

ESD TR2.0-01-00
(formerly TR05-00)

CONSIDERATION FOR DEVELOPING *ESD GARMENT SPECIFICATIONS*

Author:

G. Baumgartner
ESD West Consulting



Electrostatic Discharge Association
7900 Turin Road, Bldg 3
Rome, NY 13440

CONSIDERATIONS FOR DEVELOPING ESD GARMENT SPECIFICATIONS

Caution Notice

ESD Association standards and publications are designed to serve the public interest by (i) eliminating misunderstandings between manufactures and purchasers, (ii) facilitating the interchangeability and improvement of products and (iii) assisting the purchaser in selecting and obtaining the proper products for his particular needs. The existence of such standards and publications is not intended in any respect to preclude any member or nonmember of the Association from manufacturing or selling products not conforming to such standards and publications. Nor is it intended for a standard or publication published by the Association to preclude its voluntary used by non-members of the Association whether the document is to be used either domestically or internationally. Recommended standards and publications are adopted by the ESD Association without intending to infringe upon any intellectual property rights of third parties with respect to articles, materials or processes described in such standards. The Association does not assume any liability to any intellectual property owner, nor does it assume any obligation whatever to other parties following the recommended standard or publication.

A Technical Report is a collection of technical data or test results published as an informational reference on a specific material, product, system or process. The opinions expressed in this Technical Report are the opinions of the author(s) and may or may not be endorsed by the ESD Association.

CONSIDERATIONS FOR DEVELOPING ESD GARMENT SPECIFICATIONS

INTRODUCTION

A DISCUSSION OF ESD PROPERTIES

- Feature 1.
ESD Awareness
- Feature 2.
Surface Resistance (Conduction)
- Feature 3.
Dissipation of Charge (Static Decay)
- Feature 4.
Shielding Types
- Feature 5.
Induce Electrostatic Voltage Suppression
- Feature 6.
Anti-Static (Non-Tribocharging)

GENERAL COMMENTS

Possible Garment Tests

I. Device Damage

Device Sensitivity Types

1. Voltage Sensitive Devices
2. Energy Sensitive Devices

Discharge & Damage sources

II. Evaluation of ESD Problems

1. Determine Discharges from Clothing
2. Develop Standard Model for Induced Charge
3. Determine Amount of Field Suppression
4. Compare Background to Charged Garments
5. Determine Damage by Type and Class

IV. Garment Material Tests

1. Resistance Measurement
2. Decay test
3. Induced Voltage Test.
4. Tribocharging Tests

V. Manufactured Garment Tests

1. Resistance Point to Point.
2. Resistance to Groundable Point.
3. Charge Decay Test Through Groundable Point.
4. Tribocharge

SUMMARY AND CONCLUSION

APPENDIX

- Resistance
- Ohms Law
- Resistance/Resistivity Measurements
- Tribocharging
- Discharge of Squares
- Conductive fiber - Carbon Core
- Garment Experiment
- Definitions
- Gross Resistance
- Evaluation Test
- Acceptance Test
- Periodic Test
- Avalanche (Charge)
- Sheet Material
- "Figure of Merit"
- Ideal Garment
- References

CONSIDERATIONS FOR DEVELOPING ESD GARMENT SPECIFICATIONS

Introduction

Concerns about effective ESD garments are best addressed by starting with an understanding of electrostatic measurements and how they relate to ESD protection. Basic ESD measurements are simple, but for yarns, fabrics, or garments, measurements become difficult and complicated. An ESD Association Technical Report (TR), TR-1 “*CAN STATIC ELECTRICITY BE MEASURED?*” by Niels Jonassen [1] discusses ESD measurements at length and at a fairly high technical level. The principals stated in TR-1 are basic to understanding electrostatic measurements, and what measurements are, or are not, valid. From studying these basic principals, garment measurements can be understood. Only proper test methods will provide the information that can determine effective ESD protection.

There are many test methods applied to garments, some are applicable others are not. Some of the test methods being used today are valid measurement standards however, they were designed for other specific materials. Some test methods do provide useful information to assure device protection. Others use in-house test methods that may or may not be effective. So far, these test methods have not been demonstrated to be directly related to the protection of ESD sensitive devices.

After careful analysis, some presently proposed measurements may be discarded as improper, impractical, or meaningless. Still, there will be those that will argue about the validity and usefulness of a particular measurement because they believe that their measurement or test method will determine ESD protection. Disagreement is inevitable, as the variables of numerous protection configurations, device requirements, and static charge sources are open-ended. Only when scientifically valid models are proposed can people agree on the facts and calculations to show what is useful for determining ESD protection.

The device’s sensitivity must be considered and related to the requirements before ESD protections can be evaluated. What must be considered is the type of sensitivity of various device technologies and the possible way that devices can be damaged by common clothing, ordinary garments, or ESD garments. Only then can the requirements be evaluated to assure ESD protection.

To start the analysis of garment requirements, a list of “features” is discussed and defined. This will prevent confusion with the actual terms used to describe garment protection attributes. Then, the measurement methods can be discussed and evaluated. Also, measurement methods that could theoretically be made are analyzed and their problems discussed.

The Appendix has helpful and supporting information. The Appendix also has a definition of an ideal garment. The definitions show the contradictions of the listed requirements that are assumed to be needed for ESD protection of devices.

CONSIDERATIONS FOR DEVELOPING ESD GARMENT SPECIFICATIONS

A Discussion of ESD Protection Properties

It is necessary to list and define the “features” that are provided by ESD protective garments. A discussion of “features” or properties will clarify the protection elements, real or imagined. Some features listed may not be possible to evaluate, or test in any meaningful way. Some features are, for all practical purposes, improbable or impossible to measure, as they are not based on any engineering formula that can be used to calculate ESD protection. (The term “feature” is used in a broad sense to cover characteristics, properties, parameters, and attributes; all the terms that are sometimes used, but never clearly defined and often misused by technical as well as non-technical people.)

Here is a list of garment “features”, real and maybe not so real:

1. ESD Awareness
2. Surface Resistance (Conduction)
3. Dissipation of Charge (Static Decay)
4. Shielding Types
5. Induced Electrostatic Voltage Suppression
6. Anti-Static Property (Non-Tribocharging or Low-Charge Generating)

See Appendix for Ideal ESD Garment Definition

Feature 1.

ESD Awareness

ESD awareness is a “feature” that can be attributed to ESD garments. A garment, when it is identifiable as an ESD garment, promotes awareness. The effectiveness of ESD protection is not an issue for this valuable awareness feature. This feature is enhanced by garments being clearly identifiable as ESD garments because of color or visible conductive lines or grids.

Feature 2.

Surface Resistance (Conduction)*

The garment surface is mostly a relatively good insulator, except for the dissipative or conductive yarn woven into the fabric. The yarn conductivity spreads the charge or conducts the charge to ground, thus reducing the electrostatic field strength at the location where a charge has been generated. Resistance, to some extent, is involved with and related to all other issues even affecting tribocharging.

The charge may be on the surface of the garment or below it on the clothing of the person. Moisture given off of the person wearing the garment generally reduces the charge. Clothing items such as nylon-down jackets are the exception. Insulative yarns with conductive cores can reduce the electrostatic field strength by spreading the charge over a large surface, regardless of where the charge is located, even if these yarns have a high surface resistance (See Appendix Fig. 1).

CONSIDERATIONS FOR DEVELOPING ESD GARMENT SPECIFICATIONS

When the dissipative or conductive fibers provide a path to a grounded person or a direct path to ground, the assumption is that charge has been removed from the garment. Charge may have only been removed from the conductive yarn and the insulative surface near the conductive yarn. Charge will avalanche on the surface of an insulator as an abrupt change in charge density cannot exist on any surface. This is known as the breakdown potential (charge avalanche) of an insulative surface. Therefore, there will always be some electrostatic field measurable on the surface of an ESD garment. (See Appendix Fig. 2.) The conductive yarn connections in the garment weave or knit are important in the dissipation of charge. (Conductive, in this usage, includes the dissipative resistance range of yarns as well as the conductive range.) The connections affect the resistance values measured across seams, and from sleeve to sleeve. The connections are also a factor in the measurement of the garment surface resistance. The resistance of the yarn can be different in the x and y directions of the fabric. The connections can affect the resistance when measured in different directions on the garment fabric using a square electrode. When there is a directional factor to the fabric, the square electrode measurement value will differ from the circular electrode value. This resistance variation caused by conductive yarn direction goes unnoticed when circular electrodes are used.

The pattern of the conductive fiber for woven or knit fabrics, can affect the resistance measurement for a given yarn resistance or resistivity. Also, the resistance in the X and Y direction have been found to be quite different for woven fabrics, presumably due to the different amount of stretching that occurs during the weaving process. Also, the difference in applied voltages will cause variations in the measured values, as will the distance between electrodes. The change in distance between electrodes can have a linear resistance change or a non-linear affect on the measured resistance if the conductivity varies with the voltage gradient. A voltage gradient is the change in voltage per unit length between the electrodes. The voltage gradient changes for a fixed voltage as the electrode separation distance is changed or the gradient can change for a fixed electrode distance if the applied voltage is changed.

As previously stated the weave or knit is an import factor in the measured resistance. The resistive connection between conductive fibers needs to be examined. (See Appendix Fig. 2 & 3). The resistive connections are complicated and vary for the different fiber patterns. Models can only be developed knowing the resistance of the conductive yarn configurations and their resistive connections, as there is nothing else in the garment to produce ESD protection.

**Conductive or conductivity, as often used in this paper, describes material in the conductive range or may be used to define any material in the conductive, dissipative, or insulative (as in very low conductivity) resistivity range of resistance.*

CONSIDERATIONS FOR DEVELOPING ESD GARMENT SPECIFICATIONS

Feature 3.

Dissipation of Charge (Static Decay)

Dissipation (static decay) is an expected characteristic of an ESD garment. Dissipation (static decay) measurements are acceptable for homogeneous barrier materials (ESD bags) but not for ESD garment fabrics or non-homogeneous materials [2]. (Static decay time is directly related to resistance for materials that are homogeneous and that can be tested as stated in EIA-541 [2].) At best and when applied to the proper materials, the test produces a “Figure of Merit” and does not produce values that are related to a dissipation rate when the garment is in use. The static decay test methods, and there are several, are very controversial. They are redundant to resistance measurements [3 & 4] when applied to homogeneous materials. They can completely mislead users when applied to composites, laminates and garment materials, because the ground plane suppresses the measurement of the electrostatic field. The suppression occurs when the electrodes of the test instrument are grounded to start the decay measurement.

Charge decay is actually static dissipation by charge movement. (Charges never decay like radioactive materials.) In the dissipation process, positive or negative charge moves to establish an equal potential or a minimum stored energy when the charge is on an insulator between the conductive yarn grid. This is the result of the property of unlike charges being attracted to each other. The charges that move on a garment can only be electrons. Electrons carry a negative charge (positive charge is the absence of electrons relative to some other point). The “decay process” is the redistribution of the electrons to other places that do not have as high a charge density.

In the case of a garment fabric, the dissipation rate is a function of resistance. The time constant TAU (τ) is determined by the product of resistance (R) and capacitance (C). The time constant equation,

$$\tau = R C \quad (1)$$

shows that the variables in the decay time for a fixed voltage are controlled by the resistance and capacitance. Because capacitance for a given test is fixed, the only variable is the resistance. Unfortunately, the resistance may vary with voltage and this complicates the interpretation of the data. Also, the capacitance cannot be determined for insulative portions of a garment fabric when the garment is worn [1]. There is not much that can be done to determine how the garment material will behave in actual use because the capacitance is not definable and the conductive yarn capacitance is an uncontrollable variable. The decay test on a garment fabric only misleads the uninformed user when a non-homogeneous garment material, with possibly a nonlinear resistance, is being measured.

If the material has a true resistance it follows Ohms law, but for garment materials or conductive yarns, the resistance may be non-linear. (See Ohms Law in Appendix.)

CONSIDERATIONS FOR DEVELOPING ESD GARMENT SPECIFICATIONS

The “gross” resistance of a garment material determines how dissipative (conductive) it is, and therefore, how fast the charged material comes to a ground potential. The “gross” resistance is the resistance of the combination of the conductive yarn and the other yarns, insulative or dissipative. (The insulative yarns may still hold a charge when the decay time is measured because the electrostatic field of the charge may be suppressed depending on the conductive grid spacing. Resistance determines how quickly the charge spreads over a fabric surface to produce a near equal potential surface.

The question can be asked, is a dissipative garment required? This question can only be answered by data taken on sensitive items exposed to person wearing normal clothing.

Feature 4.

Shielding Types

There are several types of shielding; electrostatic, magnetic, and electromagnetic (RF - Radio Frequency). Shielding in electrical engineering has a definite meaning depending on the type of field and the frequency of the radiation. The electromagnetic fields are time variant radiated energy, which have electric and magnetic components. There are also static (essentially stationary) fields that can be electric, electrostatic, or magnetic.

Electrostatic Shielding

Electrostatic shielding prevents an electrostatic field from entering a closed conductive or dissipative container. Everything in the surrounding area, that is all charges and any conductive or dissipative surfaces, must remain relatively stationary (static). Under these conditions, only a solid or continuous conductive surface, with at least dissipative range resistivity, would be considered an electrostatic shield for a stationary (static) electrostatic field. If an object or a charge is moved, the lower the resistivity of the container, the faster the field will be excluded from the inside the container. A dissipative range material may take a few milliseconds to exclude the electrostatic field. Unless a garment is a closed solid surface with some conductivity and placed in a stationary environment, it cannot be considered an electrostatic shield.

Magnetic Shielding

Magnetic shielding for garments is not an ESD concern.

Electromagnetic Shielding

Electromagnetic shielding is a very complex subject. (A radiated electromagnetic field has an electric and magnetic component.) In a shielding discussion, the requirements must be related to a frequency. If the discussion is limited to what is commonly called RF (radio frequencies), light and X-ray are then excluded. Still, the radio frequency range for garments needs to be defined by an upper and lower frequency. The utility power frequencies in the 50, 60 and up to 500 Hz would generally not be of a concern for

CONSIDERATIONS FOR DEVELOPING ESD GARMENT SPECIFICATIONS

garments. This leaves a vaguely defined range of RF frequencies, but these may not be of any importance for ESD protection. Any garment that is not a solid conductive surface would not be considered a RF shield in the upper frequencies. Conductivity and the size of the holes in a shield determine the shielding ability of a material for a specific frequency.

The amount of shielding is determined by measuring and comparing the amount of power that is directed to a barrier (shield) and the amount that passes through it. Shielding attenuation values are usually associated with a continuous enclosure. Attenuation is due to a reflection at the surface and absorption in the volume of the barrier material as the electromagnetic wave passes through the material. These two effects reduce the power transmitted into the intended shielding enclosure. What power is absorbed or reflected from a garment? The power level from a source has to be identified and measured before it can be used in a calculation of attenuation. RF Field attenuation by the classical engineering definition does not apply to ESD garments.

Measurement of attenuation for a garment needs to have a valid formula before we know what is being measured. Power has to be properly measured to satisfy the following equation:

$$\text{dB} = 20 \log P_{\text{in}}/P_{\text{out}} \quad (2)$$

$$\text{dB} = 10 \log V_{\text{in}}/V_{\text{out}} \quad (3)$$

In the above equations (2&3), P is the power and V is the voltage. The voltage formula can only be used if the source and load resistance are identical as seen in the math reduction as follows:

$$P_{\text{in}} = E_{\text{in}}^2 / R_{\text{in}} \quad (4)$$

$$P_{\text{out}} = E_{\text{out}}^2 / R_{\text{out}} \quad (5)$$

$$P_{\text{in}} / P_{\text{out}} = (E_{\text{in}}^2 / R_{\text{in}}) / (E_{\text{out}}^2 / R_{\text{out}}) = V_{\text{in}} / V_{\text{out}} \quad (6)$$

In Equation (6) the resistances, R_{in} and R_{out} cancel only if the values are equal. Therefore, when measuring two voltages a large error can occur for two different situations, if the resistance of the power source and the load are not identical.

Determining or even identifying the power source for a garment measurement is difficult. Measuring the values to be used in the above equation is the problem that has to be overcome with a test method. Then the method has to be shown to be relevant to protecting the product.

CONSIDERATIONS FOR DEVELOPING ESD GARMENT SPECIFICATIONS

It does not appear that RF shielding is relevant to an ESD garment because what is being shielded has not been identified for a range of frequencies. Also, under this definition of shielding, garments would not be considered a shield nor would RF shield need to be measured.

Feature 5.

Induced Electrostatic Voltage Suppression

Electrostatic voltage suppression (or enhancement) is not a commonly used engineering term, but for a garment, voltage suppression is more relevant than shielding and can be related to basic electrostatic principals. Suppression is applicable to electrostatic induced voltage, not electrostatic fields from charged surfaces. The voltage suppression comes from the fact that when the capacitance changes the voltage on a dissipative or conductive surface varies inversely to the capacitance, provided that the charge is held constant. Suppression can be described by the equation:

$$Q = C V \quad (7)$$

And the variation $V = Q/C \quad (8)$

Where Q is the charge, C is the capacitance, and V is the voltage. This means that if an induced voltage from an electrostatic field is to be suppressed, the capacitance has to be substantially increased. The product of CV must always equal the fixed charge, capacitance increase, and voltage decrease and visa versa. The capacitance increase is accomplished by bringing a ground plane close to the charged surface.

In a garment, the grounded person's body can suppress the voltage induced in a device on a workbench. It appears that the electrostatic field strength is "suppressed," but the electrostatic field just moves and increases between the source and the ground plane (grounded person's body). Therefore, the charge source near a person's grounded body cannot induce as large a voltage as a source that does not have a nearby ground plane. A grounded garment over the person's charged clothing will "suppress" the external field outside of the ESD garment. A grounded person's skin will also "suppress" the external field, but for loose or bulky clothing the grounded person is less effective in reducing the external field. The reduction of an electrostatic field from a person's charged clothing occurs under and near the conductive yarn.

Voltage suppression as shown in Equations 7 and 8 are not valid for an insulative surface [1]. Observing that positive and negative charge can reside on adjacent areas of the same insulative surface proves that voltage cannot be defined for an insulator. Therefore, some assumptions must be made to get around this fact to assist in understanding "voltage"

CONSIDERATIONS FOR DEVELOPING ESD GARMENT SPECIFICATIONS

suppression on an insulator. For an insulator, Equations 7 and 8 can be applied, if it is assumed that the charge is evenly distributed, or if the equations are applied to each individual charge.

The most important question is “what is the amount of induced voltage that a charge under an ESD garment can produce on a device?” The variable conditions make this measurement difficult to apply to general shop practice. Some measurements have been made and they indicate that voltage induced from tribocharging, due to the operators hand-contact to a device or circuit boards, produces a much greater induced voltage than a charge from reasonable clothing that an operator would wear for production operations.

Feature 6.

Anti-Static (Low-Charging)

Anti-static materials are not truly anti-static. Today, low charging or low-tribocharging are the accepted terms, replacing anti-static in international standards. Zero tribocharging is a feature that cannot be obtained. Therefore, the desired characteristic is to have a fabric that will not tribocharge as much as some other fabric. Unfortunately, all materials will tribocharge more or less when contact is made to some other material. There is no universal low-charging fabric [5]. Because tribocharging tests are difficult to reproduce, testing all material combinations is impractical.

GENERAL COMMENTS

There are many test methods used in facilities. Tests such as static decay, tribocharging, and shielding have not been generally accepted. Instrumentation, such as hand held electrostatic field meters and other similar devices are often used incorrectly and in inappropriate applications. Some measurements have been proposed as the basis for a new garment standard in addition to the ESD Association’s present standard. The effort has not progressed since the Garment Standard Working Group has not presented evidence substantiating the need for additional test procedures. The present standard describes a resistance measurement.

Any proposed test methods must show that they evaluate the ESD garment's ability to provide ESD protection. The evaluation section below may help define what needs to be done to establish the requirements for new methods to test ESD fabrics or ESD garments. Garment test methods, or system tests,* need to clearly state what the test methods evaluate, the objective and usefulness of the test method. Garment test methods should be considered and developed for three different functions; evaluation, acceptance, & periodic test. (See Appendix for definitions of functions.)

** A system test is defined as a test of many items functioning together to determine their ability to meet a specific requirement or for evaluation purposes.*

The need to define what a garment is supposed to do for the protection of sensitive electronics is necessary, even if it is a difficult task, before a test method is developed.

CONSIDERATIONS FOR DEVELOPING ESD GARMENT SPECIFICATIONS

Most users just start to make some measurements on the fabric or a garment without a properly defined objective(s). The tendency has been to rush directly into writing test methods and specifications for their test. Unless the purpose is clearly defined with an understanding of the garment's intended function(s), the user will fail to produce a meaningful test method(s).

The ease of testing is an important factor in the general acceptance of a test method. Careful consideration should be given to test methods that require a walk-in humidity chamber. Evaluation of a small material sample, under low relative humidity conditions, is much easier to perform in a glove box enclosure than testing of a full garment in the confined space. Humidity test conditions should only apply to the evaluation tests and not periodic testing. Tests on fabric are generally a "Figure of Merit" test. If a small sample is used for such a test, a relationship to a complete garment must be demonstrated.

Possible Garment Tests

- Resistance of a Conductive Garment Thread - 2-Point Measurement (Ohms)
- Resistance or Resistivity of a Garment Fabric (Ohms or Ohms/sq.)
- Resistance of Garment from Point to Point (Ohms)
- Static Decay (Neutralization of Charge) of a Garment Fabric
- Static Decay of a Charged Garment.
- Tribocharge Ability of Garment Fabric in Combination with Another Material
- Tribocharge Ability of Garment Fabric in Combination with Teflon (NASA TEST) (Tribocharging & Static Decay Test Combined)
- "Shielding" Test of a Garment Fabric
- "Shielding" Test of a Garment
- Measurement of a Residual Charge (Electrostatic Field) on a Garment Fabric
- Measurement of a Residual Charge (Electrostatic Field) on a Garment

Some of the above measurements may not be valid or possible to do if engineering definitions are strictly followed. Some tests on the list are not understood and therefore misused. Other tests need to be defined to be useful. Just because a measurement is on the list does not mean the test method is a technically valid measurement or that it provides meaningful data. Also, just because a measurement is on the list does not mean it can ever become a valid test. Unfortunately, until an engineering approach is applied to prove the validity of a test method, test methods will be contested. A combination tribocharge and decay test method using only one material (e.g. Teflon™) does not provide useful data and the data is very hard to apply to specific applications.

Some tests on the above list are not well defined or the objective is not defined. An engineering approach is one in which the objective is defined and proven by circuit or computer models. The

CONSIDERATIONS FOR DEVELOPING ESD GARMENT SPECIFICATIONS

models must predict protection results for a given garment in a given situations and for a given device sensitivity.

All garment tests are inner-related by the resistance of the conductive threads. For example, resistance may affect the bleed-back (charge return between two dissipative surfaces) in a tribocharging test and also can affect decay times. Resistance is also a main component of the suppression property of a material.

The configuration of the material and the conductive threads are all-important in affecting most garment fabric and garment measurements. Resistance particularly affects undefined “shielding” measurements, even if shielding is erroneous for fabrics and garments. Some fabric measurements may be related to the characteristic that is intended when the material is made into a garment, but the proof has not been presented. Therefore, those measurements should not be used.

Most test methods have a poor relationship to an actual garment or may provide misleading information. An example of this is the static decay test, Method 4046, which is only valid for homogeneous materials and for small test specimens, not the whole garment.

Another questionable test is the rolling tribocharge test. This tribocharge test rolls quartz and Teflon™ cylinders down an inclined plane covered with the material under evaluation. The cylinders are caught in a Faraday Cup for charge measurement.. The roller materials used in the test method are not representative of actual material combinations found in industry and therefore provide little practical value. There is no proof that quartz and Teflon™ can define the tribocharging ability of other material combinations. The test method repeatability is also in question.

Having stated some of the problems with basic test methods, it is certain that some people have the impression that the basic tests (resistance/resistivity, charge decay, tribocharging, shielding, etc.) are definable in scientific and engineering terms. Unfortunately, it may be difficult for non-technically trained people to understand or completely appreciate that this is not true. Even the basic resistance tests have not been shown to provide a measurable amount of ESD protection. An engineering approach is the only way, no matter how difficult it is, to prove that a test method is evaluating ESD protection.

If the only goal is to identify one garment from another as being an ESD garment, without regard to any ESD protection value, then the main benefit is to the vendor of the garment. The garment will be identified as an ESD garment, but that means nothing in determining ESD protection. The secondary value is to the user. It makes everyone wearing a garment aware of ESD, and more likely to follow other ESD procedures. If nothing else, the resistance test clearly does that for garments.

I. Device Damage

In order to understand what modes of device damage are possible due to electrostatic sources, the sensitive device differences need to be examined. Voltage sensitive devices like gate oxide transistors or unprotected IC's can be damaged by induced voltages as well as by a direct discharge. Magneto-Resistive (MR) disk drive devices are also sensitive to induced

CONSIDERATIONS FOR DEVELOPING ESD GARMENT SPECIFICATIONS

voltage, as well as direct discharges during assembly. Energy devices are damaged by a direct discharge, but are not sensitive to being exposed to an electrostatic field.

The following types of devices and the source of electrostatic discharges or induced voltage are identified. An overview of the characteristics of sensitive types of devices is important to understand how and why the charged sources produce damage in different devices. This overview shows how complicated the problem is if the actual protection procedures are not properly addressed.

Device Sensitivity Types

- **Voltage Sensitive Devices**

Type V devices are voltage sensitive. These devices have insulative layers that are damaged when an excessive voltage is applied or induced across the dielectric material layer. The voltage can be due to an electrostatic field induced voltage or a direct discharge to the device. The voltage is the initiator of the damage process that only requires a small amount of energy. The dielectric material that is damaged is between conductive electrodes. Type V devices do not have any shunting protection across the electrodes. When the voltage on the electrodes exceeds the dielectric breakdown, the dielectric material is easily damaged, because the dielectric insulators usually are very poor heat conductors. Being a poor heat conductor allows the temperature of the dielectric material to rise to the point of melting or evaporation. Gate oxide transistors and integrated circuits (ICs) such as FET, MOS, CMOS, DMOS, etc. are voltage sensitive if there is no “on chip” protection circuits built into the device. (The vast majority of ICs now have “on chip” protection to around 2kV human body model* (HBM) level and some ICs are up to 10kV HBM. Flat panel and charged coupled device (CCD) displays are voltage sensitive in the 50 to 150 volt range. Magnetic recording heads of computer disk drives are voltage sensitive and energy sensitive. The gap spacing is the voltage sensitive element in the magnetoresistive (MR) head, often having about a 50-volt breakdown level.

CONSIDERATIONS FOR DEVELOPING ESD GARMENT SPECIFICATIONS

- Energy Sensitive Types

Type E devices are energy sensitive. Energy sensitive devices normally can conduct the designed level of current in a steady state fashion and dissipate the heat generated. Energy sensitive devices need to dissipate the heat for the current that passes through the device. For a short period of time, the current may exceed the steady state by many times the design limit and still not damage the device. The shorter the time period, the higher the current can be, but if the heat dissipation of the device is insufficient to prevent a reasonable temperature rise, the device will be damaged by diffusion, melting, or evaporation.

Because an energy sensitive device is designed to pass current, electrostatic fields can induce a voltage that causes current to flow. P/N junctions can turn on in the forward polarity and avalanche in the reverse polarity. A small amount of current does not damage the device because the induced voltage is usually applied too slowly to cause a sufficient current flow over the time period. Junction devices such as, P/N, Schottkey diodes and light emitting diodes are energy sensitive devices. Junction transistors and most ICs (MOS, CMOS etc.) are also energy sensitive. Magnetic recording heads of computer disk drives are both voltage sensitive and energy sensitive, with magnetoresistive (MR) element being the energy sensitive element. A fairly small increase in current through the MR element that is above the operating current will cause a sufficient rise in temperature to change the recording properties of the MR head.

* Note: The HBM and machine model (MM) test standards do not make a distinction between Type V and Type E devices. Voltage and energy devices are finally discussed in the ESD Association Standard, ESD 20.20 [6]. Device type information should be included in the test standards.

Discharge & Damage Sources

- Electrostatic Fields - Insulators and Conductors

Both charged insulated conductors and insulators will induce a voltage in an ESD sensitive device. The strength of the electrostatic field and the distance from the device will determine the amount of induced voltage. For Type V (voltage sensitive) devices the induced voltage will also depend on the capacitance of the device. If the capacitance is large the voltage will be low, and if the capacitance is very small the induced voltage will be very high. The two extremes are a MOSFET power transistor and a small signal FET.

The induced voltage should always be compared to the voltage created by tribocharging the surface of the device by hand or material contact.

CONSIDERATIONS FOR DEVELOPING ESD GARMENT SPECIFICATIONS

- Direct Discharges - Insulators

Direct discharge can come from a highly charged surface. If the insulator is tribocharged while on a grounded surface (near the grounded person's skin), the charge density can be very high. When the charged insulator is removed from the grounded surface, charge may either avalanche to the conductive yarn of the garment or arc to a nearby device. Conductive or dissipative yarn can cause an avalanche from the insulative surface of the garment. Charge will discharge (avalanche) along an insulative surface if the electrostatic field gradient is large enough.

A discharge to a device depends on the charge density, the distance to the discharge point, and the radius of the point. The arc distance of the discharge will depend on the radius of the point on the device that the arc hits. For example, a Ping-Pong ball size radius will discharge up to a 1.5 inch (3.8 cm) distance. A sharp needlepoint will discharge the insulator's surface at a distance of at least 11 inches (28cm). Because ESD garments have a conductive grid, most of the charge will avalanche to the conductive grid and not to the device.

There is no data presented to show that an ESD garment on a grounded person can arc to a device.

If an arc does occur, a direct discharge most likely will damage type V devices. A direct discharge will damage Type E devices only if sufficient energy has been transferred. A large portion of the energy in an arc will be dissipated depending on the resistance of the device when it is in a conduction state.

- Direct Discharges from Conductors

Direct discharge from conductors can transfer far more energy than an insulator. The total surface the conductor will deliver most of the energy that is stored on the surface. The arc will extinguish when the stored energy is dissipated or the potential gradient can no longer support the arc. An ESD garment with conductive yarn that is not worn by a properly grounded person could discharge more energy into a device than a garment that has dissipative yarn.

- Contact Discharge - Insulators and Conductor

Direct contact to a conductor or an insulator will discharge the surface. More charge will be available from the conductor than will be available for an insulator. A charged insulator will avalanche charge to the point of contact

CONSIDERATIONS FOR DEVELOPING ESD GARMENT SPECIFICATIONS

until the voltage gradient is reduced to the level where the surface will not conduct any longer. For an ESD garment, the conductive grid covers the charged area and therefore most of the charge will be transferred to the dissipative yarn.

II. Evaluation of ESD Problems

This section is intended to suggest what needs to be determined to establish that there can be ESD damage caused by worst case clothing or garments that might be used by personnel.

1. Determine Discharges from Clothing

It is important to consider and prove that clothing, non-ESD or if even an ESD garment, is a source of direct ESD (arc) that can damage sensitive devices. This mode of damage needs to be documented and evaluated.

The energy levels of possible discharges need to be compared to the HBM or MM level for energy types of devices. This will involve determining the possibility of a discharge from a charge density that could be established in the presence of various capacitances (looseness of garment) to the grounded person's body. The worst case may be a discharge from a person that is not grounded, but that case should not be seriously considered. It must be assumed that in an ESD controlled area a person is always grounded by a wrist strap or ESD footwear, even when wearing non-ESD garments. Although given that maximum voltages for ungrounded personnel appear to be overstated, it may be of interest to compare discharges from an ungrounded person versus a grounded person wearing an ESD smock. A conductive garment made with low resistivity threads may be a machine model (MM) type of discharge and this should also be evaluated. The chances are that the MM damage will occur only with contact with conductors in the low Ohm range.

2. Develop Standard Model for Induced Charge

This section suggests what should be considered and measured for a charged source that can be under the ESD garment surface or on its surface. The magnitude of the charge source and the distance to the device are variables. A model must be developed for these items to show how induced voltages are applied to sensitive devices due to the coupling of surface charge from an operator's clothing. Then, induced voltage measurements need to be made for a reasonable range of these variables.

This will involve determining the magnitude of the E-field coupling to circuits, devices, IC chips, wafers or MR heads. Data should also be collected to determine the magnitude of charge from possible sources due to any tribocharge that possibly could occur under the smock and on the surface of the smock when worn. This involves determining what the amount of charge is when the two surfaces are close together, and what the

CONSIDERATIONS FOR DEVELOPING ESD GARMENT SPECIFICATIONS

electrostatic field strength is as the clothing and the garment fabric are separated within the confines of the garment. The induced voltages can then be determined for various coupling capacitances to gate oxide capacitances, or to the total circuit and gate oxide capacitances.

When the model is developed, what must be determined is whether the induced voltages from garments are above or below the induced voltages from other charged objects or tribocharging of the device by operator contact. Charge is normally produced on circuit boards by tribocharging that occurs due to manufacturing operations, even with grounded personnel. Induced voltages from garments, normal or ESD protective, can be measured and compared to the charge created on the circuit board, which also results in an induced voltage.

3. Determine Amount of Field Suppression

Data should be generated to determine the amount of electrostatic field suppression that is required of a garment for various distances to sensitive devices and assemblies.

Assuming the tribocharged source is the clothing underneath, the amount of the electrostatic field that passes through the garment as a function of the separation of the two surfaces that produced the charge has to be determined.

It is difficult to determine the difference between the ESD garment's dissipation of charge on clothing and suppression of the electrostatic field. The question that has to be answered is "how much charge is to be dissipated by a garment over charged clothing?" The moisture that continually comes from the person's body will also dissipate charge. It may be difficult to calculate the time constants for body moisture and a specific garment type. This calculation is important for determining the dissipation rate of charge for ESD garments.

Keep in mind that the amount of charge from a source is variable, therefore, how to determine the amount of required suppression is a problem. This is the same as the problem discussed earlier for attenuation, if attenuation could be measured. Because of the variable source problem, the amount of suppression cannot be easily specified in the test method.

The task is to determine the maximum allowable electrostatic field level at some reasonable distance. Also, the electrostatic field level needs to be related to the type of device sensitivity. The induced voltage will be related to the electrostatic field strength and the coupling factor to the device.

4. Compare Background to Charged Garments

Electrostatic fields from garments might be below levels generated by normal handling of sensitive devices. Data has not been shown that proves the threat from a garment is above background electrostatic field levels due to other tribocharged sources around the work place such as the device or circuit board itself. Induced voltages can be measured