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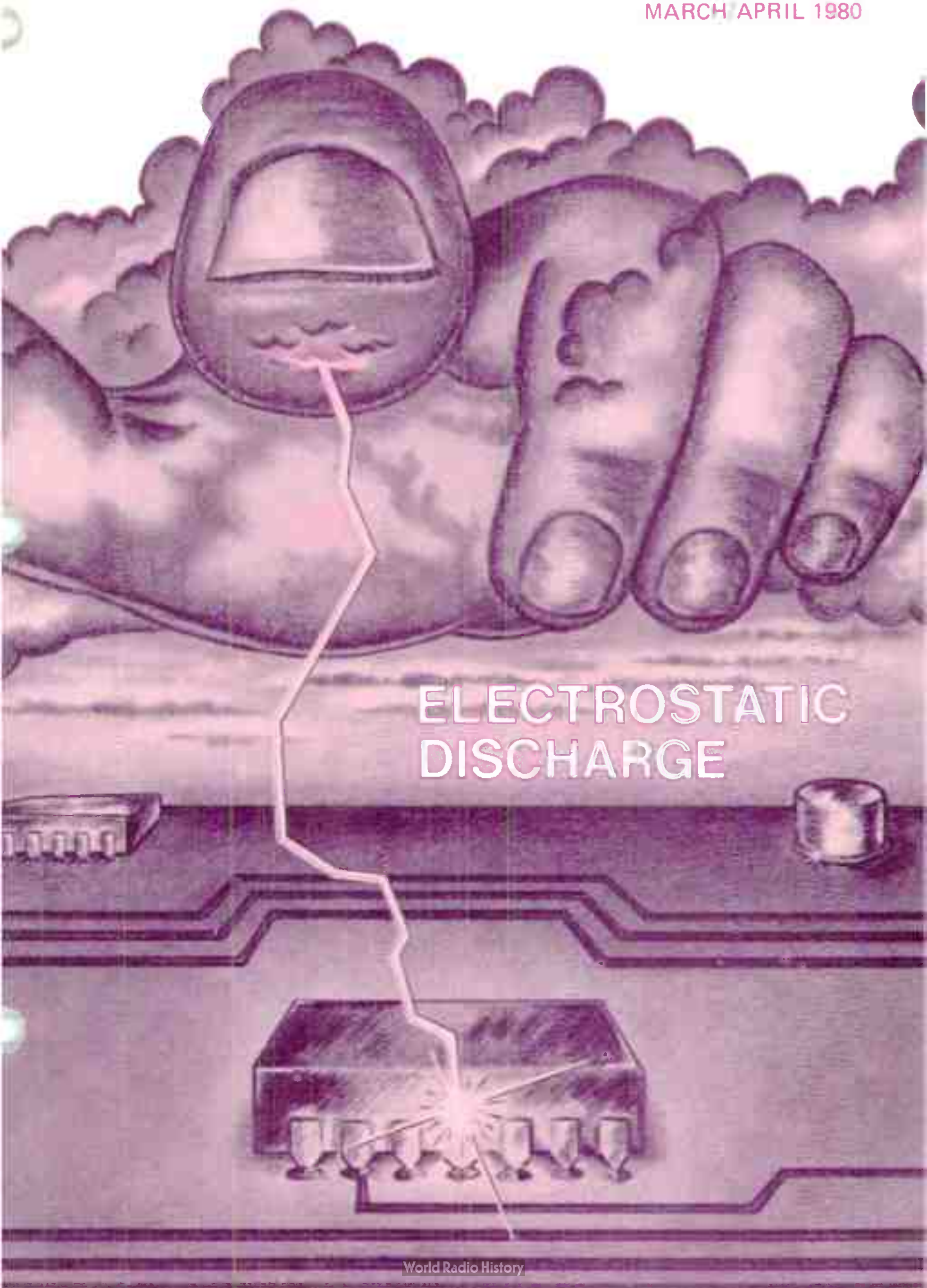

ELECTROSTATIC DISCHARGE

Electrostatic discharge is a common cause of microelectronic circuit failures. Some of these devices can be seriously damaged or destroyed by the discharge resulting from an electrostatic voltage as low as 20 Volts. The following article discusses the causes of static electricity and the failure mechanisms of electrostatic discharge sensitive devices. The prevention and removal of excessive electrostatic charges are also described.

All microelectronic and most semiconductor components are sensitive to static discharge. Among commonly used devices, the most highly-sensitive are metallic oxide semiconductor (MOS) integrated circuits and field effect transistors (FET's). An increasing number of these devices are being used in telecommunications equipment.

As reported in several recent issues of the Demodulator, very large scale integration (VLSI) technology is producing integrated circuits with increased packaging density, complexity and functional speeds. These newer devices are even more sensitive to electrostatic discharge than their predecessors.

Microprocessors and codecs (COders DECoders) are typical VLSI products used extensively in telecommunications equipment. Reliable system operation is often dependent upon the proper functioning of these "Circuits on a Chip". Since the circuitry can be damaged by a discharge of static electricity, personnel working with or handling equipment containing these items should be familiar with the causes and prevention of electrostatic potential accumulation and discharge.

Causes of Static Electricity

Static electricity is electrical energy at rest. When two substances are rubbed together, separated after being in contact or flow relative to one another, one of the substances accumulates electrons and the other gives them up. The substance which accumulates electrons is negatively charged. The substance which gives up electrons is positively charged. The charges are equal and opposite.

An electrostatic field is generated between two objects with different numbers of electrons (electrostatic potentials). Objects entering this electrostatic field will be charged by induction. Substantial voltage can be generated by induction alone.

Almost everyone is familiar with the generation of static electricity by rubbing. This is known as the "Triboelectric Effect". A triboelectric series has been established which lists substances in the order of their ability to be positively or negatively charged (see Table 1).

A substance will be positively charged when rubbed with a substance lower on the list. The magnitude of the electrostatic charge is proportional to the separation, between the two materials, on the

Table 1. Triboelectric Series

POSITIVE
+
ACETATE
GLASS
HUMAN HAIR
NYLON
WOOL
FUR
ALUMINUM
POLYESTER
PAPER
COTTON
WOOD
STEEL
ACETATE FIBER
NICKEL, COPPER, SILVER
BRASS, STAINLESS STEEL
RUBBER
ACRYLIC
POLYSTYRENE FOAM
POLYURETHANE FOAM
SARAN
POLYETHYLENE
POLYPROPYLENE
PVC (VINYL)
KEL F
TEFLON
-
NEGATIVE

WHEN ANY TWO SUBSTANCES IN THE LIST CONTACT ONE ANOTHER AND ARE SEPARATED, THE SUBSTANCE HIGHER ON THE LIST IS POSITIVELY CHARGED.

triboelectric list. Non-conductors will contain the charge within a localized area but a conductor will dissipate the charge over its surface and the surface of other conductors with which it comes in contact, ground for example.

Clothing made from synthetic materials can generate large electrostatic voltages as a result of normal movements by its wearer. These voltages are one of the principal causes of damage to electrostatic discharge sensitive components.

In fact, a human being will build up and dissipate substantial electrostatic charges many times during normal activities. These are imperceptible to the average person if the charge is less than 3,000 volts. Table 2 shows charge potentials generated by a few simple activities. The wide range of potentials, for each activity, is due to differences in relative humidity. The effects of humidity are discussed later.

Substantial electrostatic charges can also be generated between two objects of the same material, if they are in intimate contact and suddenly separated. Common plastic is an example of such a material. Packing, shipping and unpacking are activities where this kind of generation might occur. Any consequent damage to components may not be readily apparent and the time of occurrence may be hard to determine, particularly if the units are stored for sometime before installation.

Charged objects discharge into the atmosphere. The time required for the object to discharge is inversely proportional to the amount of water vapor in the air. A film of water on an object causes it to become antistatic, for all practical purposes. Electrons can return to the object that is becoming positively charged so an electrostatic potential does not usually develop.

Under ordinary circumstances, static charges will quickly "bleed" off into the air, if the relative humidity is 25% or greater. When the relative humidity falls below 25%, the danger of electrostatic discharge increases. A relative humidity in the 25 to 40% range is probably optimum. Higher humidities greatly reduce the electrostatic risks but this advantage is

Table 2. Typical Electrostatic Voltages

ACTIVITY	VOLTAGE GENERATED (VOLTS)
WALKING ACROSS CARPET	1,500 – 35,000
WALKING ACROSS VINYL FLOOR	250 – 12,000
WORKING AT BENCH	100 – 6,000
PICKING UP COMMON POLYETHELYNE BAG FROM BENCH (BAG POTENTIAL)	1,200 – 20,000

outweighed by the increased possibility of corrosion and other damage which results from excessive humidity.

Failure Mechanisms

Two types of failures, catastrophic and latent, may result from a discharge through an electrostatic discharge sensitive (ESDS) device. As the name implies, catastrophic failures happen suddenly and the resulting malfunctions are immediately apparent. On the other hand, malfunctions will probably not be apparent when a latent failure occurs. The impaired device may seem to be in good operating condition but greater impairment and circuit malfunctions will occur in time. The following paragraphs discuss catastrophic and latent failures in turn.

Catastrophic Failure Mechanisms

An electrostatic discharge can short-circuit any device which contains a conductor separated from a channel region by a thin dielectric with a low resistance path to external terminals. An MOS transistor contains metallized gates separated from a channel region by a metal-oxide layer from 800 to 1,000 Angstroms thick (an Angstrom is 10^{-10} meters).

An electrostatic potential of sufficient magnitude can break down the metal-oxide dielectric and discharge through it. The resulting puncture will be metallized, thereby short circuiting the transistor. Catastrophic failure results.

Many operational amplifier IC's have an MOS capacitor connected directly to a terminal. An electrostatic voltage can break-down the dielectric and cause the same kind of short circuit described for the transistor. Catastrophic failure of the IC is the probable result.

Bipolar (P-N) junction devices also can be damaged by electrostatic discharge. An emitter-base junction is usually partially melted by the discharge. Shorting and catastrophic failure follows.

An electrostatic discharge of sufficient magnitude can also damage film resistors. The microscopic crystals, forming the film, are melted and create small shunts which change the effective resistance.

The failure mechanisms of other ESDS devices follow the same patterns of dielectric break-down or melting of materials.

Latent Failure Mechanisms

Electrostatic discharge can cause dielectric break-down of a transitory nature, when the current is not limited. The device may appear to be alright but will actually have a tiny puncture in the gate metal-oxide. Eventually, metal will migrate through the puncture and cause a short-circuit.

Latent failure can also occur in MOS devices when a highly limited current, dielectric break-down occurs. Again the device appears to be alright, but the dielectric break-down voltage may be reduced to as low as one third of its original value.

Some MOS devices have a metallic path from the input connection to the gate and a separate metallic path to the input protection circuitry. An electrostatic discharge can open the lead to the protective circuitry while leaving the gate and its connecting lead intact. A subsequent discharge through the gate may cause a catastrophic failure.

Bipolar devices may experience marginal P-N junction damage which results in a smoothing of the break-down curve or an increase in leakage current. In either case, the result is a lowered damage threshold.

Human Factors

People are the major cause of damage to electrostatic discharge sensitive equipment. A charged person may damage equipment by discharging through it or inducing voltages into it.

The charging path for a human body is a current limiting resistor in series with a capacitor for storing the charge. The body's contribution to the discharge path impedance is a non-inductive resistor. A simplified equivalent circuit is shown in Figure 1.

Typical human capacitance ranges from 50-250 picofarads but may be as high as several thousand. Human non-inductive resistance is usually 100 to 1500 ohms but may range up to 100,000 ohms. Capacitance can be changed by such factors as variations in position, clothing and floor materials.

The wide range of human resistance is due to variations in the moisture, oil and salt composition of the conductive sweat layer. Dry, calloused skin has the highest resistance. The following paragraphs discuss how variations in capacity and resistance effect the electrostatic charge and discharge of an RC circuit.

First let us consider one simple equation for the charge of a capacitor:

Equation 1: $Q = CE$ where:
Q is the charge in Coulombs
C is the capacity in Farads
E is the applied voltage in volts

From the equation, it is apparent that a large capacitor does not require as high a voltage as a small one, to accumulate a given charge.

From the physical view point, the charge is considered to be stored in electrostatic lines of force between the plates of a capacitor. Capacitance is directly proportional to the area of the plates. So, to store a given charge, a large capacitor requires fewer lines of force per unit of area than a small one.

The density of lines of force per unit area is a function of the voltage (electrostatic potential) across the plates. So to store a given charge, a small capacitor requires a higher voltage than a large one.

Capacitance is inversely proportional to dielectric thickness. However, thin dielectrics have a lower break-down voltage than thicker dielectrics of the same material. This explains the suscep-

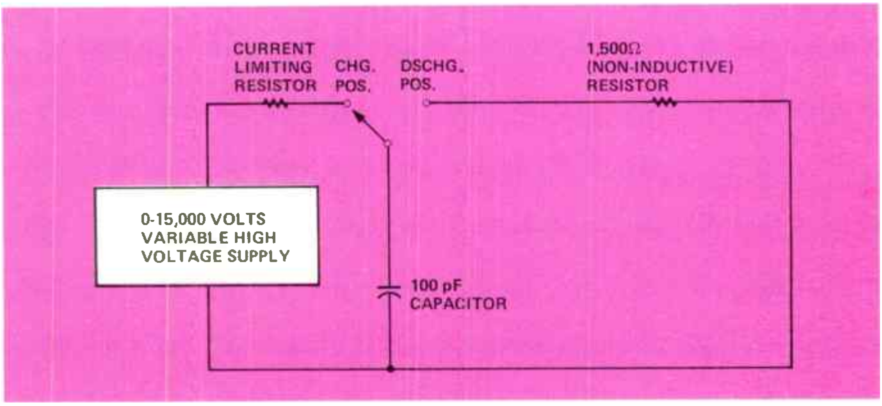

Figure 1. Simplified Human Equivalent Circuit

tibility of CMOS capacitors to electrostatic discharge. The relatively high capacitance and low break-down voltage of electrolytic capacitors, compared to mica or ceramic types, is another illustration of the relationship between dielectric thickness, capacity and break-down voltage.

Changing the capacitance of a charged body, while holding the charge constant, effects the voltage. This is readily apparent when equation (1) is solved for the voltage (E). Any change in C will change the quotient of $\frac{Q}{C}$ which is the value of E.

Equation 2: $E = \frac{Q}{C}$

When the capacitance is reduced, the voltage will increase and may cause an arc.

The capacitance of a human is a function of the position of the body relative to other objects. Therefore, the capacitance can be changed by simple movements. Table 3 shows actual, measured changes resulting from such movements.

The time required to charge or discharge a capacitor is proportional to the resistance in the path. Increasing the resistance limits the charge or discharge current, thereby increasing the time required.

Damage Prevention

It is better to remove static from the environment than to rely on protective devices which may not be effective. The design and effectiveness of protective circuitry varies between manufacturers. Zener diodes may not act quickly enough to protect the more sensitive components. The use of diffusing and limiting resistors is restricted to the voltages they can withstand. Also, protective circuitry sometimes reduces the performance of a device. This could be a heavy penalty for applications requiring high-performance.

This is not to say that protective circuits are useless. Any electrostatic discharge sensitive device with external connections should have a protective network. The 20 to 80 volt normal damage threshold can be increased to 500 to 800 volts by protective circuitry. Also, any apparatus containing sensitive devices should have adequate grounding of all controls which require human contact.

However, the best way to prevent electrostatic damage is to maintain a static free environment around the sensitive device at all times. A plug-in unit, circuit board, piece of test equipment or other apparatus is generally considered to be as susceptible to electrostatic damage as its most sensitive component.

Both conductive and anti-static materials are used to protect and package ESDS devices and components. Conductive materials are metal, metal coated and metal or car-

Table 3. Changes in a Person's Capcitance with Movement.

DESCRIPTION OF MOVEMENT	INITIAL CAPACITANCE	FINAL CAPACITANCE	% CHANGE
PERSON SEATED, RAISING ONE FOOT	192	163	15% DECREASE
PERSON SEATED, PICKING UP BOTH FEET PLACING THEM ON THE FOOT REST	192	129	33% DECREASE
PERSON SEATED, LEANING FORWARDS IN CHAIR (DESK TYPE CHAIR WITH BACK)	192	184	4% DECREASE
STANDING PERSON RAISING ONE FOOT	167	141	16% DECREASE
SEATED PERSON STANDING UP	192	167	13% DECREASE

bon impregnated. Carbon impregnated plastic is one of the most popular conductive materials.

Anti-static materials are generally plastics which have been impregnated with an anti-static substance such as detergent. The substance migrates to the surface of the plastic and combines with the moisture in the air to form a slippery, slightly conductive layer. This layer prevents the build-up of electrostatic charges.

ESDS components are generally encased in conductive or anti-static materials for transportation and storage. In these circumstances, it is also a good idea to short-circuit any external leads and connections.

Shorting bars, clips and "Foam" are used for shorting the connections. Foam is a carbon impregnated plastic. It is available in various densities and degrees of flexibility.

Particular attention should be paid to providing a static free environment for work areas where electrostatic sensitive devices are handled. All conductive materials in these areas must be grounded. This is accomplished by properly grounding work surfaces and equipment.

Since the human body can act as a conductor it too must be grounded. This is accomplished by a wrist strap. The path from the point of skin contact to ground should contain a resistor, to avoid hard grounding of personnel or equipment. The resistance should be located close to the wrist to avoid accidental shunting of the resistor and providing a "sneak-path" to ground. A resistance between 250 kilohms and 10 megohms is suitable for most installations. A one megohm resistor is commonly used in wrist straps.

The criteria for minimum resistance is to limit leakage current to five milliamperes maximum, if the person wearing the strap comes in contact with the highest potential available at the work station.

These same precautions apply to the ground straps for work surfaces and equipment. In other words all connections should be to the same reference potential and not to hard ground. Figure 2 illustrates this principle.

The criteria for the maximum resistance to hard ground is determined by the decay time for an

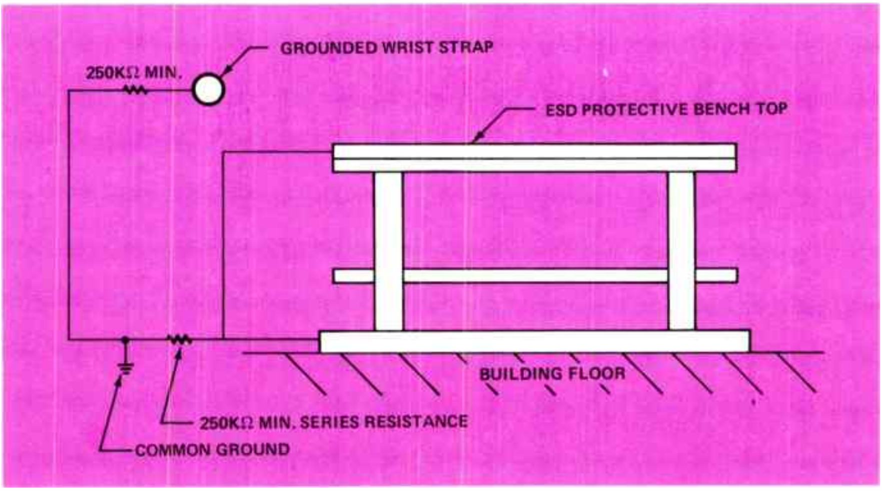

Figure 2. Work Station Grounding System

electrostatic charge. The decay time is based on the capacitance and resistance of the human equivalent circuit shown in Figure 1 plus the resistance to hard ground. This time should be short enough to dissipate charges at, or faster than, the rate they are normally generated.

As a rule of thumb, a discharge time of one second or less is short enough. The ohmic value of the resistor to hard ground should be selected so that one second equals at least 5 time constants. A capacitor will be 99.3% discharged in a period of 5 time constants. A time constant is defined as t = RC where t is in seconds, R is in ohms and C is in farads.

The 250 kilohm minimum resistance mentioned above will limit the leakage current to 5 milliamperes or less from sources up to 1200 volts. However, larger values are generally used in wrist straps to provide an extra margin of safety. One megohm is typical. The 10 megohm maximum will limit residual voltages from static generation to approximately 10 volts, at a typical ESDS work station.

Since the resistor is selected to limit the current, from the highest source voltage, to 5.0 milliamperes and static generators have very high internal impedance, the resistor will not have to dissipate much power. A one watt resistor is more than adequate.

Grounding a non-conductor will not provide protection against static discharge. Current cannot flow through an insulator. Work sheets, plastic boxes, coffee cups and clothing can accumulate substantial charges which grounding will not dissipate.

As previously stated, maintaining a relative humidity of 25 to 40% will permit these static charges to dissipate into the air. However, maintaining humidity at these levels is not always feasible. In this case, an ionized air blower is recommended for ESDS work stations.

The blower supplies a steady stream of positive and negative ions. Charged objects will neutralize themselves by attracting and holding ions of the opposite charge. Unused ions recombine or combine with other materials at the work station.

An ion blower is not a practical device for discharging a person. Human body capacitance is much greater than that of most non-conductors, so a much longer time is required to neutralize the charge. The time required for an electrostatic build up and discharge could be much shorter than this neutralization time. However, placing one's hand in the air flow from an ion blower before picking up a sensitive component is a reasonable precaution.

Soldering irons, drills, and other electrically powered devices should be equipped with a power cord containing a ground lead and three prong plug. The equipment should only be plugged into a suitable receptacle. The ground connection should make first and break last. Precautions must be taken to avoid placing these devices on a conductive surface connected to ground through a resistor. Such an action could shunt the resistor and create a path direct to hard ground. This could be hazardous to personnel.

In fact, precautions must always be observed when employing parallel paths to ground. Personnel should always be aware of possible hazards involved in these situations.

Conductive mats should be used to cover the floor in the vicinity of a work station, particularly if the surrounding area is carpeted. The mats should extend far enough so that the work surface cannot be reached without standing on them. The mats should be connected to ground through a resistor of the same value used for the work surface and wrist straps.

From the previous discussion, it is apparent that adequate grounding and charge neutralization are basic to maintaining a static free environment. A third preventive measure is to keep static producing materials away from areas where electrostatic discharge sensitive items are handled.

Some static producing materials are: common plastics, most carpets and nylon. Things to be avoided at a static free work station include tools with plastic or insulated handles, ungrounded soldering irons and drills, common solder suckers and brushes, particularly those with synthetic bristles.

Table 4 lists some typical charge generators which should be excluded from the work area. Figure 3 shows a static free work station.

Practically all fabrics, with the exception of untreated cotton, are static generators so most clothing is a potential hazard. Shoes with insulating soles, such as crepe rubber or cork, prevent discharge through conductive floor mats. Personnel should be furnished antistatic smocks and

Figure 3. Typical antistatic work station showing basic requirements of gounded work surface and connected wrist strap supplemented with common auxiliary items.

Table 4. Typical Charge Generators

WORK SURFACES	• FORMICA (WAXED OR HIGHLY RESISTIVE) • FINISHED WOOD • SYNTHETIC MATS
FLOORS	• WAX FINISHED • VINYL
CLOTHES	• COMMON CLEAN ROOM SMOCKS • PERSONNEL GARMENTS (ALL TEXTILES EXCEPT VIRGIN COTTON) • NON-CONDUCTIVE SHOES
CHAIRS	• FINISHED WOOD • VINYL • FIBERGLASS
PACKAGING HANDLING MATERIALS	• COMMON POLYETHYLENE – BAGS, WRAPS, ENVELOPES • COMMON BUBBLE PACK, FOAM • COMMON PLASTIC TRAYS, PLASTIC TOTE BOXES, VIALS
ASSEMBLY, CLEANING, TEST AND REPAIR AREA ITEMS	• SPRAY CLEANERS • COMMON SOLDER SUCKERS • COMMON SOLDER IRONS • SOLVENT BRUSHING (SYNTHETIC BRISTLES) • CLEANING, DRYING • TEMPERATURE CHAMBERS

suitable foot wear or at least requested to wear short sleeved garments and leather or composition soled shoes.

The effectiveness of static free work stations should be verified on a regular basis. Megohmeters and electrostatic voltmeters are the best instruments for this purpose. Ordinary VOM's are not satisfactory.

Many things can impair the effectiveness of a work station. The conductivity of floor mats and work surfaces can be reduced by dirt or contamination. Ground connections can be broken by error, accident or simple wear and tear.

Probably the single most important thing that can be done to prevent damage to electrostatic discharge sensitive items is the education of personnel who handle them. Training of installers and field technicians is particularly important since maintaining a static free environment is not practical at many field sites. Many of the references listed in the bibliography contain suitable material for personnel training.

A few precautions which can be exercised without elaborate equipment are:

- Workers not wearing ground straps should always ground themselves before handling ESDS items.
- ESDS items should not be handled by their leads or terminals.
- Static generating actions should be avoided while working on ESDS equipment or while in areas where such equipment is located. Actions to be avoided include:
  a) Wiping feet
  b) Putting-on or taking-off garments: coats, sweaters, smocks, etc.
  c) Rubbing hands together.
  d) Moving equipment, tool boxes, plastic containers and similar items by sliding.
- Tools and test equipment should be properly grounded. Hand tools should be metallic and not have insulated handles (anodized aluminum is considered to be an insulator).

The foregoing general precautions apply to all activities in areas where ESDS devices are located. The following, more specific precautions apply to work involved in installing, maintaining and troubleshooting ESDS equipment:

- Perform diagnostic tests with unit installed and power on. All connections should be properly made. Signals should not be applied to unpowered MOS or FET devices.
- Shut off power to equipment (if practical) before installing, removing or replacing ESDS devices.
- Before touching an ESDS device, personnel should be grounded, preferably through a wrist strap connected to rack or chassis ground through a resistance.
- Avoid probing or testing ESDS items with a VOM. If this action is considered necessary, it should only be done under conditions of high humidity or in the air stream from an ion blower.
- When an ESDS item is removed, immediately insert shorting devices or conductive foam on the edge connectors. Ground an empty protective container and immediately place the item in it. This should be done even if the item is believed to be faulty. Otherwise the cause of the fault may be obscured, or the original problem compounded, by further damage.
- Ground the protective package containing the replacement part

before opening. Open at connector end if possible.

- Touch the shorting bar or other protecting device, before it is removed, to neutralize any charge. Avoid touching the connectors or circuitry.
- Complete all installation procedures, i.e. electrical connections, securing to rack or cabinet, replacement of covers, etc. before removing wrist strap. Restore power to equipment.

Figure 4. Approved Label for Electrostatic Sensitive Devices

The Electronic Industries Association (EIA) has approved a symbol to identify electrostatic discharge sensitive items. The symbol (EIA RS-471) is shown in Figure 4. All ESDS items should be marked with this symbol. Shipping containers and packages containing ESDS items should also have a label showing the symbol.

Gummed labels bearing the symbol and a cautionary notice are available from the EIA Type Administration Office, 2001 Eye St., N.W. Washington, D.C. 20006. The labels are offered in quantities of 1,000 or multiples thereof. The current price is $67.50 per thousand.

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