate controls for devices with withstand thresholds of 100 volts HBM, 200 volts CDM.
- Define the EPA in which all conductive and dissipative materials, including personnel, are bonded or electrically connected and attached to a known ground (or contrived ground as on an aircraft, ship or other vehicle).

- Limit the presence of insulating materials in the EPA. Assess the risk associated with charge that may be present on insulators in the EPA. Provide ionization systems to neutralize the charge on the necessary insulators.
- Define the transportation packaging requirements for all phases of the operations.
- Provide routine audits of the EPA and other control plan elements (e.g., training of personnel).

2.8 For Further Reference

ESD ADV1.0, Glossary of Terms

ANSI/ESD S1.1, Wrist Straps

ANSI/ESD STM2.1, Garments

ANSI/ESD STM3.1, Ionization

ANSI/ESD S4.1, Worksurfaces – Resistance Measurements

ANSI/ESDA/JEDEC JS-001, Sensitivity Testing, Human Body Model (HBM)

ANSI/ESDA/JEDEC JS-002, Sensitivity Testing, Charged Device Model (CDM)

ANSI/ESD S6.1, Grounding

ANSI/ESD STM7.1, Floor Materials—Characterization of Materials

ANSI/ESD S8.1, Symbols—ESD Awareness

ANSI/ESD STM9.1, Footwear—Resistive Characterization

ANSI/ESD SP10.1, Automated Handling Equipment (AHE)

ANSI/ESD STM11.11, Surface Resistance Measurement of Dissipative Planar Materials

ANSI/ESD STM11.12, Volume Resistance Measurement of Dissipative Planar Materials

ANSI/ESD STM11.13, Two-Point Resistance Measurement

ANSI/ESD S11.4, Static Control Bags

ESD ADV11.2, Triboelectric Charge Accumulation Testing

ANSI/ESD STM11.31, Evaluating the Performance of Electrostatic Discharge Shielding Materials—Bags

ANSI/ESD STM12.1, Seating - Resistive Characterization

ANSI/ESD S13.1, Measuring Electrical Potential from Soldering/Desoldering Hand Tools

ANSI/ESD SP15.1, In-Use Resistance Testing of Gloves and Finger Cots

ANSI/ESD S20.20, ESD Control Program

ESD ADV53.1, ESD Protective Workstations

ANSI/ESD STM97.1, Floor Materials and Footwear - Resistance Measurement in Combination with a Person

ANSI/ESD STM97.2, Floor Materials and Footwear - Voltage Measurement in Combination with a Person

ESD TR53-01, ESD Compliance Verification

ANSI C63.16, American National Standard Guide for Electrostatic Discharge Test Methodologies and Criteria for Electronic Equipment

ASTM D991, Standard Test Method for - Rubber Property - Volume Resistivity of Electrically Conductive and Antistatic Products

MIL-STD-750 Method 1020, Military Standard, Test Methods for Semiconductors Devices, Electrostatic Discharge Sensitivity (ESDS) Classification Protection of Electrostatic Discharge Susceptible Items - Volume Resistance Measurement of Dissipative Planar Materials

MIL-STD-883 Method 3015, Department of Defense, Test Method Standard, Microcircuits, Electrostatic Discharge Sensitivity Classification

MIL-STD-2073-1 Department of Defense, Standard Practice for Military Packaging MIL-PRF-19500 Performance Specification, General Specification for Semiconductor Devices

QML-19500 Qualified Manufacturers List of Products Qualified Under Military Specification MIL-PRF-19500, General Specification for Semiconductor Devices

MIL-PRF-38535 Performance Specification, General Specification for Integrated Circuits (Microcircuits) Manufacturing

QML-38535 Qualified Manufacturers list of Advanced Microcircuits Qualified under Military Specification MIL-PRF-38535, General Requirements for Microcircuits Manufacturing

3.0 DEVICE DAMAGE, THREAT CATEGORIES, AND MODELS

3.1 Effects of ESD on Devices

ESD can happen anywhere from the initial fabrication of the device, through packaging and board assembly, during operation, to field service of systems. When devices are handled or processed without proper ESD controls and proper ESD protection severe irreversible effects can occur.

3.1.1 Device Damage

When an electronic device is subjected to an ESD event, a very short pulse of electrical current passes through the device. This current causes the device to heat rapidly in and near the path of current flow. If the local temperature of the materials conducting this current exceeds the melting point, or some other important characteristic temperature of the material, the device will be permanently altered or “damaged”. This physical damage can typically only be “seen” by disassembling the device and then through the aid of very high magnification and often other sophisticated instrumentation. Another form of failure is dielectric breakdown (e.g., gate oxide). In modern deep sub-micron processes, gate oxide damages are possibly more common in practical applications (e.g., testing, assembly).

3.1.2 Device Failure

The most serious consequence of physical damage is that the device, in most cases, will lose its ability to perform its intended function with its expected reliability. In many cases this loss of function will be catastrophic. That is, there will be an immediately detectable loss of function and the device will fail one or more of its characteristics as described in the device specification or data sheet. The good news of catastrophic failure is that it can be detected in production test and the manufacturer can avoid shipping a defective part to the customer. In other cases, there may be an immediate shift of one or more parameters that are still within the data sheet limits. These could, in principle, also be detected by production test programs but may not be screened out. This can lead to one type of “latent” failure.

3.1.3 Latent Defects

A device that is exposed to an ESD event may be partially degraded yet continue to perform its intended function. If this degradation is not detected by testing or if it is within specified parametric limits set for the device, it will still be shipped to the customer. In some cases, this degradation may lead to a significant reduction in the useful operating life time of the device. A product or system incorporating devices with these latent defects may experience a premature failure after the user places them in service. Such failures can be costly to repair and in some applications may create personnel hazards. Establishing that a device has failed due to a latent defect is difficult, if not impossible in many cases. For this reason, the extent of latent failures due to ESD is a controversial topic.

3.2 ESD Threat Categories and Models

In all ESD events, charge flows rapidly either from or to a device. The effect this discharge has on a device is less dependent on the direction of charge flow than it is on the resistance to the charge flow in a given event and on the rise time of the event. ESD models have been developed to help

distinguish between major types of stress in production and to provide a basis for the determination of relative ESD sensitivities of devices.

3.2.1 Threats in Electronic Production Lines

ESD threats in electronics manufacturing can be classified into three major categories:

- Charged personnel – When one walks across a floor a static charge accumulates on the body. Simple contact of a finger to a device lead of a sensitive device or assembly which is on a different potential, e.g., grounded, allows the rapid transfer of charge to the device.
- Charged (floating) conductor – If conductive elements of production equipment are not reliably connected to ground, these elements may be charged due to triboelectric charging or induction. Then these conductive elements may transfer charge to a device or assembly which is at a different potential.
- Charged device/boards – During handling, devices or boards can acquire a static charge through triboelectric charging or can acquire an elevated electrostatic potential in the field of nearby charged objects. In these conditions, contact with ground or another conducting object at a different electrostatic potential will produce a very fast ESD transient.

This categorization is useful in that each category implies a set of ESD controls to be applied in the workplace. ESD threats from personnel are minimized by grounding personnel through the use of wrist straps and/or footwear/flooring systems. Discharges from conductive objects are avoided by assuring that all conductive parts that might contact devices are adequately and reliably grounded. The occurrence of ESD involving charged devices or boards is minimized by a) preventing charge generation (low-charging materials, ionization) or b) by providing low-current “soft landings” using dissipative materials.

Since these preventive measures are seldom perfectly deployed, the overall threat of ESD failure remains and the risk ultimately depends on how well the controls are maintained and the relative sensitivities of the devices being handled.

3.2.2 Models to Describe the Threats

In principle, one could determine the sensitivity of a device to each individual threat in the line through specific experimentation. This of course is not practical, so instead, simplified models intended to simulate the most important features of the ESD stresses have been developed. This simplicity implies that some details of the real world events will not be included or modeled correctly. However, they are “close enough” to provide useful information about relative device sensitivity while simple enough to use for event modeling and for building and defining hardware to simulate ESD events. These models, have in turn, been implemented as test methods that are standardized. In these methods, stress simulation hardware is defined so that devices can be stressed in a repeatable way from location-to-location and from one simulation machine to another. Further compromises are made to create the hardware definition and these make the faithful connection between reality and simulation imperfect. The two models and test methods that are recognized widely today are human body model (HBM), for simulation of discharges from personnel and charged device model (CDM), originally intended for simulation of discharges from charged devices, including discharges caused by static induction. Schematic representations of these models and their characteristic current pulses are given in Figures 3-6.

In the hardware realization of HBM there are three major departures from real world stresses. First, the test method requires that the device be grounded during the discharge. This grounding does not always occur in a real world event and this makes the standard somewhat more stressful than reality on average. Second, most testers have significant parasitics (unintended electrical effects) that can distort the intended stress. Parasitics vary with the tester and can cause both false passing and false failing of devices due to mechanisms that are not found in real world events. Third, the test method requires that devices be tested using many different stress/ground combinations. For practical reasons, these must be done on the same device and can result in unrealistic cumulative effects. Over the last decade, the second and third departures have been understood and the test

methods have been modified to minimize them. The first departure remains intrinsic to the standard method.

The hardware realization of CDM also has some systematic departures from the real world. The primary one is the very high equivalent capacitance of the test set up. This produces a higher discharge current than would be expected in most real world CDM events. This makes CDM withstand thresholds to the measured electrostatic voltages for a given device lower than they might be expected to survive in production.

It was originally thought that the remaining category of threats (discharges from charged metal) would be covered by a test method called the “machine model” (MM). The conceptual model schematic might have been reasonably expected to do this. However, the test method that emerged was a modification of existing HBM testers and did not do this. It has been shown that the standard MM has effects very similar to the standard HBM. The thresholds of MM and HBM correlate within given technologies and the two produce the same failure mechanism and design fixes. Finally, MM does not include the expected fast leading edge transient expected for a metal-to-metal discharge. If a design meets minimum requirements for HBM and CDM it will be reasonably robust to discharges from charged metal objects.

3.3 Device Sensitivity

Clearly, devices may be more or less sensitive to damage from the previously described ESD events. Some devices may be more readily damaged by discharges occurring within automated equipment, while others experience damage from handling by personnel.

Determining the ESD sensitivity of a device and determining the most sensitive device are the first steps in knowing what degree of ESD protection is required in processes to provide protection for devices and assemblies. Once the sensitivity of the ESDS products to be handled in an operation have been established, one can create a static control program and specific requirements for an auditing program. The objective is to avoid electrostatic discharge greater than those that will damage the most sensitive device in an operation.

3.4 Determining ESD Sensitivity Through Device Testing

Device-level ESD testing is used to provide data for categorizing component sensitivity and establishing the appropriate ESD control levels as part of the ESD control program plan. Exposure of devices to discharges from defined HBM and CDM circuit test models are used to provide a standardized test protocol. ESD sensitivities are expressed as the voltage or current withstand thresholds for each model. While both models are necessary for a complete standard characterization of a device, CDM has emerged as the most important model because CDM controls are harder to implement and verify in production, and the vast majority of ESD failures seen today are due to CDM-like mechanisms.

3.4.1 Human Body Model (HBM)

HBM has been in use for over 100 years. It was first defined to allow measurement and evaluation of explosion hazards for underground mining operations. There are a few different test standards describing the HBM for military and commercial applications, but the differences are in the application of the test, calibration of the system, and other ancillary items. The waveform, as defined by the human body resistance and capacitance, is virtually identical among all the test standards. The most widely used standard is ANSI/ESDA/JEDEC JS-001. The HBM test standard uses a stressing circuit which charges a 100 pF capacitor to a known voltage and discharges through a 1500-ohm resistor as shown in Figure 3. The simulators are verified by measuring various features of the current waveform, some of which are shown in Figure 4. Full details for tester qualification and waveform verification are described in ANSI/ESDA/JEDEC JS-001.

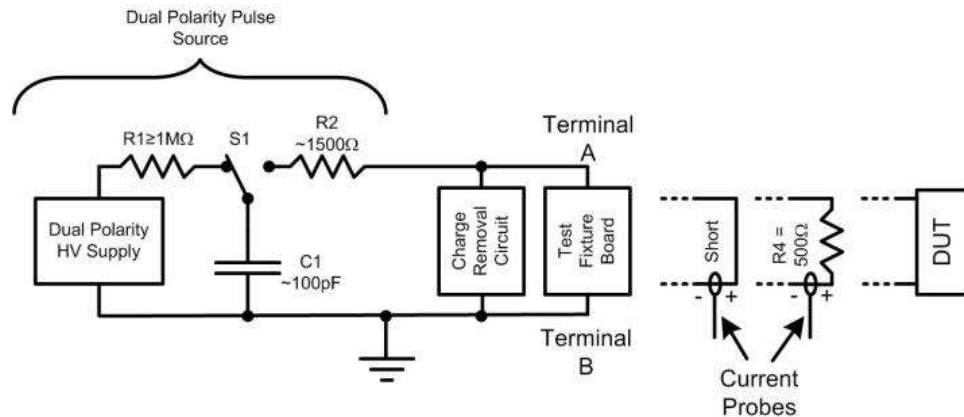


Figure 3: Simplified HBM Simulator Circuit

NOTE: The evaluation loads are used to qualify the tester and verify the waveforms before use.

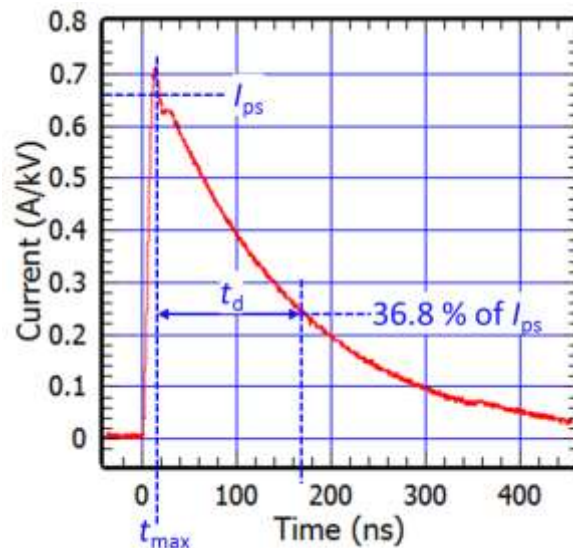


Figure 4: HBM Current Waveform Through a Shorting Wire Indicating Decay Time (t_d) and Peak Current (I_{ps})

3.4.2 Charged Device Model (CDM)

In principle, there are two variations of CDM. The first considers the situation of a device that is charged (through tribocharging) on its package, lead frame, or other conductive paths followed by a rapid discharge to ground through one pin or connector. The second considers the situation of a device which is placed in an electric field due to the presence of a charged object near the device. The device's electrostatic potential is increased by this field. This process is sometimes referred to as static induction. The device will discharge if it is grounded while still in the electric field. In both cases, the device will discharge, the failure mode will be the same, and the failure type and location will be the same. The most widely used CDM standards use the static induction approach. In CDM simulators, the device is grounded by a pogo pin contacting one pin or lead of the device. The current through the pogo pin can be measured and recorded which is particularly important as the discharge current determines the ESD threshold, a schematic of this is shown in Figure 5.

Experimental results show that the CDM discharge current is very fast, with rise-times measured often below 100 ps with a "pulse width" (full width half-maximum [FWHM]) of less than 500 ps to

1 ns, an example waveform with the key parameters is shown in Figure 6. By comparison, the HBM discharge has a typical rise-time of 2 to 10 ns and durations of hundreds of ns. Until 2014, the most commonly used CDM standards were JEDEC JESD22-C101 or ANSI/ESD STM5.3.1. These have now been superseded by ANSI/ESDA/JEDEC JS-002.

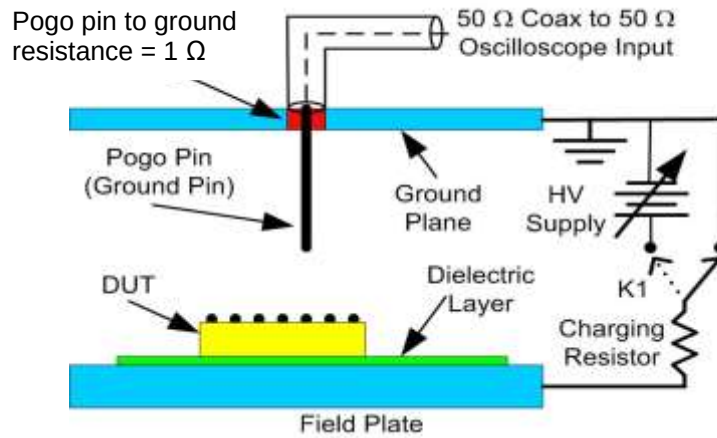


Figure 5: Schematic of the CDM Test Setup from ANSI/ESDA/JEDEC JS-002

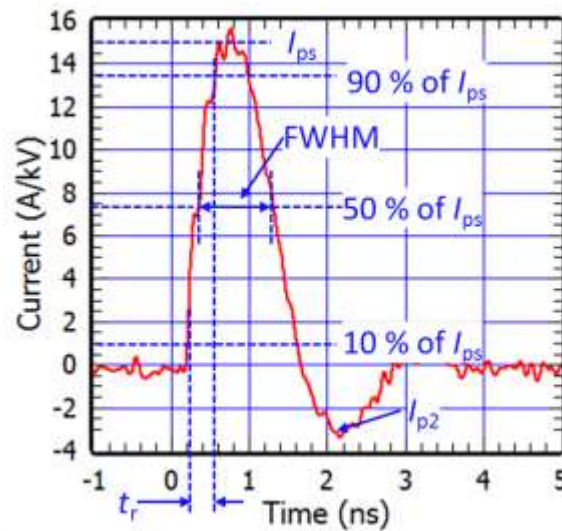


Figure 6: Typical CDM ESD Waveform Using a Single-Shot 8 Gigahertz Bandwidth Oscilloscope Indicating Peak Current and Full Width Half-Maximum (FWHM)

3.5 Summary

Devices can be damaged so that they fail immediately. Less severe damage may escape immediate detection, but cause devices to fail prematurely once in service.

The sensitivity to a damaging ESD event varies depending on the type of discharge. The ESD event may involve charge transfer from an external object to the device, from the device to another object, as well as charge transfers resulting from electrostatic fields.

HBM discharges usually produce electro-thermal failures and CDM discharges usually produce gate oxide failures.

3.6 For Further Reference

ANSI/ESDA/JEDEC JS-001, Sensitivity Testing, Human Body Model (HBM)

ANSI/ESDA/JEDEC JS-002, Sensitivity Testing, Charged Device Model (CDM)

4.0 PERSONNEL SAFETY

4.1 Overview

The ESD Association considers personnel safety to be a prime consideration in the development of an ESD control program. As such, the following statement on personnel safety is included in all newly released documents, including ANSI/ESD S20.20.

THE PROCEDURES AND EQUIPMENT DESCRIBED IN THIS DOCUMENT MAY EXPOSE PERSONNEL TO HAZARDOUS ELECTRICAL CONDITIONS. USERS OF THIS DOCUMENT ARE RESPONSIBLE FOR SELECTING EQUIPMENT THAT COMPLIES WITH APPLICABLE LAWS, REGULATORY CODES, AND BOTH EXTERNAL AND INTERNAL POLICY. USERS ARE CAUTIONED THAT THIS DOCUMENT CANNOT REPLACE OR SUPERSEDE ANY REQUIREMENTS FOR PERSONNEL SAFETY.

GROUND FAULT CIRCUIT INTERRUPTERS (GFCI) AND OTHER SAFETY PROTECTION SHOULD BE CONSIDERED WHEREVER PERSONNEL MIGHT COME INTO CONTACT WITH ELECTRICAL SOURCES.

ELECTRICAL HAZARD REDUCTION PRACTICES SHOULD BE EXERCISED AND PROPER GROUNDING INSTRUCTIONS FOR EQUIPMENT SHALL BE FOLLOWED.

THE RESISTANCE MEASUREMENTS OBTAINED THROUGH THE USE OF THIS TEST METHOD SHALL NOT BE USED TO DETERMINE THE RELATIVE SAFETY OF PERSONNEL EXPOSED TO HIGH AC OR DC VOLTAGES.

NOTE: These statements apply to personnel safety only as it pertains to the use of ESDA standards and testing ESD control materials. The test voltages outlined in these standards may be much lower than might be encountered in the workplace. The reader should be aware that the resistance of ESD control materials may change drastically when in contact with AC/DC current sources that exceed those used to test the materials.

4.2 Ground Potential of Electrical Equipment and Power Tools

The design and construction of the EPA and ESD grounded work benches should ensure that all external parts, surfaces, and shields in electronic test equipment and power tools are at a common ground potential at all times during normal operation. The design should include consideration of potential ground faults and hazardous voltage levels which may exist in the protected area. Tools and test equipment used in an EPA can bypass any intentional resistance (e.g., wrist strap with a built-in 1-megohm resistor) resulting in a potential electrical shock hazard. As an added precaution for personnel safety, a ground fault circuit interrupter (GFCI) can be used with the electrical equipment. The GFCI senses leakage current from faulty equipment and interrupts the circuit almost simultaneously when these currents reach potentially hazardous levels. CAUTION MUST BE OBSERVED IN EMPLOYING PARALLEL PATHS TO GROUND THAT COULD REDUCE EQUIVALENT RESISTANCE OF PERSONS TO GROUND TO UNSAFE LEVELS. Personnel

grounded through wrist straps or floor and footwear systems may have alternate paths to ground that could by-pass built-in resistors.

4.3 Conductive Worksurface Considerations

Worksurfaces constructed of conductive materials such as stainless steel require careful design and evaluation regarding personnel electrical safety.

4.4 Grounding Trade-offs

The exact grounding methods selected for use in a given facility involves a series of technical trade-offs that are dependent upon the exact materials selected for use and their relationship to the organization's ESD handling procedures. The methodology and techniques selected must not compromise personnel safety. The use or non-use of current limiting resistors in grounding circuitry is intimately related to the material selected for ESD protective worksurfaces (which can range from metallic conductors, such as stainless steel, to dissipative materials). See Section 7.0 for more information.

5.0 ESD CONTROL PROGRAM PLAN - ADMINISTRATIVE REQUIREMENTS

5.1 Developing an ESD Control Program Plan

5.1.1 Determining Part, Assembly, or Equipment ESD Sensitivity

The first step in developing an ESD control program plan (Plan) is to determine the part, assembly, or equipment sensitivity level under which the Plan is to be developed. Although the requirements outlined in ANSI/ESD S20.20 are effective for handling parts sensitive to 100 volts HBM and 200 volts CDM, the organization may choose to assess whether their items have a higher sensitivity threshold; or in other words, less sensitive to ESD events. In a case where a higher threshold has been determined, the organization may wish to tailor the contents of ANSI/ESD S20.20 and incorporate a plan that is consistent with the part sensitivity assessment. If a contractual situation exists where the Plan must be approved by both parties, the new sensitivity threshold and tailored requirements must be agreed upon.

Several methods can be used to determine the ESD sensitivity of the products that are to be handled.

- 1) The best approach is actual testing done by suppliers using accepted test methods:
 - ANSI/ESDA/JEDEC JS-001 (preferred for HBM)
 - ANSI/ESDA/JEDEC JS-002 (CDM)
 - Other methods can be used such as MIL-STD-883, Method 3015 or MIL-STD-750, Method 1020 (these do not include CDM)
- 2) If data is not available through the data sheet or supplier for some devices, one may assume that ESDS components or devices have a sensitivity of greater than or equal to 100 volts HBM and 200 volts CDM. However, device sensitivity could be lower; consulting the device manufacturer for critical devices is recommended.

5.1.2 Initial Process and Organizational Assessment

Before the Plan can be developed, an initial assessment of the processes and organizations impacted by an ESD control program should be conducted. Some of the organizations and processes that might be affected include:

- purchasing
- design engineering
- receiving inspection
- quality assurance
- manufacturing

- test
- maintenance
- packaging and shipping
- field service
- failure analysis
- repair services
- spare parts storage
- material handling and parts conveyance
- receiving

An assessment of the areas where ESDS parts may be handled should be conducted in order to determine ESD hazards and possible ESD process procedures. In addition, the organizations that will be affected by the ESD control program need to be informed about their duties and responsibilities as part of the Plan. The information accumulated through these steps form the basis for developing the Plan.

5.1.3 Scoping and Documenting the ESD Control Program Plan

After gathering the above information, the organization is in a position to begin documenting the Plan. The Plan should provide the scope of the program which includes the tasks, activities, and procedures necessary to protect the ESDS items at or above the ESD sensitivity level chosen for the Plan. Although the primary focus of the Plan is to outline strategies for meeting the administrative and technical elements of ANSI/ESD S20.20, other items may be beneficial to incorporate as well. Some of these additional items might include:

- ESD sensitivity of the parts, assemblies, and equipment under which the Plan is being written (i.e., 100 volts HBM or as otherwise determined).
- Organizational responsibilities.
- Defined roles and responsibilities between the organization and subcontractors and suppliers.
- Strategies for monitoring product yields and processes that might be important in determining the effectiveness of ESD control measures currently in place or in assessing whether additional measures should be taken.
- ESD control program effectiveness.
- An approach for utilizing program data and documentation.
- A list of approved ESD control products and materials.
- Failure analysis process.

The administrative and technical elements of ANSI/ESD S20.20 to be addressed in the Plan unless tailored otherwise include:

- Training plan
- Product qualification plan
- Compliance verification plan
- Technical elements:
 - Grounding / equipotential bonding systems
 - Personnel grounding
 - ESD protected areas
 - Packaging
 - Marking

5.1.4 Baseline an ESD Control Program

After the Plan has been developed, it is important to ensure the ESD control materials, processes, and procedures outlined in the Plan are in place prior to launching the organization's ESD control program. This might include conducting ESD work area surveys, process certifications, or qualifications and other tasks necessary to baseline the program. The requirements outlined in the Plan are impossible to audit or monitor until all materials, processes, and procedures are established and in place.

5.2 Developing a Training Plan

5.2.1 Personnel Training

Personnel training is a critical element in the implementation of an ESD control program, and as mentioned earlier, it is a key component in the development of the organization's Plan. A sustained commitment and mindset among all employees that ESD prevention is a valuable ongoing effort by everyone is one of the primary goals of training.

Although personnel training can take several forms (i.e., instructor, computer based, etc.), the preferred technique for initial training is by the use of an instructor. Special care must be exercised in finding a "suitable" instructor. The instructor should have a good understanding of the organization's Plan and the processes, procedures, and materials prescribed within. In addition, if manufacturing spans more than one culture, careful consideration must be given to customs and religious beliefs. Besides cultural differences, other factors such as education, experience, and age should be considered. All training should be done in a secure, nonthreatening environment.

One of the first steps is to determine the type(s) of ESD training methods that will work best for the organization. Several possible training methods are:

- In-house, instructor led class
- In-house, consultant led class
- Computer based training
- Industry symposia, tutorials, and workshops

The initial training program should cover the fundamentals of ESD, the details of the organization's Plan, and each person's role in the Plan. Basic questions of what ESD is, how it occurs, and how it effects the quality of goods should be explained. A careful explanation of the protection process as part of company policy should be included. No matter which type of training method is chosen, the program should be designed so that all trainee questions that arise can be answered. In addition, a knowledgeable person in the organization should be available to answer trainee questions once they have begun working. Opening the lines of communication is the beginning of a successful ESD training program. This type of communication should continue in the workplace and form the basis for an ongoing education process.

Subcontractors and suppliers should also be aware of ESD because of the role they play in quality of goods and services they provide to the organization. Subcontractors and suppliers can participate in the organization's training programs, or special programs may be developed separately. The former will provide an opportunity to receive feedback directly from employees within the organization. It is fundamentally important that subcontractors and suppliers be as committed to ESD training as the organization and that it is incorporated as a fundamental part of their Plan.

Because ESD control programs cover such a variety of job disciplines and educational levels, it may be necessary to develop special training modules for each organizational entity. Advanced modules should emphasize the main concerns of each discipline. Course emphasis should be tailored to each group's specific needs. For example, the modules developed for management, engineering, technicians, and field service could differ significantly, because their day-to-day concerns and responsibilities are very different.

Ongoing or recurring training is also vital to any organization's training plan. It should reinforce the basic fundamentals taught during initial training, but also should incorporate program updates and changes, and the reasons for those changes. As with the initial training, the organization must

decide which type of training will be used and how frequently the recurring training will be required. The method chosen should keep everyone informed, renewing his or her commitment to the total ESD effort. Recurring training is also a good feedback loop for monitoring the program's effectiveness. Suggestions and problems can be voiced in these sessions, and action items can be assigned which improve the organization's overall ESD control program.

After training (initial or recurring) sessions have been completed, it is important to ensure that the trainee understands and has retained the ESD control program concepts taught during these sessions. ANSI/ESD S20.20 requires that an objective evaluation technique be incorporated as part of the training plan. This can be accomplished in a number of ways that include written tests, question and answer sessions with an instructor, or multiple choice questions at the conclusion of a computer based training session. Regardless of the method selected, the organization must establish a pass/fail criterion to ensure adequate training has been accomplished. Records should be maintained for all employees that successfully complete the training. The records should be stored such that they are readily available to management and customers who want objective evidence that the Plan is being adhered to. Organizations may choose to "certify" employees who have successfully completed ESD control training, but those procedures must also be documented in the Plan. Finally, since ANSI/ESD S20.20 requires recurring or "refresher" training, a recall system should be established to highlight when employees are due for retesting and/or recertification.

A repository or central information source of educational ESD control materials should be kept for reference at any time by organization employees. This repository might include:

- material from initial and recurring training sessions
- ESD bulletins or newsletters
- videos or CDs
- computer based training materials
- technical papers, studies, standards, and specifications
- ESD control material and equipment product sheets

5.2.2 For Further Reference

ANSI/ESD S20.20, ESD Control Program

Smallwood, J., and Viheriäkoski, T., "Optimizing Investment in ESD Control" EOS/ESD Symposium Proceedings, 2014

Swenson, D., "ESD Control in the Factory of the Future or 20.20 to the Rescue" EOS/ESD Symposium Proceedings, 2000

Swenson, D., "Compliance Verification: The Critical Component of a Certified ANSI/ESD S20.20 ESD Control Program Plan" EOS/ESD Symposium Proceedings, 2004

Viheriäkoski, T., et al., "Benchmarking of Factory Level ESD Control" EOS/ESD Symposium Proceedings, 2015

5.3 Developing a Product Qualification Plan

During the selection process for ESD control materials such as worksurfaces, floors, packaging or any other control item, the item must be qualified per ANSI/ESD S20.20. This is an initial testing to ensure that the item(s) selected meet the ESD Association material standards. Those standard test methods are listed in Tables 2 and 3 of ANSI/ESD S20.20.

Typically, they require testing to be done under strict temperature and humidity controls. When environmental conditions are required they are usually 23° C and 12% RH.

Proof of qualification can be done in several ways. The recommended method is to conduct testing by the user if the equipment and conditioning environment is available. An alternative can be testing done by an independent third party that is capable. A third way would be to use the supplier data