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Electrostatic discharge - understanding and controlling the phenomenon: A Handbook for packaging professionals

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ELECTROSTATIC DISCHARGE—UNDERSTANDING AND CONTROLLING THE PHENOMENON: A HANDBOOK FOR PACKAGING PROFESSIONALS

By

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ABSTRACT

This thesis is designed to be a handbook on the phenomenon of electrostatic discharge (ESD) and its deleterious effects on electrically-sensitive electronic devices. Packaging and handling of sensitive devices occurs at every step in the assembly of such devices. Once the hardware is designed (and this may include some ESD-protective mechanisms), it is the packaging of ESD-sensitive devices that determines their ultimate fate: being 100% reliable, being among the "walking wounded," or being completely useless.

Electrostatic discharge is a phenomenon experienced in many industries from foods to pharmaceuticals, aerospace to communications, medical packaging to explosives, military to optics, and--most predominantly--the electronics industry. An understanding of ESD phenomenon is essential in some industries, critical in others.

This handbook focuses on the problems of the electronics industry. It is an industry that touches all others, and it is plagued, often critically, with the problems of ESD. There is a general lack of understanding of the problems caused by electrostatic discharge. The unfortunate side effects of this lack of understanding are the purchase of inappropriate materials and little impact on rising damage to electrically-sensitive components. Competent, knowledgeable packaging professionals play an important role in ensuring the successful manufacture, handling, packaging, and transport of sensitive electronic devices. It is the purpose of this handbook that packaging professionals have knowledge of this subject prior to being faced with all the challenges of ESD control.

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PREFACE

Why should there be a handbook on the phenomenon of electrostatic discharge (ESD) and its deleterious effects on sensitive electronic devices written for the packaging professional? To respond by saying "because there isn't one" may seem trite. After reviewing article upon article on the subject, after reading a few of the existing texts on the subject and after studying the few training manuals and handbooks aimed at people in general who work with sensitive devices, the answer to the question became clear. Packaging and handling sensitive devices occurs at every step in the assembly of those devices. Once the hardware is designed (and this may include some ESD-protective mechanisms) it is the packaging of sensitive devices that aids in determining their ultimate fate: to be 100% reliable, to be "walking wounded", or to be completely useless and "dead-on-arrival".

There isn't a handbook on ESD that is written specifically for the packaging professional. Electrostatic discharge is a phenomenon that is experienced in many different types of industries from foods to pharmaceuticals, aerospace to communication, medical packaging to explosives, military to optics, and most predominantly, the electronics industry. An understanding of ESD is essential in some industries, critical in others.

Why should there be a handbook on the phenomenon of electrostatic discharge (ESD) and its effect on sensitive devices written for the

packaging professional? Because there is not one and there should be. This handbook will focus on the problems of the electronics industry. It is an industry that touches all others and is plagued, often critically, with the problems of ESD.

The information included in this text is directed to those of you who are just beginning to learn about electrostatic discharge (ESD) and its ramifications. There seems to be a real dearth of knowledgeable professionals working with the problems caused by ESD. The unfortunate side effects of this lack of understanding are the purchase of inappropriate materials and little impact on the rising damage estimates for sensitive components. It is hoped that this handbook will provide the packaging professional with the correct fundamental information on which to build a solid foundation for developing expertise in the control of ESD. Competent, knowledgeable packaging professionals play a very important role in insuring the successful manufacture, handling, and transport of sensitive electronics devices. Having this knowledge prior to being faced with all the challenges of ESD control is more efficient and quality oriented that trying to gain the right expertise while being faced with the challenges.

CHAPTER 1 - THE MAGNITUDE OF ESD-RELATED DAMAGE

The magnitude of ESD related damage in the electronics industry is not well known nor well understood by many individuals. There are two groups of individuals who are of particular interest to the packaging professional: those who are the primary end users of delicate devices such as electronic components and those who provide protection for these devices. The controls presently used in industry to decrease ESD-related damage are not consistent and may not even be implemented at sites where static safe environments are warranted.

ESD is a major source of electronic equipment failure. The greater the need for equipment reliability, the more critical the problem. The aerospace and communications industries, as well as the military, look for approximately 1% failure in some ordered parts. Without the proper procedures in handling sensitive parts, failure rates that low cannot possibly be achieved in great quantities.

In order to begin to understand the problems created by electrostatics, consider one hundred complimentary metal oxide silicon (CMOS) devices (microcircuits) and the damage ESD can impart to them from their inception as wafers to their use in the field. This is a worst case scenario, but it will quickly illustrate some starling truths about ESD.

From wafers to the field

By the time the silicon wafers, the basic substrates or medium for a CMOS device, reach the microship assemblers ('slicers and dicers') the loss of silicon medium alone to ESD damage is critical. As will be seen by the following scenario, a high percentage of the microcircuits produced are damaged to the point of severely affecting their total life cycle. At the onset, ten percent of the damage to microcircuits will lead to catastrophic failure. This means ESD damage has 'zapped' the material to total destruction. Sixty percent of the remaining 90 circuits have been latently damaged or 'zinged' leaving 36 potentially reliable microcircuits. The latently damaged microcircuits have joined the ranks of the 'walking wounded' rendering them unpredictable as far as performing their intended functions. Latent failure imposes the fear of the great unknown. Will failure happen? When will failure happen? How severe will failure be? The material may fail completely at any moment or never fail. Failure may be intermittent: working fine one moment, malfunctioning the next.

A chip that has been 'zapped' is unquestionably and permanently out of commission. A chip that has been 'zinged', or latently damaged, has the potential to make it all the way through the testing system, only to eventually fail in the field.

Latent failures cause the greatest concern. If a latently damaged chip is responsible for the red "on" light on your PC and the light is dimmer than usual, the situation is far from critical. If that chip is part of an on-board computer on a military aircraft, or part of such aerospace applications as the space shuttle, such intermittent behavior could lead to critical problems.

The remaining 36 wafers are now at the formatting stage where they will become integrated circuits (IC's). Another 30% of this yield will be lost to ESD damage. From the original 100 wafers only 25 IC's will survive to be packaged in DIP tubes (dual in-line packages) where they will be packaged into an overall pack for distribution. At this stage a 3 - 10% loss can occur, leaving approximately 22 IC's to be forwarded to board populators who 'stuff' the boards at work stations. From the work station to the burn-in station, less than a 1% loss is typically seen. At this point the boards may go to a sub-assembly or to storage as field replacements. A 10 - 15% loss can be expected in the field.

This worst case scenario has a final yield of 16 working devices; 84% of the devices have failed (see chart 1-A). Keep in mind that it is not known how many, if any, of those 16 devices are

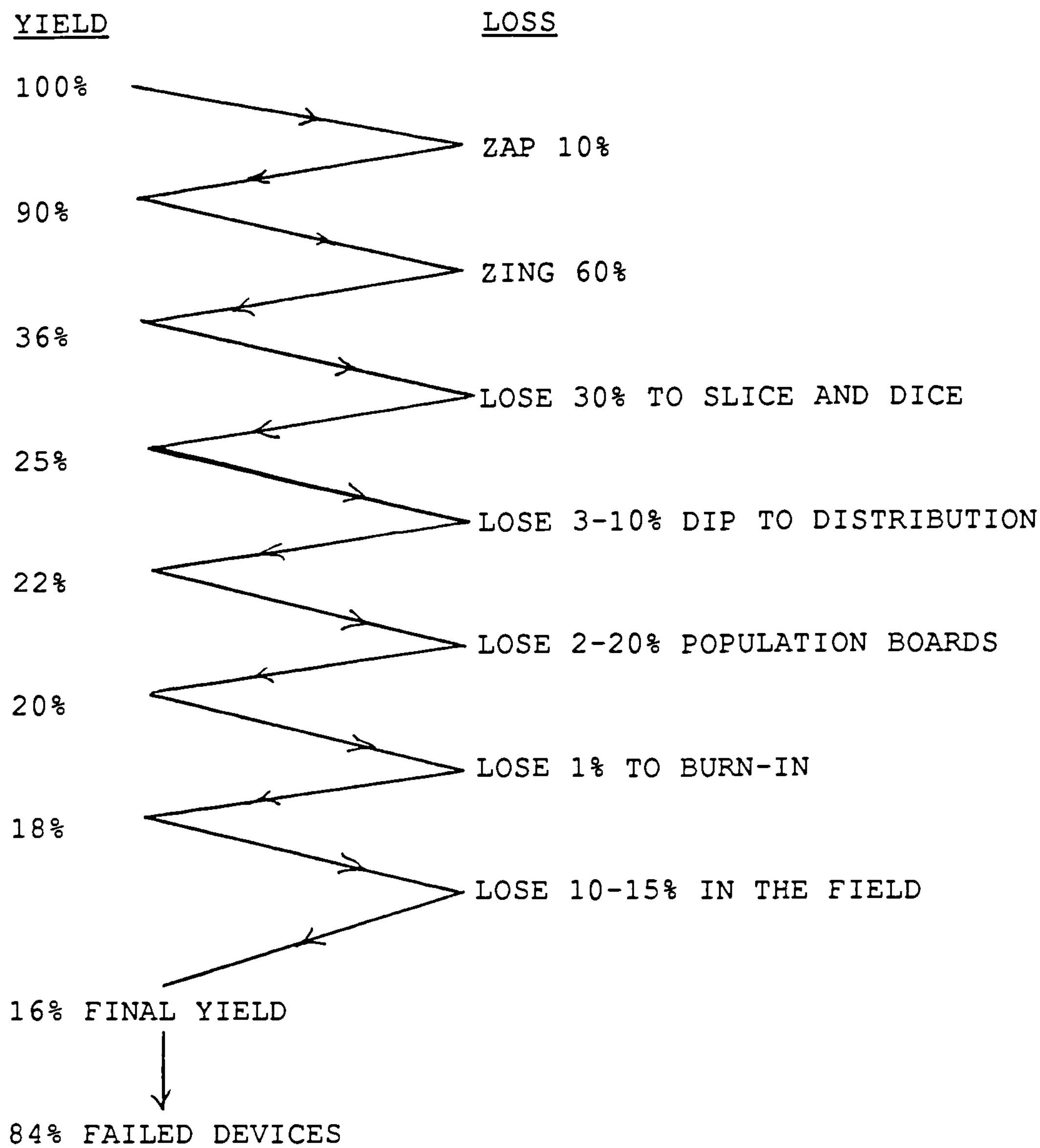

YIELD
LOSS
100%
ZAP 10%
90%
ZING 60%
36%
LOSE 30% TO SLICE AND DICE
25%
LOSE 3-10% DIP TO DISTRIBUTION
22%
LOSE 2-20% POPULATION BOARDS
20%
LOSE 1% TO BURN-IN
18%
LOSE 10-15% IN THE FIELD
16% FINAL YIELD
84% FAILED DEVICES

CHART 1-A

latently damaged. Also, keep in mind the industries that look for a 1% failure rate. To meet those demands for quality, manufacturers of microcircuits will produce many failed devices in an attempt to produce a few good ones. The statistics from real field data, seen on chart 1-A, indicate that some very significant losses are seen in industry.

The capital involved in a chip is small, maybe 1/2 cent, and is hardly worth any great concern. Or is it? If a board carrying the chip fails catastrophically, it may cost thousands of dollars. Now the loss of capital is becoming alarming. If this board fails in a low earth orbit satellite, the cost could be tens of millions of dollars; and, if a space shuttle could be launched to repair it, the "housecall" would cost hundreds of millions of dollars.

Why do the problems associated with ESD seen to be more urgent now than they were ten years ago? Cell geometries have become smaller and smaller with time. Smaller geometries means greater sensitivity, faster switching, and more capacity with less area. Metallization and oxide thicknesses are getting thinner and thinner (in some cases from 1500 angstroms to 800 angstroms). It takes less voltage to "turn on" an integrated chip (IC). It will take less voltage to damage one as well (1).

INFORMAL SUMMARY OF STATIC LOSSES BY LEVELS*

	MIN %	MAX %	AVE %
COMPONENT MANUFACTURER	4	96	16-22
SUB-CONTRACTOR	3	70	9-15
CONTRACTOR	2	35	8-14
USER (FIELD)	5	70	27-33

CHART 1-B

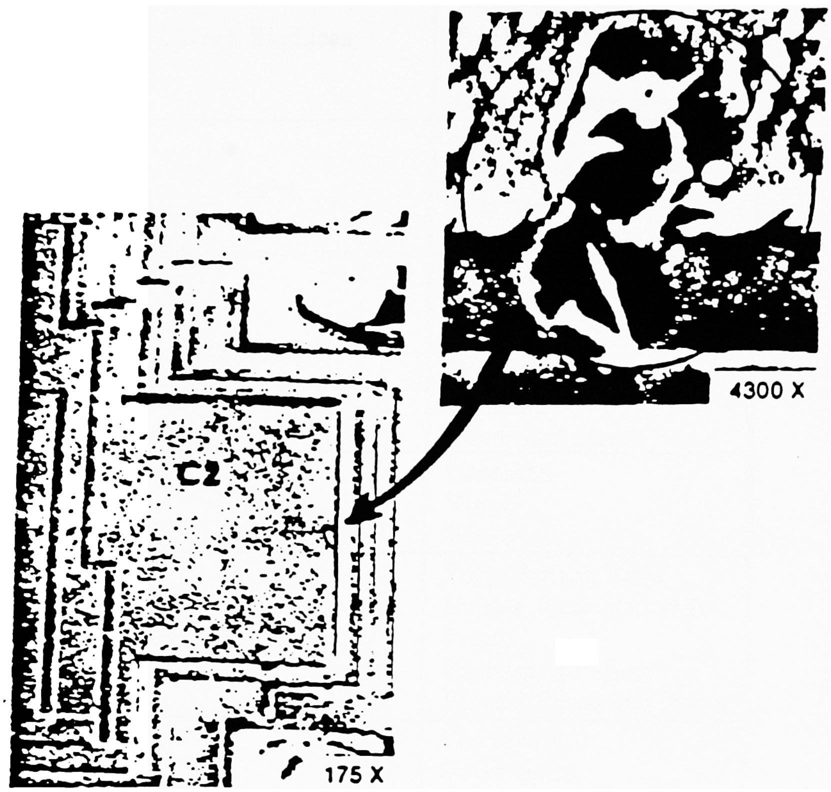
* STEVE HALPERIN - "FACILITY EVALUATION: ISOLATING ENVIRONMENTAL ESD PROBLEMS"

"At McDonnell-Douglas over 50% - 60% of the avionic components are sensitive to less than 100 volts" (2). Newer technologies will continue to accentuate the sensitivities. The packaging engineer will continue to face more and more challenges in regard to component protection and static safe work environments as devices become more and more sensitive (3).

Not only can the current or spark discharge (a mini-lightning bolt) damage a device, but a spark also creates an electromagnetic interference (EMI) pulse which may contribute to intermittent as well as hard failures. (More on this subject later). Electrical overstress (EOS) may be the actual microscopic puncture or melted area caused by the spark within the device. Place that device in a piece of equipment and apply current and the results are a short circuit. "Electrical overstress accounts on the average for 30 - 40% of all electronic part failures. For parts highly sensitive to ESD up to 70% of the failures are often categorized as EOS" (4).

What are the sources for static charges? Sources are common and plentiful. The worst generators of static charges are insulators, and people become the facilitator of generated static. Normal everyday movement combined with any and all of the following are only a few of the sources of static electricity: clothing, shoes, furniture, plastics, cigarette wrappers, styrofoam cups, packaging containers, parts bins, vibration in transit, walking and sitting. As you will see, it is very simple to build up static charges high

enough to damage sensitive devices, assemblies, and equipment (see table 1-C).



A highly magnified closeup showing damage caused by ESD.

TABLE C

TYPICAL CHARGE GENERATORS

ITEM	TYPE
Work Surfaces	Formica* Finished Wood Synthetic Mats Ungrounded Metal Glass or Fiberglass
Chairs	Fiberglass Vinyl, Other Plastics Ungrounded Metal Finished Wood
Clothing	Clean-Room Garments Finger Cots Gloves Wool Synthetics Shoes and Boots
Floors	Carpeted Vinyl Waxed
Packaging Materials	Polyethylene Bags Bubble Pack Material Foam Packaging Pellets Plastic Trays and Boxes
Manufacturing Processes	Conveyors Drive Belts Machinery Nylon Scrub Brushes Nonconductive Liquids High Velocity Air Flow Temperature Chambers Environmental Ovens

* Trademark of L. E. Carpenter & Co.

CHAPTER 2 - THE NATURE OF ELECTRICITY

Matter is anything that has mass and occupies space. Atoms are the building blocks of matter and are composed of three basic subatomic particles: electrons, protons, and neutrons. The various combinations of these give us our elements (see diagram 2-A).

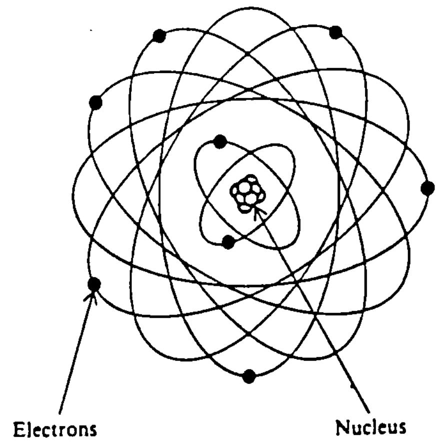
The nucleus of the atom is composed of neutrons and protons. Fundamentally, neutrons are neutral, protons are positive, and electrons are negative. Electrons are found in concentric orbits revolving around the nucleus.

In its natural state an atom contains the same number of electrons and protons. Electrons have a very small mass (9.1×10^{-13} KG) and are loosely held in the valence orbit. The electric charge of an electron is the smallest existing amount of charge (-1.6×10^{-19} coulomb or C). The mass of a proton is about 2000 times larger than the mass of an electron or 1.7×10^{-27} KG. The proton is numerically equal to the electron in charge except it is $+1.6 \times 10^{-19}$ C. When the number of electrons equals the number of protons the atom is considered neutral, or in balance, because the charges negate each other.

A neutral atom is stable and has a certain amount of energy. This energy is equal to the sum of the energies of the electrons. The electrons occupy concentric rings, or shells, around the nucleus

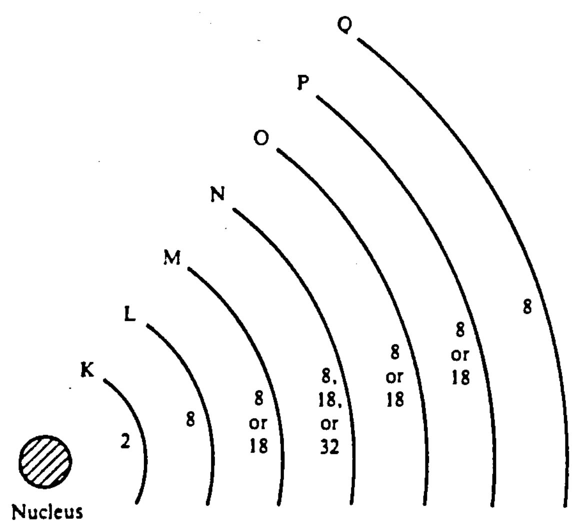
and each ring has a different energy level. This energy level is proportional to its distance from the nucleus. The electrons farther from the nucleus have the greatest energy levels. High energy levels are required to maintain an orbit. Each ring around an atom has a quota and can only be occupied by so many electrons is the quota is filled, the atom is said to be inert. If the outer shell lacks its quota of electrons, it is capable of gaining or losing electrons. Ionizations is the process by which atoms gain or lose electrons (see diagram 2-B).

If the atom loses electrons (protons now outnumber electrons), it has a net positive charge and is called a positive ion. If the atom gains electrons (electrons now outnumber protons), it has a net negative charge and is called a negative ion. Materials that easily give up or take on electrons are called conductive materials. Non-conductive (insulative) material may readily take on or give up electrons, but are very resistant about reversing that activity and returning to the neutral state. Keep in mind that conductivity or insulativity is a relative property (see chart 3-A). A material is always more conductive than some materials and less conductive than others. How readily a material takes on or gives up electrons is the key to its conductivity.



Electrons and nucleus of an atom

DIAGRAM 2-A



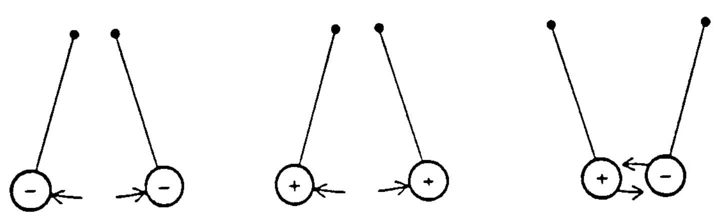
Energy shells and the quota of electrons for each shell

DIAGRAM 2-B

The outermost ring of an atom is occupied by valence electrons. These electrons gain energy when, for example, heat, light, friction, or electrical energy are applied externally. Because they gain energy the electrons want to move to "a higher energy level (farther from the center of the atom). An atom in which this has occurred is said to be in an excited state. An atom in an excited state is unstable" (5). This is an important concept to keep in mind.

Valence electrons have the least amount of attraction to the protons held within the nucleus of an atom. If enough external energy is applied to the atom, the valence electrons will actually leave their orbit and become free electrons. (It is this movement of free electrons that is the current in a conductor). Some materials have a tendency to gain electrons; some have a tendency to lose electrons. This give electrons an opportunity to transfer form one material or object to another. The equal distribution of charges, negative and positive, no longer exists. A pair of objects with unlike charges, one negative and one positive, are said to be oppositely charged. The law of electric charges states that like charges repel each other; unlike charges attract each other (see diagram 2-C).

DIAGRAM 2-C



Like – charges repel (a) Like + charges repel (b) Unlike charges attract (c)

Force between charges

The number of electrons compared with the number of protons determines the magnitude of electric charge. The symbol for charge is (Q); the unit is expressed in coulombs (C). One positive coulomb means a body contains a charge of 6.25×10^{18} more protons than electrons. One negative coulomb means there are 6.25×10^{18} more electrons than protons.

As the distance between the charges increases, the force between them decreases rapidly. Upon investigating this balance it was found that: "(A) the force between two small charged bodies is directed along the line joining them; (B) the force is proportional to the product of the charges; (C) and inversely proportional to the distance between them" (6).

A basic characteristic of an electric charge is its ability to exert a force. This force is present in the electrostatic field surrounding any charged object. When two objects of opposite polarity are brought near each other, the electrostatic field is concentrated between them Every charged object has a field around it and the force is present in the field (see diagram 3-B). If there is no immediate transfer of electrons to or from a charged object, the charge will be retained. This is a charge at rest or static electricity (4).

Because it has a force, an electric charge can do the work of moving another charge by attraction or repulsion. This ability to

do work is called the charge's potential. When one charge is different from another, there is a difference in potential. The unit for potential difference, or voltage is the volt (v).

Theoretically, an indefinite buildup of a charge on a body would make the potential infinite. This does not happen because an object in the air (an insulator) could become charged only so much before the air is forced to become conductive (dielectric breakdown). Air becomes conductive at about 3×10^6 v/m.

The subsequent movement of electrons by potential difference is called current (I). The unit for current is the ampere (A). "One ampere of current is defined as the movement of one coulomb past any point of a conductor during one second of time" (Halperin).

Charge (Q) differs from current (I) in that charge is an accumulation of electrons and current is the intensity of the flow of electrons. Where:

$$I = Q/T \text{ or } Q = IT$$

I = current in ampere

Q = charge in coulombs

T = time in seconds

In a conductor, free electrons move with relative ease by a potential difference. Electrons flow from negative potential to positive potential. Why is this true? "Electrons will flow to where electron energy is lowest" (5). Therefore, "a static electric field cannot exist within a conductive mass" (2). Free electrons move with ease and would neutralize or nullify the field. This means that on a conductor charges cannot accumulate and potential differences cannot be formed. This is the basis for electrostatic shielding. No charge can exist on a shield as long as it is continuous and unbroken. Whatever is inside the shield is protected from charged objects coming near the shield. Electrostatic field shielding is called a Faraday Cage. More information on shielding will be presented later in the chapter on materials.

CHAPTER 3 - GENERATING STATIC ELECTRICITY

TRIBOELECTRIFICATION

Tribo is Greek for friction. Triboelectricity means the generation of electricity by friction, rubbing, contact and separation of two materials. The amount, or magnitude of triboelectricity is influenced by many factors: intimacy of contact, surface characteristics (smoothness), pressure, speed of separation, lubricity and ambient conditions (temperature (T) and relative humidity (RH)). When two materials are separated, an equal and opposite charge develops on the surfaces of each material. Static electricity is a surface phenomenon; charges only accumulate on the surface of the object, not all the way through the object (2).

If the material is conductive, it retains the charge until grounded. The charge then becomes mobile and "travels" to ground. If the surface is insulative, it retains the charge. Grounding cannot neutralize and insulator because the charges are not mobile on an insulator and will remain immobile until the insulator is neutralized by some means other than grounding. One method used to neutralize insulators, ionization, will be discussed in a later chapter.

It is not possible to discuss triboelectrification without mentioning a triboelectric series chart. Whether materials are gases, solids, or liquids, static charges can accumulate through any tupe of contact and separation of any two materials. The polarity (positive or negative charge) generated by two materials depends on their relationship to each other in the series. (See chart 3-A). If you were to rub a glass rod with wool, the glass rod would acquire a more positive charge (since it is higher up on the chart) and the wool would acquire a more negative charge (since it is lower on the chart). If you rubbed a steel rod with wool, the opposite would happen because of their relationship to each other on the chart. Also, it is possible that the farther apart materials are on the chart, the greater the magnitude of the charge that will exist between them. Magnitude is influenced to a greater degree by many other factors such as intimacy of contact, surface characteristics, etc.

What must be accepted is that any two surfaces can triboelectrically charge: your skin rubbing on your clothes, your shoes contacting and separating from the carpet, and your clothing rubbing the air as you walk. At all times when there is movement, one material is becoming more positively charged and one is becomeing more negatively charged.

Movements of air masses will discharge a lightning bolt when the charge accumulation is great enough. Fuel running through a hose

TABLE A TRIBOELECTRIC SERIES	
MATERIALS	POLARITY (+ OR -)
Asbestos	Acquires a more positive charge
Acetate	
Glass	
Human Hair	
Nylon	
Wool	
Fur	
Lead	
Silk	
Aluminum	
Paper	
Polyurethane	
Cotton	
Wood	
Steel	
Sealing Wax	
Hard Rubber	
Acetate Fiber	
Mylar*	
Epoxy Glass	
Nickel, Copper, Silver	
401 Epoxy Resist	
UV Resist	
Brass, Stainless Steel	
Synthetic Rubber	
Acrylic	
Polystyrene Foam	
Polyurethane Foam	
Saran†	
Polyester	
Polyethylene	
Polypropylene	
PVC (vinyl)	
Kel F‡	
TEFLON*	
Viton*	
Silicone Rubber	Acquires a more negative charge

* Trademark of E.I. du Pont de Nemours

† Trademark of Dow Chemical U.S.A.

‡ Trademark of 3M.

needed to fill a jet will also accumulate a charge. Fortunately, in this situation the hose is grounded, thus avoiding disaster.

It is very easy to generate a charge, and it is just as easy to generate a charge that has enough magnitude to damage sensitive devices. Once an electrical charge has accumulated, a static potential develops. A static potential is the difference in potential between the two objects. When a charged conductor contacts another conductor at different potential (i. e. a ground), or when an insulator is so highly charged that its electric field breaks down the medium separating the charged object from another object at a different voltage (dielectric breakdown), there is an electrostatic discharge or an ESD event. The resistance (how insulative or conductive) of the path of discharge determines the rate of discharge. The more insulative a material is, the slower the discharge; the less insulative (or more conductive) a material is, the faster the discharge. Once the charge becomes mobile it is no longer static electricity but dynamic electricity!

You have had the experience of walking across a carpet, reaching for a doorknob, and getting a shock on your fingertips from the doorknob. Let's break this scenario down and see what happens.

Your body is a capacitor. This means your body will store the charge accumulated by walking across the carpet. Remember, there is repeated contact and separation between your feet and the

carpet. As you walk, this charge is building. When you reach the doorknob, if the charge stored in your body is large enough, the insulative air between your fingers and the doorknob breaks down, becomes momentarily conductive, and you experience and ESD event which is the shock and/or spark that you feel and/or see. How many times have you walked across a carpet and touched a doorknob without being shocked? Simply, your body did not store enough of a charge to differ greatly from the doorknob and, even though electrons passed from your body to the knob, you did not feel anything because the potential difference was not great enough.

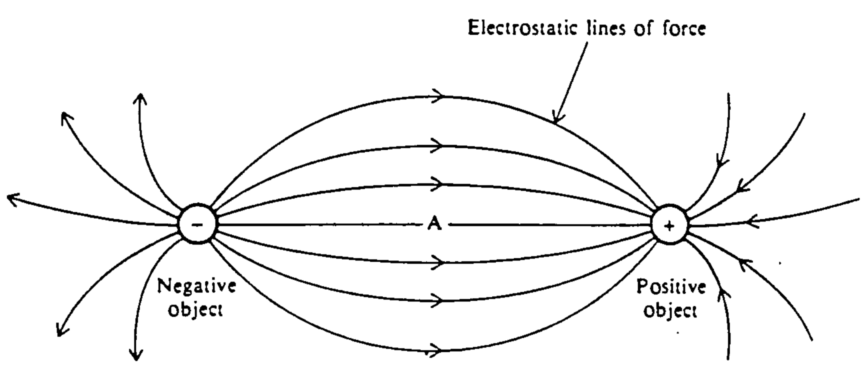
What caused the large difference in potential to cause the startling shock in the above example? Ambient conditions are largely responsible. The drier it is (wintertime) the more shocks due to lack of moisture. (The moisture of high humidity is conductive and does a fairly good job dissipating any charge before its existence is felt.) There are also the other factors that influence the magnitude of the charge listed on the first page of this chapter (i.e. intimacy of contact, smoothness, etc).

Late at night, and without permission, Reuben would often enter the nursery and conduct experiments in static electricity.

INDUCTION

Triboelectrification, or charging by contact, is not the only way a static charge can be generated. Charging by induction means that a charged object brought close to an uncharged object can induce a charge on that object without even touching it.

A charged object has an electromagnetic field or lines of force surrounding it. The field is similar to the one surrounding a magnet. Remember the experiments you performed as a youth using iron filings and a magnet? The magnet only had to come close in proximity to the iron filings to make them orient themselves along positive and negative poles. The electromagnetic fields can have same effect on an uncharged object (see diagram 3-B).



The electrostatic field between two charges of opposite polarity

DIAGRAM 3-B

When an uncharged conductor is moved through a field, or a field moves through a conductor, an electrical current is induced in the conductor. Opposite charges will attract each other; like charges will repel. The closer the uncharged object is to the field, the stronger the field. Since like charges repel, the uncharged object has positive charges lineup on one side and the repelled negative charges lined up on the other. The closer the materials are, the stronger the forces and the fields are between them, thus attracting more charges of opposite polarity and escalating the activity (6).

The object being charged will establish its own field. Electrostatic induction charging polarizes ungrounded objects. If the object touches a ground while polarized, the excess electrons will flow leaving the object with a net positive charge. If the polarized object is left alone, the charges will redistribute and the object will return to its unpolarized state.

If the two objects do contact each other, the electromagnetic field will collapse. Polarization and induction are completed. The materials may even "stick" together if they are light enough, held together by electrostatic forces. It will appear that there is no longer any type of charge present. But once the two materials are separated the field will reappear.

The failure of an electronic part can occur due to the flow of

current induced within that part during electromagnetic induction. This often happens when a charged (non-grounded) person touches an uncharged part. This is current induced damage. (Voltage induced damage occurs when the arc from a spark actually blows a microscopic crater into a component.)

Four things to remember regarding static fields and induced charges (6):

1. Static fields are invisible. They exist around all charged materials
2. Physical contact is not necessary to induce a charge
3. As long as a field passes near a conductor or a conductor passes through a field, and induced current will flow in the conductor
4. The amount of current depends on the strength of the field and the speed of the movement

Induction is responsible for causing the greatest amount of damage to end products. It exists everywhere and is not easily detected. Insulators are notorious for having electrostatic fields present because they cannot be grounded and will hold on to whatever charge they accumulate. It is imperative that insulators not be allowed in the vicinity of sensitive devices. (It is interesting that the flexible packaging materials used by the industry are basically insulative martials made conductive!) One method of neutralizing a charged insulator is to use ionization.

There are numerous other ways to charge an object which are beyond the scope of this text. They are listed here for your own information (2).

1. Charging by freezing
2. Spray charging - electrification of sprayed particles through mechanical atomizers
3. Thermionic emission charging - increasing temperature
4. Photoelectric charging - light quanta ejecting surface electrons from a material
5. Corona charging - ionized plasma gas containing particles through a corona and becoming charged with predominate polarity

POLARIZATION

Polarization is a phenomenon that occurs when a conductor and an electrostatic field are both stationary. Remember, when a material is charged, it is surrounded by an electrostatic field. If the charged object is a conductor, it will only hold the charge until it is grounded. If the charged object is an insulator it will hold the charge a long, long time and it will not give up the charge to ground (6).

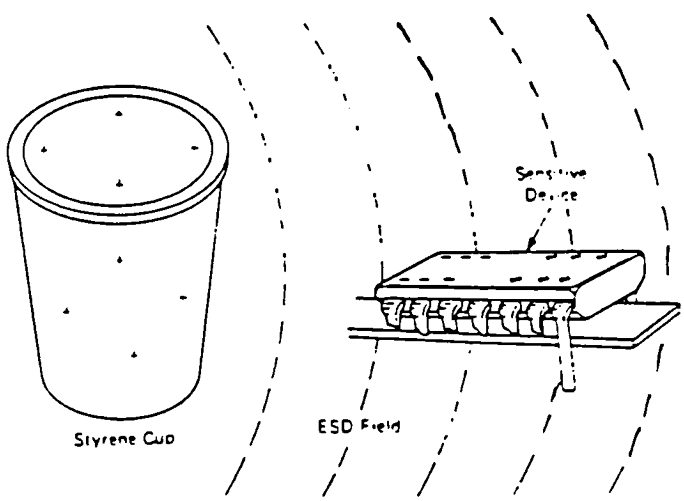
Expanded polystyrene (styrofoam) is a greedy insulator. It gives up electrons easily and prefers to stay positively charged. Let's see what happens when a styrofoam cup comes near a sensitive device. (See diagram 3-D)

As the worker puts the cup down on the bench the cup is freely giving up electrons as it charges triboelectrically through the air. If the charged cup passes by a sensitive device a current will be induced to flow. (See induction) This current may damage or even destroy the part. But the process does not stop here. Let's say the cup is finally resting the bench and is in the near proximity of another sensitive device for the first time. Both are stationary. The device is in the field created by the cup and mobile electrons in the conductive device move as close to the cup as they can (6).

Remember, opposites attract and the cup is very positive. The other end of the device away from the cup is left with more protons and is therefore more positively charged. The electrons are behaving as they should. Unlike charges are attracting; like charges are repelling. The device is now polarized.

The instant the device is picked up and moved out of the field it becomes charged. If it should touch a ground, it will then discharge. A discharge to ground may cause electrons to move so fast the enough heat may be generated to melt parts of the device. The device may have been weakened by initial induction and completely damaged when a charge created by polarization is finally discharged.

It is easy to create charges at a workbench. How these problems can be avoided will be discussed in the section that includes information on grounding.



Polarization.

CHAPTER 4 -PRIME SOURCES OF DAMAGE: MODELS AND MECHANISMS

There are essentially two families of events that constitute the prime sources of damage to sensitive devices. These are:

1. Electrostatic Discharge (ESD) Events
2. Waveform Events:
   Electromagnetic Interference (EMI)
   Radio frequency Interference (RFI)
   Electromagnetic Pulse (EMP)

ELECTROSTATIC DISCHARGE (ESD) EVENTS

"Electrostatic discharge (ESD) occurs when a charged conductor contacts another conductor at a different potential as an electrical ground or resistive path to ground, or when an insulator or conductor is so highly charged that its electric field breaks down the medium separating the charged object from another charged object at a different voltage" (6). The resistance of the path determines the rate of charge. The resulting failure is thermal failure. The three ESD events that can cause this failure are represented by the following models:

1. Human Body Model (HBM)
2. Charged Device Model (CDM)
3. Field Induced Model (FIM)

When a sensitive device is in the discharge path it may be damaged

(thermally degraded) by one of three mechanisms (7):

1. thermal breakdown
2. metallization melt
3. dielectric breakdown

HUMAN BODY MODEL - HBM

We have already seen how easy it is for a human to develop a charge with common everyday movements. The human body's equivalent capacitance is 120 - 250 picofarads (pf) and equivalent resistance is 1000-3000 ohms. These equivalent values may exceed the damage rating of a device. The following tables show the magnitude of charge buildup during certain activities (see table 4-A) and the sensitivity of select devices to the HBM (see table 4-B). As you can see, ambient conditions have a significant effect on charge magnitudes. Voltages can easily exceed 15,000 - 50,000 volts. Keep in mind that devices are sensitive to levels much less than that. For the equivalent circuit of the HBM see diagram 4-C.

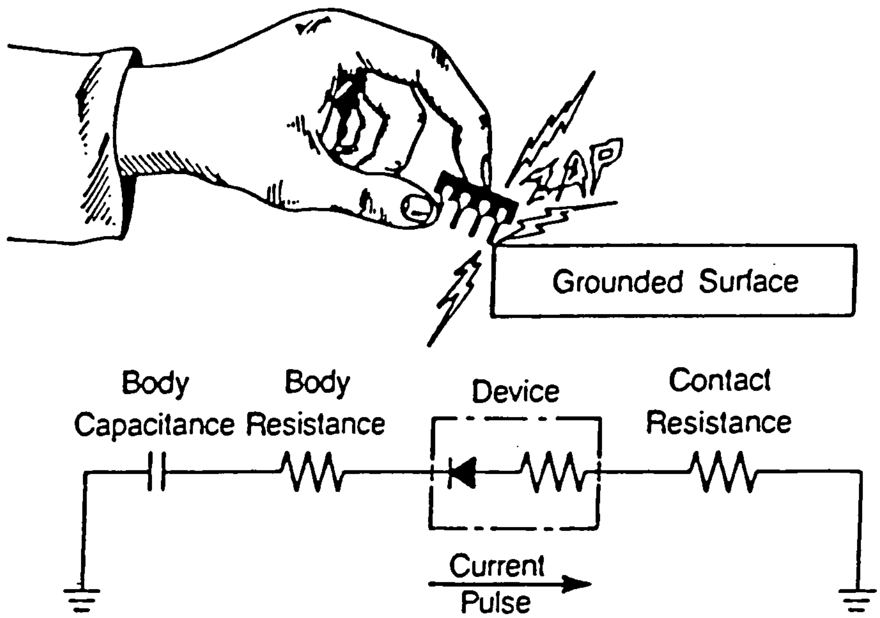
It is easy for an individual to develop potentials that will degrade or destroy sensitive devices. There may be enough power to melt small volumes of silicon and create craters in the surface. (See fig. 4-D) When a charged person touches a device some of the energy stored in the body (a capacitor) is transferred to the device or through the device to the ground. Protection to resist this transfer can be designed into most IC's but, these designs generally have protection capability limits of 1000 - 3000 volts. This will give satisfactory protection in some operations but not in all (3).

TYPICAL ELECTROSTATIC VOLTAGES (VOLTS)			
EVENT	RELATIVE HUMIDITY		
	10%	40%	55%
Walking across carpet	35,000	15,000	7,500
Walking across vinyl floor	12,000	5,000	3,000
Motions of bench worker	6,000	800	400
Remove DIPs from plastic tubes	2,000	700	400
Remove DIPs from vinyl trays	11,500	4,000	2,000
Remove DIPs from Styrofoam	14,500	5,000	3,500
Remove bubble pack from PWBs	26,000	20,000	7,000
Pack PWBs in foam-lined box	21,000	11,000	5,500

CHART 4-A

DEVICE SENSITIVITY TO HUMAN-BODY MODEL	
DEVICE TYPE	RANGE OF ESD SENSITIVITY (VOLTS)
VMOS	30 - 1,800
MOSFET	100 - 200
GaAsFET	100 - 300
EPROM	100 - 2,500
JFET	140 - 7,000
OP AMP	190 - 2,500
CMOS	250 - 3,000
Schottky Diodes, TTL	300 - 2,500
Film Resistors (Thick, Thin)	300 - 3,000
BIPOLAR Transistors	380 - 7,000
ECL (PC Board Level)	500 - 1,500
SCR	680 - 1,000
Schottky TTL	1,000 - 2,500

CHART 4-B

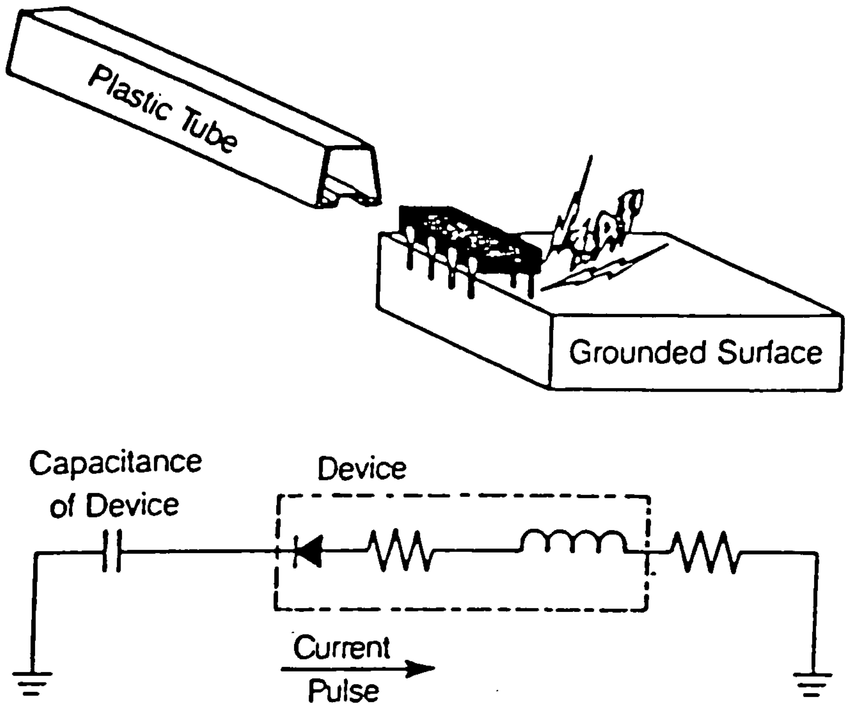


Equivalent Circuit of Human-Body Model

DIAGRAM 4-C

Damage at the input of a CMOS circuit due to a human-body discharge of approximately 2 kV. From [5].

DIAGRAM 4-D



Equivalent Circuit of Charged-Device Model

DIAGRAM 4-E

The HBM figure shows that discharge to a single lead while another lead is connected to ground. Typically, the discharge path through a lead with all other leads floating or not connected to ground. An HBM discharge through a device to ground is much more damaging that an HBM discharge to a floating device.

CHARGED DEVICE MODELS - CDM

The charged device model is set up around the device charging triboelectrically on the lead frame (and other conductive paths), and then quickly discharged to ground through one pin. Charges flow through the die and can damage junctions dielectrics, and components that are in the discharge path. This model represents the association between the devices and the package. For the circuit representations or CDM (see diagram 4-E).

Devices can triboectrically charge in several ways: movement during shipping, unloading from shipping tubes into insertion equipment, sliding across a work surface, and/or charging during assembly operations. A charged device will eventually contact a ground at some time and discharge. The end pins are most likely to contact a ground first and are associated with a significant number of device failure (3).

Acquired charges may be mobile or immobile. A mobile charge is the charge on the metal lead from and to conductors. An immobile charge is on the nonconductive portions of the device. The

immobile charge cannot develop currents and cannot directly damage the device, but can indirectly damage the device by maintaining a charge and creating a field. Devices are usually unloaded from shipping tubes and may charge (Mobile) upon dispensing. The first ground a device touches, usually by an end pin, will cause the device to discharge. To minimize ESD damage, mobile charges must be kept at a low level.

Damage or failure thresholds resulting from CDM are different from damage resulting from HBM. The capacitance of the device package at the time of grounding determines the energy released during ESD and whether the threshold for damage will be exceeded. In the HBM the devices are floating and, though they may not be damaged on contact, the devices will charge, ultimately having the ability to discharge.

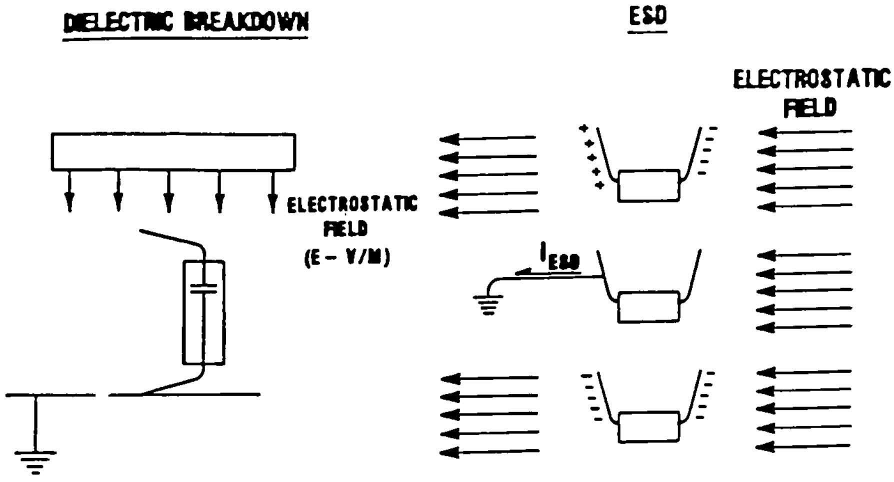
"The capacitance of the device package at the instant of grounding plays a strong role in determining the energy released during the ESD and whether the threshold for damage will be exceeded. Charging a packaged device while it is positioned near ground and then moving it away from ground will have the effect of increasing the potential as well as increasing the energy stored on the device. The discharge will be more damaging than it would be if the device were discharged near ground. The increase in potential and energy is inversely proportional to the capacitance ratio. Although the device energy storage capacity is limited in the CDM,

when compared to the HBM, the discharge pulse can occur so fast that the power density exceeds the damage threshold" (9).

FIELD INDUCED MODEL - FIM

An external field can affect a device in two ways. First, dielectric breakdown can occur which is not very common. The induced potential across an oxide would be below the "oxide punch through strength" (2). Increased field strength would first break down the air, reducing the field before affecting the dielectrics of the device. Second, a more common event associated with the device in a field is charging by induction, or the separation of mobile charges. A non-zero potential may develop for a gate structure of a device inserted into a field. "If a device is grounded while in the influence of an electrostatic field, it will experience a surge of current through the grounded lead" (6).

"Devices having very small geometries which cannot sustain potential gradients can also fail in a high electrostatic field" (2). (For a representation of the FIM Model see diagram 4-E.)



Equivalent Circuit of Field-Induced Model

DIAGRAM 4-F

FAILURE MECHANISMS

"Failures caused by exposure to an ESD pulse can be soft as well as hard" (2). A soft failure can result from a spark discharge setting up an electric or magnetic field, and ESD pulse, or a direct ESD discharge through a signal path. Soft failures are characterized as temporary distortion or information loss. There is no hardware damage and equipment operation can resume. Devices that require small changes in energy to switch states are most affected (e. g. CMOS). Soft failures usually occur only when the equipment is operating.

Hard failures can occur at any time and are represented by three failure mechanisms (for semiconductors) (2):

1. Thermal Breakdown or Avalanche Degradation - indiscrete semiconductors, bipolar integrated circuits

2. Dielectric Breakdown - discrete MOS, MOS integrated circuits
3. Metallization Melt - all integrated circuits, both bipolar and MOS

THERMAL BREAKDOWN

Thermal breakdown is a short circuit caused by an ESD event of enough magnitude and duration to actually melt a portion of the junction. There is little diffusion of heat with large temperature gradients. "Hot spots" result creating junction shorts due to melting. (see diagram 4-E)

DIELECTRIC BREAKDOWN

Dielectric breakdown occurs when there is a potential difference applied across a dielectric region of a structure which is greater than its dielectric strength or breakdown characteristics. A puncture through the dielectric results. Subsequent damage may be latent or catastrophic depending on the magnitude of the event.

METALLIZATION MELT

Metallization melt is usually a secondary failure mechanism. A short circuit caused by other failure mechanisms may draw enough current to melt the metallization. The junction or oxide fails first with metallization melt as a result.

Though beyond the scope of this handbook, a list of other failure

mechanisms includes (7):

Metallization to metallization arc over

Surface breakdown

Bulk breakdown

Surface

Surface inversion

WAVEFORM EVENTS

EMI, RFI, AND EMP EVENTS

Electromagnetic interference (EMI), Radio Frequency interference (RFI, and Electromagnetic Pulse (EMP) differ from an ESD event in one important way. They are waveforms that cannot pass through a sensitive device (such as FIM), but actually frequency couple with the device.

An example of frequency coupling would be a soprano singing and holding a certain note which starts vibrating a crystal goblet. The frequency of the note is the same as the frequency of the goblet. This causes the goblet to vibrate with the sound. As the magnitude of the vibration becomes too great the stiffness of the glass material will prevent vibration beyond a certain point, and the material will stress and then shatter. Stress cracking is the failure mechanism for these waveforms.

In a sensitive device the result of stress cracking is mechanical failure. There is one instance when these models can cause thermal

failure. If the vibrations are great enough to cause heat, the heat may lead to degradation. The difference between this thermal failure and ESD thermal failure is that thermal failure by waveform is global or all the way through (much like to the way water is heated in a cup in a microwave), and an ESD thermal failure is pinpoint in origin (microlightning).

FREQUENCY COUPLING

Certain radio frequencies (radar, microwave) can be picked up by electrical components and those components can be damaged or destroyed through a process called frequency coupling (6). A common example of frequency coupling occurring is at an auditorium and as the speaker begins to talk into the microphone an ear piercing screech results.

"Sound wave picked up by a microphone are converted to electric pulses. The magnitude of the pulses is boosted by the amplifier, passed on to the speaker assembly, and converted back to sound waves. If the speaker assembly is placed in a position where the sound waves are picked up by the microphone, and the distance from speaker to microphone and the frequency of sound waves are just right, another set of electrical pulses is generated by the microphone and the entire cycle keeps repeating."

Throughout the complex distribution system, transportation by truck or rail can easily pass through areas where damaging frequencies

exist. Microwave transmitters radar units supporting tv stations and airports, and military radar installations dot the landscape. As a vehicle passes through the waveforms and, if distance and frequency are just right, damage to sensitive components can result. "Actual cases of computer fire-control and guidance systems failures on naval vessels and in military aircraft have been traced to frequency coupling damage caused by the search radar unit of an adjacent ship or aircraft" (6).

From zero to peak (rise time) voltage sensitive devices can be damaged if the resulting voltage is too much for the device. From peak to zero (decay time) devices that are power sensitive can be destroyed if the decay time is too long. Fortunately, the waveforms will not pass through barrier materials such as aluminum foil. Barrier materials should limit peak voltage and reduce decay time rapidly. This is shielding effectiveness to both electromagnetic interference (EMI) and electromagnetic pulse (EMP).

CHAPTER 5 - ESDCP: ELECTROSTATIC DISCHARGE CONTROL PROGRAM

The "envelope" is the electronic industry's buzzword for all the variables that are implemented to control electrostatic discharge and the damage to sensitive devices. Everything from personnel grounding to work stations, packaging materials to safe handling procedures, failure analysis to proper field service handling become part of the "envelope". Before an "envelope" can be put into practice successfully, three major phases of an electrostatic discharge control program (ESDCP) must be completed: justifying an ESDCP, implementing an ESDCP, and auditing an ESDCP. Without these steps any effort to control ESD will be incomplete and marginally successful, at best.

JUSTIFYING AN ESDCP

There are many reasons for failed attempts to put an ESDCP into practice. Two common reasons that contribute to this failure are:

1. A lack of understanding the phenomenon of ESD and how static is generated. Too much effort is aimed at the symptoms and not at defining the problem by isolating the causes.

2. A lack of conclusive evidence that ESD was the cause of failure. ESD is not visible, can be difficult to diagnose, and there is a lack of expertise in knowing

how to initiate an investigative process to provide conclusive evidence.

For effective progress top management must be supportive of all three phases of an ESDCP. Convincing top management can be a large challenge in itself. All of the damage resulting from ESD must be translated into dollars. Whether the problem is being looked at from a department level, a facility level, or a corporate level with time, information, and effort it is possible to put a dollar figure to the losses and impress management with the need for implementing an ESDCP. In other words, management will have to spend money to save money and to make money. If the effort is not made to provide complete information on cost and quality impact for a thorough analysis of the problem the need for static controls loses its impact.

The following approach was developed by Stephen Halperin of Stephen Halperin & Associates. It is a straightforward approach to providing management with the information it needs to make a quality decision regarding the control of ESD. An ESDCP is based on throughput analysis which "provides a means to evaluate the impact of static on the complex organization, and satisfy the managerial requirements for quantitative information which lead to profitable static control programs" (7).

Throughput analysis tracks the quantity and flow of goods in

production. When accurately conducted, throughput analysis can indicate (9):

1. Which components may be failing due to static
2. Where in the operation most of the losses are occurring
3. Estimate the total cost of potential static losses
4. Highlight the areas that, with immediate attention, will yield the greatest return over the short-term

"Most important, throughput analysis provides the foundation for the development of the organization's static control program" (Halperin).

Justifying an ESDCP has three phases (9):

1. Identification of ESDS devices and the difference between volume purchased and volume used
2. Definition of device utilization
3. Definition of burden costs associated with ESDS devices

The following analysis will be part of a class exercise. What is provided in this handbook is a broad overview of the justification process.

<u>STEP ONE:</u> Identify static sensitive components and determine the discrepancy between the volume purchased and actual use in production (9).

Obtain the original plan for finished goods volume and contrast that to actual production figures. If actual

production figures are less, determine the reason for lower volume. The reasons may be potential static related problems and might include:

rework

restricted parts available

excessive in-process redesign

field problems

Determine the sensitivity of the devices. (see chart 5-A). An ESDCP will be governed by the most sensitive device and its required protection level. There are three sources for ESD sensitivity information (9):

Actual sensitivity testing of devices

Vendor test information

Generic device sensitivity listing reference (IE. RAC - Reliability Analysis Center, Rome, NY., see appendix)

(see 5-B, table I).

STEP TWO: Define ESDS device utilization, including average inventory levels and location, requisitioning departments, purchase volume and unit cost (9).

Document the following information:

1. The actual number of each ESDS item purchased to support the annual production period
2. The unit cost of each item

3. The average inventory level
4. Location of inventory storage
5. The identity of requisitioning departments - who uses ESDS devices

(see 5-C, table II).

STEP THREE: Define burden costs associated with ESDS devices and assemblies (9).

The burden factor takes into account the actual labor required to replace an item, the cost of the facility, lights, and power, the present value of funds tied up in rework inventory and so on. The easiest to calculate is the estimated average cost applied to all items. Once the cost of the deviant units is determined and then multiplied by the estimated burden cost, the sum of the material dollar cost and the total burden cost of each item can be calculated. (see 5-D, chart III).

There are many reasons for deviations. The point is that the deviations do exist and include ESDS devices.

The ABC Analysis - Potential ESD Loss

Once all the calculations have been completed the smallest portion of the inventory with the largest potential static losses can be identified. Also, the losses can be identified by department. The value of static control has been established and the first phase of an ESDCP has been successfully completed (9). See tables 4-7.

Table 1

5-A

DEVICE UTILIZATION DATA FOR ESD-SENSITIVE DEVICES USED IN PRODUCTION			
Item #	ESDS* (V)	Items/ F/G	Data Source
1	60	2	test
2	500	4	vendor
3	2,000	6	RAC
4	5,000	10	vendor
5	2,500	1	RAC
6	200	2	test
7	1,100	4	test
8	1,500	6	RAC
9	4,200	2	RAC
10	6,000	2	test

*ESDS: ESD-sensitivity

Table 2

INITIAL REVIEW OF ITEM NEEDS, INVENTORY, PURCHASES AND USAGE												
Item #	ESDS* (V)	ESDS Items/ F/G	Units Reqd/ Year	Units Purch/ Year	Unit Cost	Avg Invent Each	Deviations Units Each	Deviations Cost x Units	Units Req by Mfg	Units Req by Rework	Units Req by Fld Svc
1	60	2	2,000	4,700	$10.60	200	-2,500	($26,500)	2,250	1,750	500
2	500	4	4,000	7,200	$3.80	400	-2,800	($10,640)	4,280	1,960	560
3	2,000	6	6,000	8,000	$2.25	600	-1,400	($3,150)	6,140	980	280
4	5,000	10	10,000	12,000	$0.70	1,000	-1,000	($700)	10,100	700	200
5	2,500	1	1,000	1,400	$1.10	100	-300	($330)	1,030	210	60
6	200	2	2,000	4,600	$0.90	200	-2,400	$2,160)	2,240	1,680	480
7	1,100	4	4,000	6,300	$1.40	400	-1,900	($2,660)	4,190	1,330	380
8	1,500	6	6,000	8,800	$0.80	600	-2,200	($1,760)	6,220	1,540	440
9	4,200	2	2,000	2,600	$0.40	200	-400	($160)	2,040	280	80
10	6,000	2	2,000	2,300	$1.80	200	-100	($180)	2,010	70	20
Totals:		39	39,000	57,900		3,900	-15,000	($48,240)	40,500	10,500	3,000

*ESDS: ESD-sensitivity

Table 3

DEVICE DEVIATION WITH BURDEN-LOSS ESTIMATE					
Item #	ESDS* (V)	Deviation Units Each	Deviation Cost x Units	Estimated Lost Burden @$14.50 Each	Estimated Lost Burden Material & Burden
1	60	−2,500	($26,500)	($36,250)	($62,750)
2	500	−2,800	($10,640)	($40,600)	($51,240)
3	2,000	−1,400	($3,150)	($20,300)	($23,450)
4	5,000	−1,000	($700)	($14,500)	($15,200)
5	2,500	−300	($330)	($4,350)	($4,680)
6	200	−2,400	($2,160)	($34,800)	($36,960)
7	1,100	−1,900	($2,660)	($27,550)	($30,210)
8	1,500	−2,200	($1,760)	($31,900)	($33,660)
9	4,200	−400	($160)	($5,800)	($5,960)
10	6,000	−100	($180)	($1,450)	($1,630)
Totals:		−15,000	($48,240)	($217,500)	($265,740)

*ESDS: ESD-sensitivity

Table 6

PURCHASING ANALYSIS

Item #	Unit Cost	Units Reqd/ Year	Cost to Purch	Avg Invent Each	Cost of Invent	Units Purch/ Year	Value of Unit Purch	Deviations Units Each	Deviations Cost x Units	Est % Loss of Total ESDS Purch
1	$10.60	2,000	$21.200	200	$2,120	4,700	$49,820	−2.500	($26,500)	−20.3%
2	$3.80	4,000	$15,200	400	$1,520	7,200	$27,360	−2,800	($10,640)	−8.2%
3	$2.25	6,000	$13,500	600	$1,350	8,000	$18,000	−1,400	($3,150)	−2.4%
4	$0.70	10,000	$7,000	1,000	$700	12.000	$8,400	−1,000	($700)	−0.5%
5	$1.10	1,000	$1,100	100	$110	1,400	$1,540	−300	($330)	−0.3%
6	$0.90	2,000	$1,800	200	$180	4,600	$4,140	−2,400	($2,160)	−1.7%
7	$1.40	4,000	$5.600	400	$560	6,300	$8,820	−1,900	($2,660)	−2.0%
8	$0.80	6,000	$4,800	600	$480	8,800	$7,040	−2,200	($1,760)	−1.4%
9	$0.40	2,000	$800	200	$80	2,600	$1,040	−400	($160)	−0.1%
10	$1.80	2,000	$3.600	200	$360	2,300	$4,140	−100	($180)	−0.1%
Totals:		39,000	$74,600	3.900	$7,460	57,900	$130,300	−15,000	($48,240)	−37.0%

*Includes percent of estimated units lost and percent of total dollars lost by item

Table 4

DATA SORT BY DEVIATION COST

Item #	ESDS* (V)	Deviations Units Each	Deviations Cost x Units	Est. Lost Burden @$14.50 Each	Est. Lost Burden Material + Burden	% Material Loss Units	% Material Loss Cost	ABC Analysis Segment
1	60	−2,500	($26,500)	($36,250)	($62,750)	16.7%	54.9%	Class A
2	500	−2,800	($10,640)	($40,600)	($51,240)	18.7%	22.1%	Class B (31.4% of loss)
3	2,000	−1,400	($3,150)	($20,300)	($23,450)	9.3%	6.5%	
7	1,100	−1,900	($2,660)	($27,550)	($30,210	12.7%	5.5%	
6	200	−2,400	($2,160)	($34,800)	($36,960)	16.0%	4.5%	Class C (11.0% of loss)
8	1,500	−2,200	($1,760)	($31,900)	($33,660)	14.7%	3.6%	
4	5,000	−1,000	($700)	($14,500)	($15,200)	6.7%	1.5%	
5	2,500	−300	($330)	($4,350)	($4,680)	2.0%	0.7%	
10	6,000	−100	($180)	($1,450)	($1,630)	0.7%	0.4%	
9	4,200	−400	($160)	($5,800)	($5,960)	2.7%	0.3%	
Totals:		−15,000	($48,240)	($217,500)	($265,740)	100.0%	100.0%	

*ESDS: ESD-sensitivity

Table 5

DATA SORT BY DEVIATION COST

Item #	ESDS* (V)	Deviations Units Each	Deviations Cost x Units	Est. Lost Burden @$14.50 Each	Est. Lost Burden Material + Burden	% Material Loss Units	% Material Loss Cost	ABC Analysis Segment
1	60	−2,500	($26,500)	($36,250)	($62,750)	16.7%	54.9%	Class A
2	500	−2,800	($10,640)	($40,600)	($51,240)	18.7%	22.1%	Class B (31.4% of loss)
3	2,000	−1,400	($3,150)	($20,300)	($23,450)	9.3%	6.5%	
7	1,100	−1,900	($2,660)	($27,550)	($30,210	12.7%	5.5%	
6	200	−2,400	($2,160)	($34,800)	($36,960)	16.0%	4.5%	Class C (11.0% of loss)
8	1,500	−2,200	($1,760)	($31,900)	($33,660)	14.7%	3.6%	
4	5,000	−1,000	($700)	($14,500)	($15,200)	6.7%	1.5%	
5	2,500	−300	($330)	($4,350)	($4,680)	2.0%	0.7%	
10	6,000	−100	($180)	($1,450)	($1,630)	0.7%	0.4%	
9	4,200	−400	($160)	($5,800)	($5,960)	2.7%	0.3%	
Totals:		−15,000	($48,240)	($217,500)	($265,740)	100.0%	100.0%	

*ESDS: ESD-sensitivity

Table 7

INTERIM THROUGHOUT ANALYSIS REPORT
ESTIMATED ESD-LOSS SUMMARY

Estimated ESD-sensitive material losses:	$48,240
Estimated ESD-sensitive-related burden loss:	$217,500
Estimated Total ESD Impact:	$265,740

ESD Loss Distribution Based on ESDS Unit Deviation by Class	Est Material Costs	Est Burden Costs	Est Total Costs
Class A	$26,500	$36,250	$62,750
Class B	$16,450	$88,450	$104,900
Class C	$5,290	$92,800	$98,090
Totals:	$48,240	$217,500	$265,740

ESD-Sensitive Device Purchasing Data

	Required Purchases	Avg Invent	Actual Purchases	Deviation	% Deviation
Units (ea):	39,000	3,900	57,900	-15,000	-25.9%
Cost ($):	$74,600	$7,400	$130,300	($48,300)	-37.1%

Notes:
1) Burden calculated as $14.50 per unit.
2) Areas requesting ESD-sensitive devices and assemblies are:

Area	Est % of Deviation Use
Manufacturing	10.0%
Rework Area	70.0%
Field Service	20.0%

TUTORIAL

ESTIMATING ESD LOSSES IN THE COMPLEX ENVIRONMENT

OR

HOW TO CONVINCE MANAGEMENT THAT THERE IS AN ESD-RELATED PROBLEM IN LANGUAGE THEY UNDERSTAND

AN EXERCISE FOR PACKAGING PROFESSIONALS

In the last few years packaging engineers have had to face the following question:

"How do I know that static related problems are affecting the operation?"

And

"How do I define the impact of damage to the satisfaction of management?"

The following tutorial will allow you to organize the information available so that you can effectively communicate the damage in dollars in a format that management will understand.

***

You have identified the following items as possible victims of ESD. These items are part of the devices and subassemblies that are manufactured at you facility.

Organize the information as instructed in class using tables I-V.

Item 1 - Voltage sensitivity 100 V (vendor info), 1 used F/G, 2000 req'd per year, 2300 units purchased per year, unit cost $.90, average inventory 100.

Item 2 - Voltage sensitivity 1000 V (test info), 3 used F/G, 2000 req'd per year, 2600 units purchased per year, unit cost $.50, average inventory 200.

Item 3 - Voltage sensitivity 12,500 V (RAC), 10 used F/G, 6000 req'd per year, 8800 purchased per year, unit cost $.90, average inventory 600.

Item 4 - Voltage sensitivity 1200 V (test info), 4 used F/G, 4000 req'd per year, 6300 units purchased per year, unit cost $1.50, average inventory 400.

Item 5 - Voltage sensitivity 3800 V (vendor info), 2 used F/G, 2000 req'd per year, 4600 units purchased per year, unit cost $1.00, average inventory 200.

Item 6 - Voltage sensitivity 10,500 V (RAC), 8 used F/G, 1000 req'd per year, 1400 units purchased per year, unit cost $1.30, average inventory 100.

Item 7 - Voltage sensitivity 5000 V (RAC), 1 used F/G, 10,000 req'd per year, 12,000 units purchased per year, unit cost $1.20, average inventory 1000.

Item 8 - Voltage sensitivity 2000 V (test info), 6 used F/G, 6000 req'd per year, 8000 units purchased per year, unit cost $2.50, average inventory 600.

Item 9 - Voltage sensitivity 1200 V (vendor info), 2 used F/G, 4000 req'd per year, 7200 units purchased per year, unit cost $3.90, average inventory 400.

Item 10 - Voltage sensitivity 40 V (vendor info), 2 used F/G, 2000 req'd per year, 4700 units purchased per year, unit cost $12.50, average inventory 200.

***

Assignment #1 - Determine ESDS devices used in production according to table 1.

***

Assignment #2 - Perform initial review of item needs, inventory, purchases and usage according to table II.

Determine deviation for each item. This is equal to the units required each year plus the average inventory minus units purchased each year.

Determine deviation cost. This is equal to the number of deviated units multiplied by the unit cost. Place amounts in parenthesis to denote dollars lost.

***

Assignment #3 - Determine deviation with burden loss estimate using table III.

Determine estimated loss burden by multiplying $18.50 by the deviation per each unit.

Determine estimated lost material and burden adding deviation cost x units column to estimated loss burden column.

***

Assignment #4 - Using table IV sort data by unit deviation material

cost from largest to smallest amount.

Determine the % loss material units by finding what percentage each item is of the total estimated lost burden @ $18.50.

Determine the % loss material $ by finding what percentage each item is of the total deviation cost x units.

Determine the ABC analysis segments. Generally, the top 10% (class A) of the items listed account for 50 - 80% of total ESDS dollar losses the next 30% (class B) account for approximately 20 - 40% of total losses, and the remaining 60% (class C) account for less than 10 - 20% of the losses.

***

Assignment 5 - Rearrange Table V by decreasing (from most sensitive to least sensitive) device sensitivity.

Determine % loss material units by finding what percentage each item is of the total estimated lost burden @ $18.50.

Determine % loss burden and material $ by finding what percentage each item is of the total estimated lost material and burden.

Determine the ABC analysis segments. Top 10% represents class "A", the next 30% represents class "B", and the remaining 60% represents class "C".

Compare table IV and V to see how dramatic the impact of burden expense.

You have now identified the smallest portions of the inventory contributing the largest segment of potential static losses.

CLASSIFICATION OF DEVICE SENSITIVITY
(DOD-STD-1686A)

CLASS I > 0 TO ≤ 1000 V

CLASS II > 1000 V TO ≤ 4000 V

CLASS III > 4000 V TO $\leq 15{,}000$ V

(PROPOSED ADDITION)

CLASS $0 < 100$ V

DEVICE UTILIZATION DATA — TABLE II

INITIAL REVIEW OF ITEM NEEDS, INVENTORY, PURCHASES & USAGE

1 ITEM NO.	2 ESDS ITEMS PER F/G	3 ESDS UNITS REQ'D /YEAR	4 ESDS UNITS PURCHASED /YEAR	5 UNIT COST	6 AVE INVENTORY	7 DEV. UNITS EACH	8 DEV. COST X UNITS
TOTALS							

DEVICE UTILIZATION DATA TABLE III

DEVIATION WITH BURDEN LOSS ESTIMATE

1 ITEM NO.	2 DEV. UNITS EACH	3 DEV. COST X UNITS	4 EST. LOSS BURDEN @ 18.50	5 EST. LOSS MATL & BURDEN
TOTALS				

DATA SORT BY UNIT DEVIATION MATERIAL COST TABLE IV							
INCUDES % MATERIAL LOSS & ABC ANALYSIS CLASSIFICATION SEGMENTS							
1 ITEM NO	2 DEV. UNITS EACH	3 DEV. COST X UNITS	4 EST. LOST BURDEN @ 18.50/	5 EST. LOST MAT'L & BURDEN	6 % loss MAT'L UNITS	7 % Loss MAT'L $	8 ABC ANALYSIS SEGMENTS

DATA SORT BY TOTAL MATERIAL & BURDEN COST TABLE V

INCLUDES % TOTAL LOSS & ABC ANALYSIS CLASSIFICATION SEGMENTS

1 ITEM NO.	2 ESDS VOLTS	3 DEV. UNITS EACH	4 DEV. COST X UNITS	5 EST. LOSS BURDEN @18.50/	6 EST. LOSS MAT'L & BURDEN	7 % LOSS MAT'L UNITS	8 % LOSS BURDEN & MAT'L $	9 ABC ANALYSIS SEGMENTS	
									A
									B
									C

ESTABLISHING AN ESDCP

Whether simple or complex, the ESD Control Program's (ESDCP) main function is to make sure that an electrostatic discharge sensitive device (ESDS) is never placed in jeopardy. An ESDCP should be functional, cost effective, and tailored to the facility in which it resides. There can be several components in a comprehensive ESDCP. At the very least, an ESDCP program should include:

Identification of sensitive devices

Protection of devices

Grounding

Ionization

IDENTIFICATION OF SENSITIVE DEVICES

A successful ESDCP cannot exist without knowing which devices are sensitive and to what degree they are sensitive (i.e. how may volts will damage a device). The most sensitive device becomes the foundation for the ESDCP because its sensitivity level will determine how stringent the program will have to be. Identifying static sensitive devices is a straightforward process which can be accomplished in one of three ways (2):

1. Actual testing of device sensitivity by DOD-STD-1686, DOD-HDBK-263, or other standard tests (see appendix) - though the best method, it may be costly and time consuming
2. Available test data on similar devices - this method is the easiest, but may require substantiation

3. Generic devices sensitivity listing reference - i.e. the Reliability Analysis Center in Rome, NY (see appendix)

PROTECTION OF DEVICES

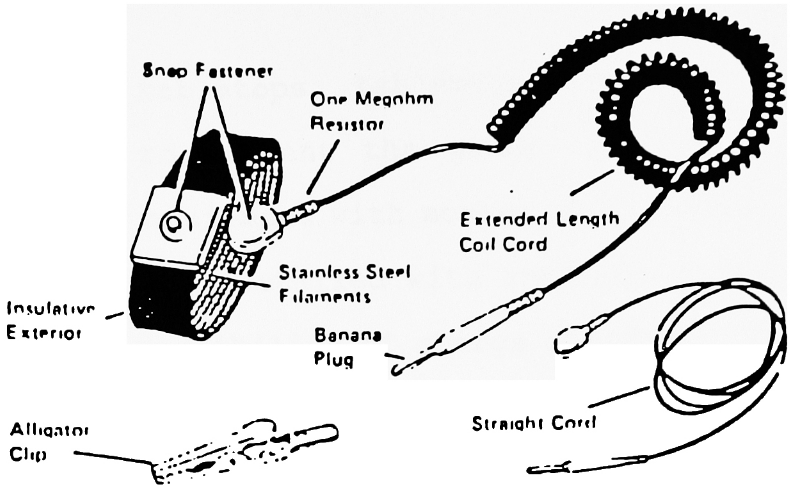
Sensitive devices must be protected from receiving, through manufacturing and testing, to shipping. The ideal program begins at the beginning - from the time the device is still an idea. While the assembly process is being established, personnel must be adequately trained to handle ESDS devices. The more sensitive the device, the more stringent the procedures. The guidelines must be written and presented so that an employee at any level of assembly can understand the task at hand. Employees should be made aware of the causes of ESD and methods of control, as well as the role of everyone involved in the control program. Protection also includes the absolute restriction of static generating materials from the sensitive areas. Sometimes this is not possible, but there are countermeasures (see ionization below) that can be taken to continue to insure the devices' safe handling.

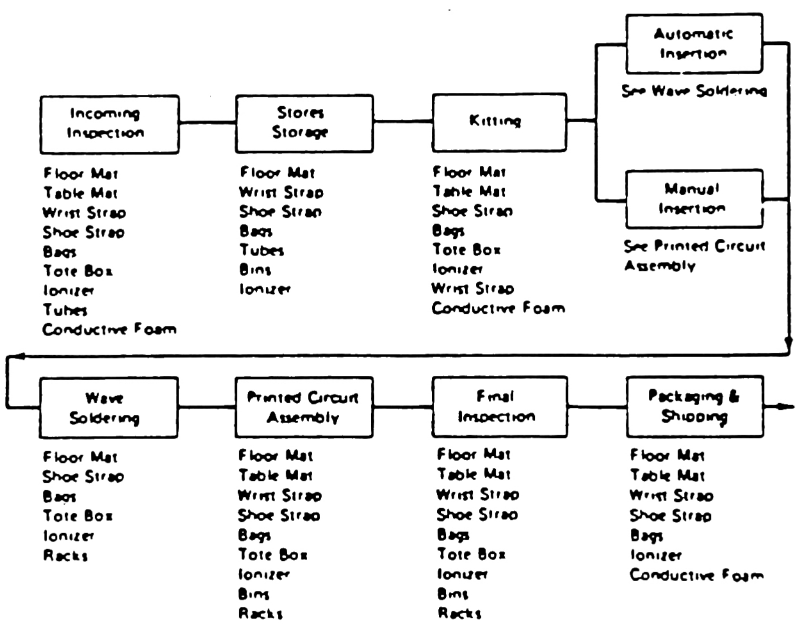
GROUNDING

Grounding is necessary to keep the potential of the work station area as close to zero as possible. Besides grounding work stations and handling devices, grounding of personnel is imperative because humans are the most common source of static generation.

Personnel grounding can be a very involved program depending on how stringent the procedures are in the control program. The most common form of personnel grounding is the wrist strap for operators that are in close proximity to sensitive devices. A human can damage a device by direct discharge or by a field effect. Grounding eliminates prime static sources by giving any charge generated a place to dissipate and neutralize itself before it can do any damage to a device. Ankle straps, leg straps, heel and bootstraps are also available. If the operator is standing, grounding can take place through conductive footwear and floormats. If the operator is sitting, grounding can take place through conductive stools (2).

Current limiting resistors (one megohm resistor) must be used when grounding people to protect them from shock should they contact a live circuit. It is also important to check the system often to verify currents and to insure compliance of the grounding system.





Typical static problem areas and their solutions.

Handling devices, tabletops, tablemats, and clothing should be conductive enough to prevent the generation and build-up of a static charge. Any equipment with moving parts, such as conveyors, should be grounded and installed with anti-static belts which can help eliminate the possibility of charge build-up. This equipment should be grounded as well.

The function of a work station is to keep charge potential near zero reducing voltage levels to at least below that of the most sensitive part. "Voltage levels in an ESD-protected area should be kept to 25 to 30% of the single zap voltage damage threshold since for many devices ESD damage is cumulative, and repeating application below threshold voltage (as low as 25%) can damage ESD-sensitive parts" (2). Work stations should be used whenever ESDS parts are removed from their protective packaging and handled by operators. That would include the following sites:

incoming inspection	PC assembly
storage	final inspection
kitting	packaging and shipping
insertion (auto/manual)	rework areas
wave soldering	failure analysis lab

IONIZATION

Ionization is the only solution to neutralizing a material that holds a charge and cannot be grounded. Ionization can also aid in neutralizing the environment and should be used in conjunction with grounding. By forming both negative and positive ions an ionizer can neutralize a charged insulator. Ionizers come in different styles (blowers, nozzles, guns) and there are three methods of operation (2):

1. Induction
2. Radioactive
3. High voltage

INDUCTION

Ionization by induction starts with grounded metal cored tinsel. When placed near a charged material, the electrical field of the material tries to induce a charge on the tinsel. Since the tinsel is conductive as well as grounded, it ionizes the air with both polarities. These polarities neutralize the charged material.

RADIOACTIVE

Ionization with radioactive isotopes can occur without electricity. Thus this method of ionization is used in explosive environments. Some radioactive materials emit charged particles of both polarities and these particles knock loose electron from a charged material until it is balanced.

The radioactive isotope is provided by the U. S. Nuclear Regulatory Commission by license. The equipment is leased and replaced yearly to guarantee the control of the potentially hazardous material.

HIGH VOLTAGE

High voltage ionization starts with a square wave signal to a static comb (a metal bar with a series of needle points). The premise under which this functions is that on a conductor, a static charge is free to flow. On a conductive sphere, a charge evenly distributes. As the radius of the sphere approaches zero, a self-repulsion of the charge will make it concentrate on the surface having the least radius of curvature or the case of the comb, the sharp needle point. Charge density ionizes the air, making it conductive and allowing for charge dissipation.

RULES OF THUMB

* Keep all static sources away from protected areas
* Control relative humidity which may not eliminate but reduces peak voltage
* Work surfaces should not triboelectrically charge
* Ground personnel in contact or in close proximity to ESDS
* Bond/ground any machinery that generates static
* Keep floor surfaces from triboelectrically charging
* Personnel should wear anti-static clothing
* Tools/test equipment should be grounded

AUDITING AN ESDCP

An effective ESDCP requires communication, coordination, and cooperation between all the departments and functions within a facility. Once policy has been implemented, an audit should be used to assure that personnel are complying with policy. Auditing or monitoring methods are provided by the DOD-STD-1686. Individuals involved with the audit committee should represent each department within an organization such as (7):

Procurement

Design Engineering

Reliability engineering

Quality assurance

Manufacturing

Test/field engineering

Packaging

ESD operating procedures can apply to many if not all of the functions in a facility. These activities can include(7):

Buying

Design

Inspection

Assembly

Rework/repair

Packaging

Storage

Transportation

Failure Analysis

An ESDCP audit should cover every aspect of the program and coverage should be made periodically. Program monitoring can include certification of ESD protected areas and grounded work benches. DOD-STD-1686 requires certification should include the following (7):

- The use of ESD protective materials
- Personnel grounding systems
- Ionizing systems or grounding for machinery
- The control of static below the level of sensitivity of ESDS devices
- The absence of prime static sources
- Grounding of tools and power equipment
- ESD protective personnel apparel
- Resistant measurement to assure protection of personnel
- Effectiveness of ESD safe areas/protective equipment

An ESDCP audit may require a formal design and program review. Design reviews (during design/development phase) must include, for example:

- Identification of ESDS items
- ESD marking of documentation and ESDS items

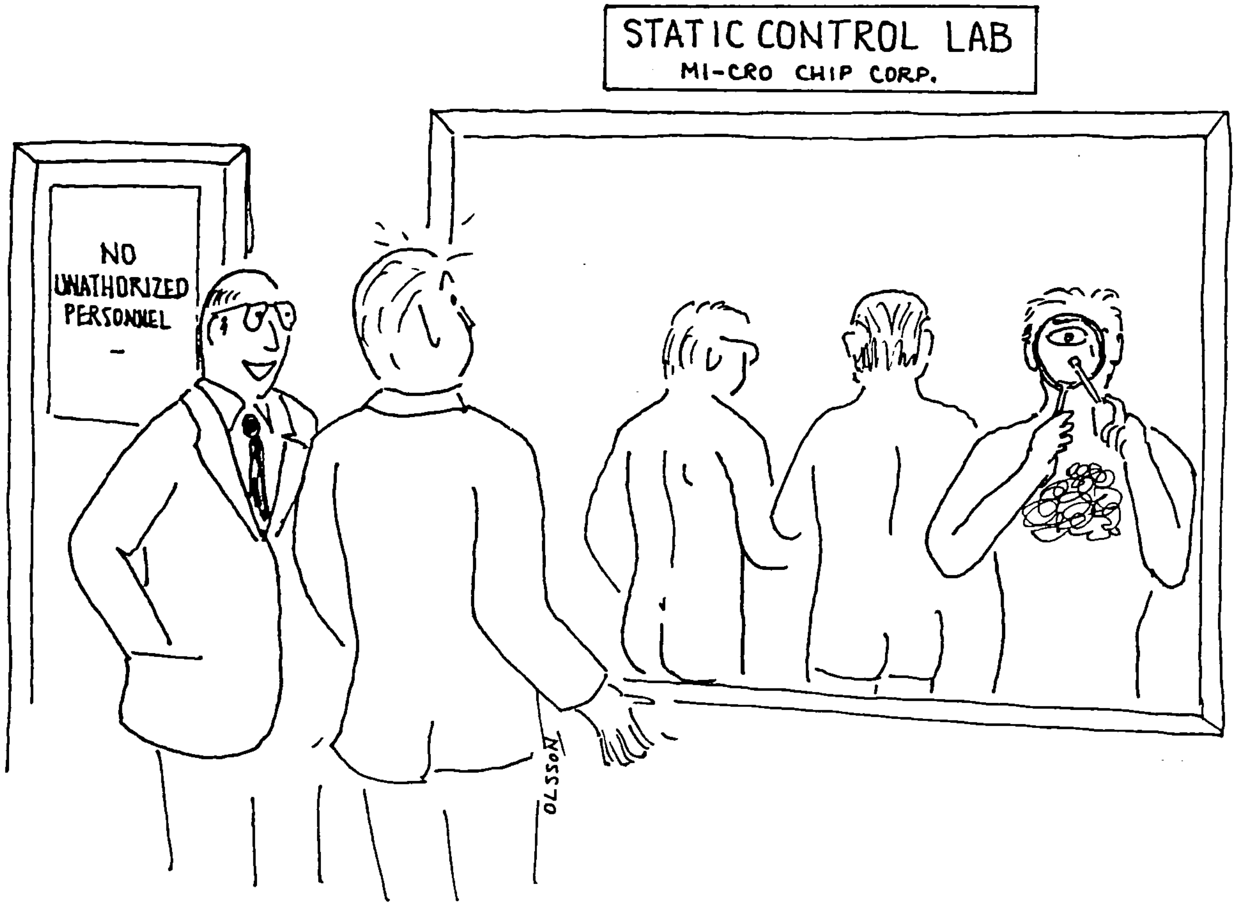
Program review (designed to production transition) must include, for example:

- Precautionary procedures

ESD awareness training

Packaging and labeling of ESDS items

Problem areas and proposed corrective actions



"...And this is our *zero-potential* product assembly area..."

CHAPTER 6 - ESD PROTECTIVE MATERIAL

There is a long chain of events from the inception of a device to ultimate utilization of that device in an assembly, and many factors contribute to the safe manufacture and delivery of a reliable device. Though primary protection is provided by safe work areas and grounding, protection cannot be achieved by those two practices alone. The total elimination of static generators and the achievement of zero potential are really not possible. Packaging and handling to prevent ESD damage are also two of the key factors involved in controlling ESD. Grounding techniques, ionization, and ESD protective materials work together to provide for every contingency.

Selecting packaging material involves the consideration of the many requirements that the package must meet such as (10):

- Mechanical - Transparency, puncture resistance, abrasion, tear, seal strength, tensile
- Electrical- Decay rate, attenuation, triboelectrification, surface resistivity
- Chemical - Corrosion, outgassing, contaminates (ionic, chemical, contact), biological reactive agents
- Performance requirements - Durability, shelf life, compatibility with the product, cleanability, slough resistance

The focus of this handbook has been on electrical requirements. Remember, ESDS devices are damaged in one of two ways: from electrical fields and from triboelectrification. Therefore, ESD safe materials are of two basic type: one type protects the device from electrical fields, and the other type protects the device from triboelectrification.

The following questions should be answered prior to material selection:

1. How sensitive is the product to triboelectrification, field effects, direct ESD, vibration, and shock? How many volts does it take to destroy the device?
2. What potentially harmful events can occur during the product's handling and distribution?
3. Which material will provide protection for the level of sensitivity of the device?
4. How compatible are the package and the product?
5. Are the costs of the materials consistent with the projected value of the product?
6. Is the product/package entering an environment (i. e. a clean room) where it may cause damage to a sensitive device already in that environment?

Most plastics are insulative. They are highly resistant to conducting electricity and are prime static sources when they are rubbed with other materials. As insulators they have high surface

resistivities, holding on to whatever charge they generate. To achieve performance levels from essentially insulative materials conductivity must be enhanced. It is necessary, and possible, to add conductive properties to insulative plastics. Why is it necessary and important? As flexible packaging materials, plastics offer many desirable attributes not matched by other materials. Some of the attributes were listed in the requirements stated above: transparency, heat sealability, cleanability, toughened, availability, reasonable cost, etc.

Conductivity of a material can be enhanced by the application of anti-static agents in one of three ways:

1. Topical application (on the surface)
2. Impregnation (throughout the volume of the material)
3. Metallization of the surface

Topical anti-stats serve two functions:

1. To reduce coefficient of friction
2. To increase surface conductivity

Topical anti-stats are simple surface coatings and are applied by wiping, brushing, rolling, dipping or mopping. "The commonest method for producing anti-static properties in synthetic material involves adding approximately 35% of surfactant, which is a hydrophilic or water-absorbing anionic, cationic, or one of the non-ionic groups on the surfaces of the material" (6).

While they can decrease surface resistivity and static generation by their dependence on humidity, topical anti-stats are essentially temporary, thus allowing a material to return to its insulative state.

Topical anti-stats are detergent-based and hygroscopic consisting of two parts: a carrier and an anti-stat. Once applied, the carrier (e. g. water, alcohol) evaporates, leaving the anti-stat behind. The anti-stat is dependent on environmental moisture to work. Static energy, though, is dissipated as heat. Heat causes evaporation and subsequent loss of the moisture layer. Some anti-stats are not humidity dependent. Instead of attracting moisture to the surface to increase conductivity, they increase surface lubricity, thus decreasing the ability to charge triboelectrically.

Anti-stats that are impregnated into a material have been compounded into the plastics during processing. Carbon powder or carbon-based material is often used as a conductive-based material. It can be 40 - 55% of the volume. Anti-static properties will vary with particle size and how evenly the carbon is distributed in the plastic. One disadvantage to this method is the tendency for carbon to flake off and become a contaminant to sensitive devices. The insulative plastic is then exposed. The development of better coating processes is presently addressing the problem.

When hit with a charge, the conductive carbon carries the charge

along the surface or through the volume of the material to the ground. Resistance is insufficient to dissipate the electrical energy into heat (like surfactants), so most of the energy of a charge must be conducted to ground. These materials do not provide a shield against RFI and EMI. Also, by adding carbon the material is weakened, thus decreasing its tear resistance and puncture resistance.

One other method of rendering an insulator more conductive is to include an anti-stat as some films and foams are extruded. This method suspends the anti-stat which migrates to the surface, making the surface more conductive. As the anti-stat on the surface wears off, more continues to migrate to the surface replenishing the supply.

Laminating a metallized layer in a structure can also enhance the conductivity of the total material. This process may render the film opaque and is generally used for EMI or RFI attenuation.

<u>SURFACE RESISTIVITY AND STATIC DECAY</u>

Surface resistivity is a material's ability to dissipate electrostatic charges over its surface. The unit of measure for resistance is ohms. To measure surface resistivity ohms/square is use. (see appendix ASTM D 257).

By measuring the resistivity of a material to the flow of

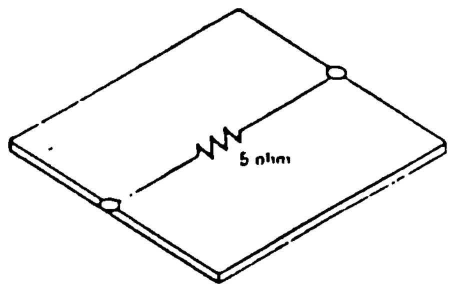
electrons, one knows its conductivity. (See diagram 6-A for an explanation of ohms/square).

ESD protective materials also have properties of static decay. Static decay is the rate at which a section of material charged to a predetermined level will decay that charge to a specific level. The DOD Handbook 263 classifies materials based on surface resistivity and static decay. These classifications are electrostatic free and shielding materials. Each is further classified into three parts.

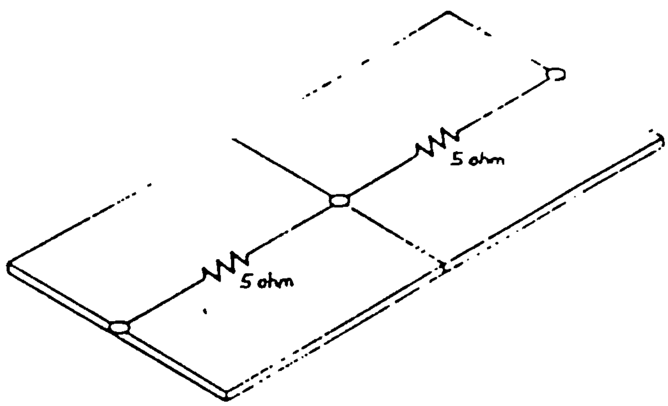
ELECTROSTATIC FREE MATERIALS

1. Conductive material

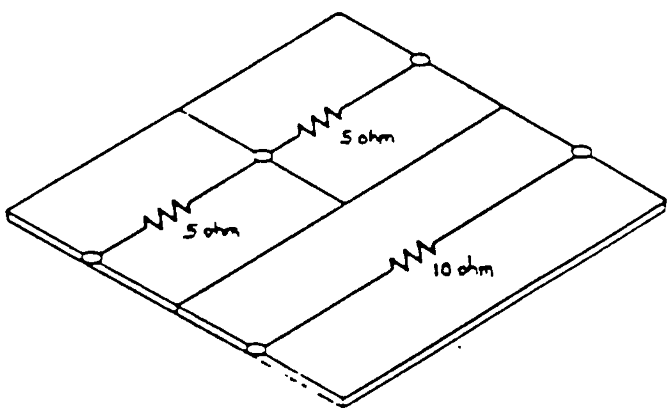
Conductive materials are defined as having surface resistivities of 10^5 ohms/sq or less and static decay rates of 0.05 seconds. (MIL-P-82646 lists examples) These materials are filled or impregnated with metal, for example. Conductive materials are the quickest materials to dissipate a charge.



The resistance of the square is constant, regardless of dimension, feet, inch, yard, etc.



Two squares side by side become a series connection: 5 + 5 = 10.



Addition of a third piece provides a second (parallel) path. Each path carries only half the current.

DIAGRAM 6-A

Conductive materials are used to shield very sensitive products and when there is the possibility of ESD damage based on the Charged-Device Model (CDM). If a charged conductive product touches a conductive surface, there will be a rapid discharge as the device attempts to neutralize itself. That flow of electrons can cause an ESD event. (Ironically, if the conductive material is exposed, it may be so non-resistant, that it could beg for a charge to hit it.)

Conductive materials distribute a charge, allowing it to drain. How quickly the charge is dissipated depends on the material's electrical resistivity. Conductive materials allow removal of charge by grounding.

2. STATIC DISSIPATIVE MATERIAL

Static dissipative materials are defined as having surface resistivities between 10^5 and 10^9 ohms/sq and static decay rates of 0.2 seconds.

Static dissipative materials are a welcome compromise between conductive and anti-static materials. Charge dissipation occurs at a sightly slower, but safer rate. Therefore, these materials are preferred. (Keep in mind that all three materials have a role to play in protection of devices).

3. ANTI-STATIC MATERIALS

Anti-static materials have surface resistivities between

10^9 and 10^{14} ohms/sq and static decay rates of 2 seconds. (see MIL-B-81705C, Type II for hygroscopic antistatic materials.)

Materials with surface resistivities greater and 10^{14} are considered insulative. Static decay does not apply to these materials. (See chart 6-B for surface resistivity and static decay.)

Anti-static plastics have a moisture layer on the surface. The moisture layer reduces friction and provides a conductive path for charges that are created during rubbing or separating. These materials are the slowest to dissipate a charge. As they provide adequate protection for most applications, they are most commonly used. These materials are usually the least expensive.

Anti-static material cannot be charged unless they are isolated and charged by induction. (This is true of any conductive material).

The reason these materials serve a purpose that cannot be met by conductive materials is that anti-statics are clean materials. Conductive materials that are loaded with carbon, for example, can slough off with use and contaminate the environment, such as a clean room environment.

STATIC-FREE CATEGORIES

CLASSIFICATION	RESISTIVITY (OHMS/SQ)	STATIC DISCHARGE RATE (SECONDS)
Normal Polymer Film	10^{14} or greater	NA
Antistatic	10^{9} - 10^{14}	Greater than 2 sec
Static Dissipative	10^{5} - 10^{9}	Greater than 0.2 sec
Conductive	Less than 10^{5}	Greater than 0.05 sec

CHART 6-B

Anti-statics resist triboelectrification and produce minimum electric charges upon separation from themselves or other materials.

A review of anti-static materials show they:

- Can be charged by induction
- Resist triboelectrification with other materials in intimate contact
- Depend on lubricity to prevent charge generation
- Should not be affected by humidity, handling, and aging or their lubricity will be lost, the base material will be exposed, charge generation is risked and retreatment may be required
- Do not solve all problems
- Are influenced by method of separation

An everyday example of and anti-static product is conditioner used for the laundry. The dryer removes all moisture, and synthetic fibers develop surface resistances so high that large amounts of static is generated. Anti-static agents, via liquid or sheet conditioners, add moisture through a soap-based agent! The agents are hygroscopic and attract moisture, lessening the static charge. The same thing could be accomplished if the laundry soap were not completely rinsed away!

SHIELDING MATERIALS

Shielding materials are capable of attenuating or lessening the force of a field, so the effect of the field does not reach the items within the shielding material and damage them. Shielding materials are also further classified in three parts: ESD shielding, EMI shielding, and EMP/RFI shielding. These materials must have all the properties of static free materials.

"Electrostatic shielding materials are capable of attenuation of an electrostatic field, so that its effects do not reach the stored or contained item and produce damage" (6). Shielding is a function of surface resistivity. (see DOD-HANDBOOK-263 for proper selection of materials). Shielding is 10^4 or less ohms/square. (See diagram 6-C) (10).

1. ESD SHIELDING MATERIALS

ESD shielding materials have a conductive layer with a surface resistivity of less than 1×10^4 ohms/square and are capable of attenuating all of an electrostatic field.

ESD SHIELDING

Those materials which are capable of attenuating an electrostatic field, so that its effects do not reach the stored or contained items and produce damage. An electrostatic shielding material shall have a conductive layer with a surface resistivity of less than 1 x 10 ohms/square, or a volume resistivity of less than 10^0 ohms-cm.

EMI SHIELDING

Those materials which are capable of attenuating a dynamic electromagnetic field, so that at 50 GHz an attenuation of 25 db is read or 25% of the field is excluded from the stored or contained items.

EMP/RFI SHIELDING

Those materials which are capable of attenuating an electromagnetic pulse or radio frequency interference field in any magnitude.

TABLE 6-C

2. EMI SHIELDING MATERIALS

EMI shielding is capable of attenuating 25% of a dynamic electromagnetic field (where 50 GHZ of 25 db is read).

3. EMP/RFI SHIELDING MATERIALS

EMP/RFI shielding is capable of attenuating an electromagnetic pulse (EMP) or radio frequency interference (RFI) field in any magnitude.

Remember the two main methods of generating a static charge: triboelectrification and induction by an electrostatic field. Conductive and anti-static materials deal with triboelectrification. To adequately deal with induction a complete conductive cage or shield must be used. That means the sensitive device must be surrounded by a conductive "cage" of material. The "cage" is normally a conductive metallized bag.

An electrostatic field cannot penetrate a conductive "cage" because any charge that is induced will be quickly swept across the surface of the material and dissipated. Whatever is inside the material will not be damaged. It is not even necessary to ground a "cage" but keep in mind that whatever is inside the "cage" cannot be removed unless in the presence of a completely static free work station.

A Faraday Cage is an electrostatic shield. While it should

surround the object it is to protect, it does not have to be made of continuous unbroken material as long as the material is electrically continuous. The conductive material can form a grid pattern instead of covering the surface completely.

EMI shielding, on the other hand, requires highly conductive shielding (less than 10 ohms/sq) and cannot tolerate large spaces or holes in the shield (2).

CHAPTER 7 - EVALUATING ESD PROTECTIVE MATERIALS

Chapter 3 presented a discussion on conductive materials and insulative materials and how they relate to a static charge. The concept of conductivity or insulativity is a relative one. According to the triboelectric series (chart 3-A), one material can be more conductive than some materials, less conductive than others.

The flexible materials used to protect sensitive devices must protect those devices from charge generation and electrostatic fields. In order for a static-free or shielding material to qualify, it must be tested. A complete, primary evaluation of materials consists of three stages (10):

1. Chemical Analysis
2. Mechanical Analysis
3. Electrical Properties Analysis

Each of the three stages represents a long and detailed analysis. the scope of this handbook will center on the analysis of electrical properties. In order to represent the entire test spectrum, an abridged chemical and mechanical analysis will be presented in the following simplified terms.

CHEMICAL ANALYSIS

Chemical analysis is represented by the following tests (10):

- Solderability
- Free Ion Analysis
- Corrosion
- Contact Corrosion

The essence of chemical analysis is to ascertain the compatibility of the material and the device. If the material (a complex polymer plus additives) creates problems with solder or causes the device to corrode, a whole new series of problems must be dealt with.

MECHANICAL ANALYSIS

Mechanical analysis is represented by the following tests (1):

- Tear
- Puncture
- Abrasion
- Tensile
- Elongation
- Heat Sealability
- WVTR

If the material used to protect a device has inappropriate physical characteristics, a new set of problems will arise. Tear and puncture resistance that is too low, or heat sealability that yields poor bag seals, can disable a package and prevent it from protecting a device from other threats.

ELECTRICAL ANALYSIS

To best represent electrical analysis, ESD protective materials will be separated by the performance characteristics previously mentioned: static free and shielding properties.

FOR ANALYSIS OF STATIC FREE MATERIALS INCLUDE:

1. Surface Resistivity - ASTM-D-257
2. Static Decay - FED-STD-101C, Method 4046
3. Triboelectrification - Faraday Cup Test

FOR ANALYSIS OF SHIELDING MATERIALS INCLUDE:

1. Surface Resistivity - ASTM-D-257
2. Static Decay - FED-STD-101C, Method 4046
3. Triboelectrification - Faraday Cup Test
4. Capacitance Probe Test - EIA 541
5. EMI Attenuation - EIA 541

Each test and performance standard is included in the appendix.

QUANTUM ANALYSIS

Quantum analysis is a secondary level of material testing that occurs once the primary level of testing has been completed. Once the material has been tested and analyzed, it must be subjected to deeper scrutiny. Keep this in mind: knowing electrical, chemical, and mechanical properties may not be enough to qualify a material for a specific use. How critical a role the packaging plays in protecting the device will determine how much analysis is required.

Quantum analysis subjects the material to worst case secnarios in regard to the type and degree of abuse a material could see in its lifetime. What is of particular interest are the relationships between chemical change, shelf life, and long term storage. Quantum analysis would include accelerated weathering studies to determine the effects of long term aging and record any chemical changes that could occur over time. The influence of temperature and relative humidity and the physical abuse of shock and vibration, all coupled with acclerated testing, would yield information not provided by primary levels of testing. In addition, corrosion analysis, solderability, electrical analysis, and fundamental physical properties would be retested. Any one of these properties could be adversely affected by accelerated testing.

Quantum analysis is not the type of testing a packaging professional would be responsible for completing. But, the packaging professional must know what to ask the supplier for if in-depth testing is called for by the needs of the product. The more information that is made available, the better the chances for making the right material choice and successfully packaging a sensitive device.

GLOSSARY

Alpha particle - A positively charged particle with two protons and two neutrons that can ionize air molecules.

Ampere - (amp or coulomb/second) A unit of electrical current. One ampere of current is 6.24×10^{18} electrons passing one point in a second.

Anti-static - Material exhibiting a surface resistance between 10^9 to 10^{14} ohms per square. Antistatic materials bleed off charges more slowly than either conductive or dissipative materials.

Bipolar Device - A current or power sensitive semiconductor.

Bonding - Connected to a conductor that is grounded.

Capacitor/Capacitance - The ability of a material to store and electric charge. Capacitance is measured in farads. Since a farad is a very large number, microfarads (millionths) or picofarads (millionths of millionths) are more commonly used.

Charge - Measured in coulombs. The static charge on a body is measured by the number of separated electrons on the body (negative charge), the number of separated electrons not on the body (positive charge).

Component - A semiconductor device.

Conductor/Conductive - A material that allows a current of electrons to travel continuously along it or through it when a voltage is applied across any two points. Less than 10^5 ohms/sq.

Cumulative Failure - A device failure resulting from multiple exposures to ESD related events.

Current - the flow of electrons past a certain point in a specific period of time. Measured in amperes. Current is measured in terms of electrons per second, but since the number would be too large, it is usually stated in terms of coulombs per second. One coulomb per second = one ampere.

Device - A package of electronic circuitry; a semiconductor or a component.

Dielectric Breakdown - A threshold effect in a dielectric medium where, at some electric field strength across the medium, bound electrons become unbound and travel through the medium as a current.

DIP - Duel-in-line Package. A housing for integrated circuits. Usually of molded plastic with two rows of pins.

Dissipative - Material exhibiting surface resistance of 10^5 to 10^{10} ohms per square. Dissipative materials bleed off charge at an optimal rate, neither too fast nor too slow.

Electrical Overstress (EOS) - May start out with an ESD from a charged person or prime static source resulting in a puncture of a dielectric layer or small junction melt within the device.

Electromagnetic shield - Electromagnetic field results from a rapidly moving electric field and its associated magnetic field. The shield is a housing placed around devices or circuits to reduce the effect of both electric and magnetic fields.

Electron - A negatively charged particle with an electrical charge equal to about 1.6×10^{19} coulomb.

Electrostatic Field - Surrounds an electrically charged object in which another electrical charge can be induced and experience a force. Quantitatively, it is the gradient between two points at different potentials.

Electrostatic Shield - A barrier that prevents the penetration of an electrostatic field. May not offer much protection against the effects of electromagnetic interference (EMI). EMI shields, however, are good electrostatic shields.

Electromagnetic Interference (EMI) - Sources are static sparks, lightning, radar, radio and tv transmissions, etc. By line conduction or air propagation, EMI can induce undesirable voltage signals in electronic equipment causing malfunction and/or damage. Protection from EMI requires the use of shields, filters, and special circuit design.

Electrostatic Discharge (ESD) - A sudden transfer of charge between two objects.

ESD Sensitive (ESDS) - Describes devices that are vulnerable to damage from electrostatic discharge.

Faraday Cage - An electrically continuous, conductive enclosure which provides electrostatic shielding.

Ground - A metallic connection with the earth to establish zero potential or voltage with respect to ground or earth. Includes water pipes, any power ground, or any large metal structural member of a building.

Insulator - A material that does not conduct electricity. A nonconductor.

Integrated Circuit (IC) - Any electronic device which includes transistors, resistors, capacitors, etc. in a single package.

Ionization - The process by which a neutral atom or molecule, such as air, acquires a positive or negative charge.

Joule - A unit of energy. The energy of a static discharge is 1/2 CV^2 where C = capacitance or the discharging object and V = voltage difference between the discharging object and the point to which it discharged.

Latent Failure - Failure that occurs when using a device that has been previously weakened and degraded by ESD exposure.

MOS Device - A device having a metal-oxide semiconductor layer structure which is voltage- or electric-field sensitive and can be damaged by a static discharge or by induction from an electrostatic field. Damage occurs as dielectric breakdown when the voltage or electric field across the dielectric layer between two relatively conductive layers exceeds the dielectric strength of that material.

Ohm - A unit of electrical resistance through which a current of one ampere will flow when a voltage of one volt is applied

Package - The enclosure of products, devices,or other packages in a wrap, pouch, bag, slide, magazine, or other container form so as to perform one or more of the following functions:

1. Containment for handling, transportation, and use
2. Preservation and protection of the contents for the life of the item
3. Identification of contents, including quantity and manufacturer
4. Facilitation of dispensing and use of the contents.

Packaging - In the electronics industry, packaging refers to the process of location, connecting, and protecting various devices, such as circuits printed onto thin film wafers electrically interconnected during fabrication. The circuits are then place into easy-to-handle elements called packages which permit convenient external connections to be made to it.

Potential - Measured in millivolts, volts, or kilovolts. Measured from a base point which can be any voltage but is usually ground, theoretically zero. Stored energy that is able to do work.

RFI - Radio frequency interference. A form of electromagnetic interference (EMI). Any electrical signal capable of being propagated and of interfering with the proper operation of electrical or electronic equipment. The frequency range usually includes the entire electromagnetic spectrum. The spark from a static discharge is a source of RFI.

Resistance - Electrical current encounters difficulty in passing through an electrical circuit or conductor. The measurement is the resistance, a bulk property of a material and depends on the material's dimensions, electrical resistivity, temperature, and voltage. Resistance of a material determines the current (electron flow) produced by a given voltage. The practical unit of resistance is the ohm.

Resistivity - a measure of the intrinsic ability of a material to conduct current independent of the dimensions of the material. The unit of volume resistivity is ohm-cm.

Surface Resistivity - The ratio of DC voltage to the current that passes across the surface of the system. Relevant only for materials where current conduction is virtually only on the surface. Surface resistivity is not relevant for volume conductive materials. The unit of surface resistivity is ohms/square.

Triboelectric - An electrical charge generated by firctional rubbing or separation of two surfaces.

Triboelectric series - A list of substances arranged so that any of them can become positively charged when rubbed with one further down the list, or negatively charged when rubbed with one further up the list. The further apart the substances, the greater the charge generated. This series is only a guide.

Volt - (V) the unit of voltage, potential, and electromotive force. One volt will send a current of one ampere through a resistance of one ohm.

Volume Resistitivy - The ratio of DC voltage per unit of thickness, applied across two electodes in contact with or embedded in a specimen, to the amount of current per unit area passing through the system. Generally geven in ohm-cm.

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APPENDICES

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