Protecting Power MOSFETs from ESD

by STEVE BROWN and BOB GHENT, Applications Engineering Department

WARNING!
STATIC SENSITIVE DEVICES

Most power MOSFET users are very familiar with this warning. The problem is that familiarity may breed contempt, especially if one has never destroyed a power MOSFET by improper handling. Statistically, it is unlikely that a particular MOSFET will be destroyed by Electrostatic-Discharge (ESD). However, when thousands of MOSFETs are handled, even a statistically small number of failures may be significant. In view of the fact that IR rejects less than 100 parts per million (ppm) at outgoing Q.A., it is evident that destroying 1 or 2 parts per 1,000 during incoming handling will have a significant impact on the "perceived" quality of the units.

Any effective ESD Control Program is very detailed and specific by nature. But its basic underlying concepts may be summarized by ten simple rules:

1. Always store and transport MOSFETs in *closed* conductive containers.
2. Remove MOSFETs from containers only after grounding at a Static Control Work Station.
3. Personnel who handle power MOSFETs should wear a static dissipative outer garment and should be grounded at all times.
4. Floors should have a grounded static dissipative covering or treatment.
5. Tables should have a grounded static dissipative covering.
6. Avoid insulating materials of any kind.
7. Use anti-static materials in one-time applications only.
8. Always use a grounded soldering iron to install MOSFETs.
9. Test MOSFETs only at a static controlled work station.
10. Use all of these protective measures simultaneously and in conjunction with trained personnel.

International Rectifier has an outstanding ESD control program in place in their HEXFET® manufacturing facility. This Application Note will discuss how HEXFET users can implement and benefit from similar ESD control programs.

What is ESD?

ESD is the discharge of static electricity. Static electricity is an excess or deficiency of electrons on one surface with respect to another surface or to ground. A surface exhibiting an excess of electrons is negatively charged, and an electron deficient surface is positively charged. Static electricity is measured in terms of voltage (volts) and charge (coulombs).

When a static charge is present on an object, the molecules are electrically imbalanced. Electrostatic-Discharge (ESD) takes place when a re-establishment of equilibrium is attempted through the transfer of electrons between one object and another that is at a different voltage potential. When an ESD-sensitive device, such as a power MOSFET, becomes part of the discharge path, or is brought within the bounds of an electrostatic field, it can be permanently damaged.

Generating Static Electricity

The most common way of generating static electricity is triboelectrification. Rubbing two materials together will cause triboelectrification, as will bringing two materials together and then separating them. The magnitude of the charge is highly dependent upon the particular material's propensity toward giving up or taking on electrons. Dissimilar materials are particularly susceptible, especially if they have high surface resistivity.

Another way of placing a static charge on a body is by induction. Induction could be caused, for example, by placing a body in close proximity to a highly charged object or high-energy ESD.

ESD Failure of the Power MOSFET

Failure Mode

One of the biggest operating advantages of the power MOSFET can also be the cause of its demise when it comes to ESD — ultra-high input resistance (typically $>4 \times 10^9$ ohms). The gate of the power MOSFET may be considered to be a low voltage (± 20V for HEXFETs) low leakage capacitor. As can be seen in Figure 1, the capacitor plates are formed primarily by the silicon gate and source metallization. The capacitor dielectric is the silicon oxide gate insulation.

ESD destruction of the MOSFET occurs when the gate-to-source voltage is high enough to arc across the gate dielectric. This burns a microscopic hole in the gate oxide which permanently destroys the device. Like any capacitor, the gate of a power MOSFET must be supplied with a finite charge to reach a particular voltage. Since larger devices have greater capacitance they require more charge per volt and are therefore less susceptible to ESD than are smaller MOSFETs. Also, immediate failure usually will not occur until the gate-to-source voltage exceeds the rated maximum by two to three times.

A typical ESD destruction site can be seen in Figure 2a. This was caused

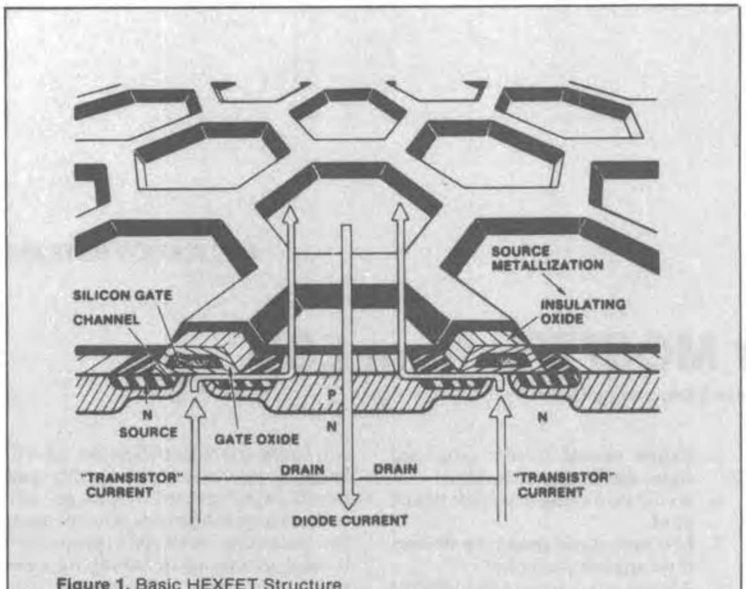

Figure 1. Basic HEXFET Structure

by a human body model charged to 700 volts being discharged into the gate of the device. This photo was taken at a magnification of 5,000 with a scanning electron microscope after stripping the surface of the die down to polysilicon. The photo of Figure 2b shows that no damage was visible on the surface of the die prior to stripping. The actual failure site shown in Figure 2a is only about 8 microns in diameter. The electrical symptom of ESD failure is a low resistance or a zener effect between gate and source with less than ± 20 volts applied.

The voltages required to induce ESD damage can be 1,000 volts or higher (depending upon chip size). This is due to the fact that the capacitance of the body carrying the charge tends to be much lower than the C_{iss} of the MOSFET, so that when the charge is transferred, the resulting voltage will be much lower than the original. The graph of Figure 3 shows the relationship between chip size and voltage required to induce ESD damage.

Electrostatic fields can also destroy the power MOSFET. The failure mode is ESD but the effect is caused by placing the unprotected gate of the FET in a Corona Discharge path. Corona Discharge is caused by a positively or negatively charged surface discharging into small ionic molecules in the air (CO_2+, H+, O_2-, OH-).

Is ESD Really a Problem?

As previously mentioned, when dealing with small quantities of MOSFETs, ESD may not seem to be a problem. The results in this case may be occasional unexplained failures. When dealing with very large quantities, particularly when quality is of prime consideration, ESD can be a real problem.

The graph in Figure 4 gives a good graphical illustration of the magnitude of the problem and its solution. This graph was derived from data taken at an internal point of International Rectifier's manufacturing facility and does not represent the much lower AOQL levels. Between April 1982 and October 1983, gate-related failure dropped by nearly a factor of 7 at this inspection point as a direct result of the institution of ESD protective measures.

Of significant interest is the drastic increase of failures during the "witche's wind" period of October through December of 1982 in El Segundo, California. These winds cause extremely low relative humidity (RH) which tends to aggravate the ESD problem. Effective control of ESD during a similar weather period of October through December of 1983 is evidenced by no significant increase of failures.

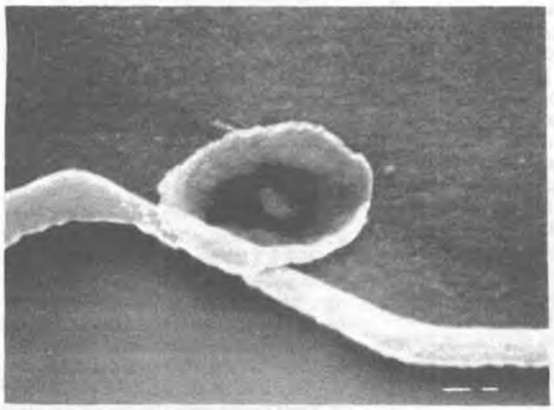

Figure 2a. Typical ESD Failure Site

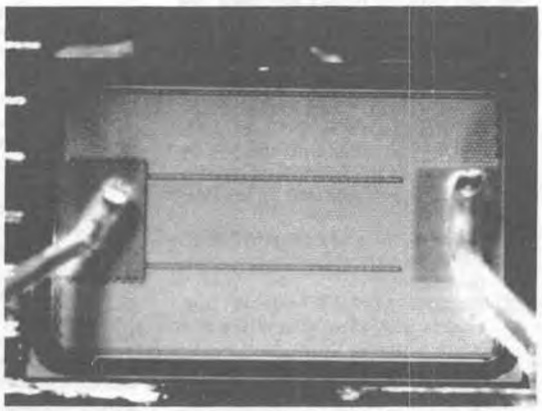

Figure 2b. ESD Damaged Device at Low Magnification before Stripping

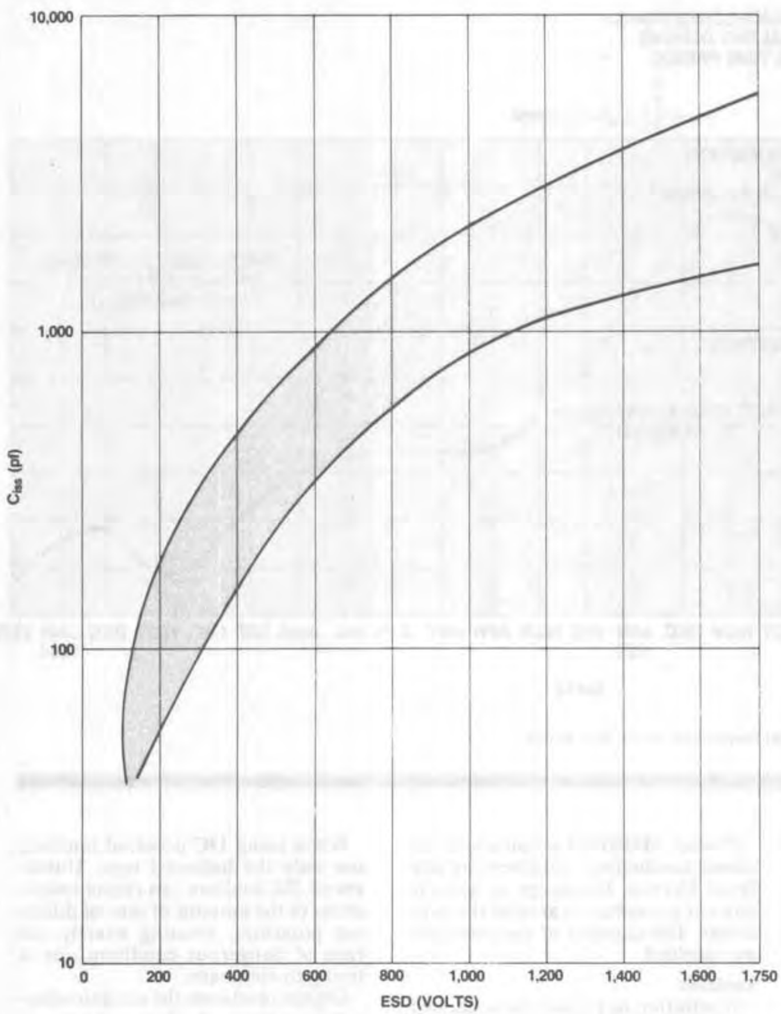

Figure 3. C_{iss} versus ESD Failure Voltage.

Materials and Methods for ESD Control

Direct Protection Method

In protecting any power MOSFET from ESD or any other excess gate voltage, the primary objective is to keep the gate-to-source voltage from exceeding the maximum specified value (± 20 for HEXFETs). This is true both in and out of circuit.

Direct protection of the MOSFET could involve methods such as shorting the gate to the source, or applying zener protection gate-to-source. While effective for in-circuit or small quantity applications, the direct method is usually impractical in the manufacturing environment because of the large volume of power MOSFETs involved. The basic concept of complete static protection for the power MOSFETs is the prevention of static build-up where possible and the quick, reliable removal of existing charges.

Materials in the environment can either help or hinder static control. These may be placed into four categories of surface resistivity: Insulating (>10^{14} ohms/Sq.*), Anti-Static (10^9-10^{14} ohms/Sq.*), Static-Dissipative (10^5-10^9 ohms/Sq.*), and Conductive (<10^5 ohms/Sq.*).

Ideally, to protect the HEXFET, one should have only grounded conductive bodies in the facility. Additionally, all personnel involved in the manufacturing process should be hard grounded. Unfortunately the humans involved in the manufacturing process would then become vulnerable to electrocution by faulty electrical equipment. Also, when traveling long distances, it can be difficult to maintain a ground connection. Consequently, protective materials and methods must be chosen based on the situation.

Insulating Material

Because of their propensity for storing static charges and the difficulty with discharging them, it is imperative to keep objects made of insulating materials away from power MOSFETs and out of the environment entirely, if possible. Since electric current cannot flow through an insulator, electrical connections from an insulator to ground are useless in controlling static charges.

Insulating materials include: polyethylene (found in regular plastic bags), polystyrene (found in Styrofoam cups and packing "peanuts"), Mylar, hard rubber, vinyl, mica, ceramics, most other plastic, and some organic materials.

When plastic products must be used in a power MOSFET handling facility, use only items impregnated with a conductive material and/or treated with anti-static compounds.

Anti-Static Material

Anti-static material is resistant to the generation of triboelectric charges, but does not provide a shield from electric fields. Corona Discharge will pass right through an anti-static enclosure, possibly destroying any MOSFETs which are inside. Because of its high surface resistivity, grounding anti-static material is not very effective for removing a charge.

Some plastic insulators can be treated with anti-static agents which chemically reduce their susceptibility to triboelectrification and lower their surface resistivity. Most anti-static agents require high relative humidity (RH) to be effective. Therefore, the RH of facilities where power MOSFETs are handled should be kept above 40%. Also, anti-static agents tend to wear off or wear out after a period of time, and most of them use reactive ionic chemicals which can be corrosive to metal. Anti-static plastics should be limited to short-term use in one-time only situations, such as DIP and TO-3 tubes and packing materials for shipping.

**The size of the square does not effect the surface resistivity.*

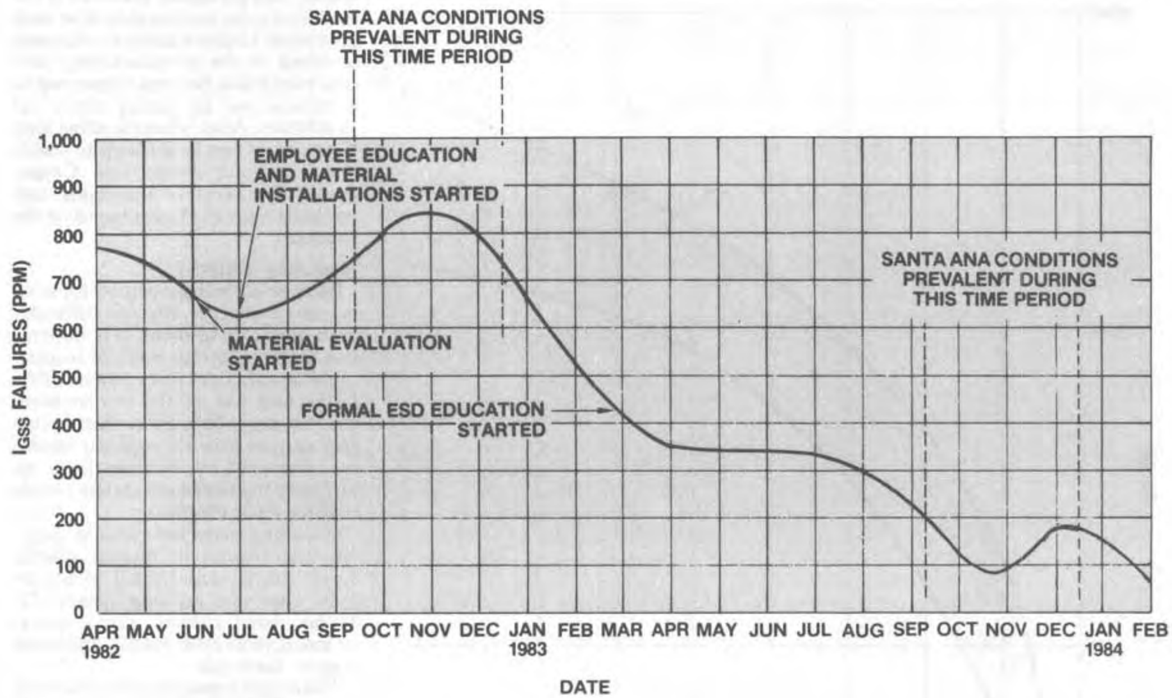

Figure 4. Gate-Related Failures at an Internal Inspection Point. Not AOQL.

Static-Dissipative Material

Static-dissipative materials are effective for application on any surface to facilitate the removal of static charges by conducting them to ground. It is possible to generate triboelectric charges in static-dissipative materials but the charges will be dissipated throughout the material and can easily be discharged to ground. Static-dissipative material is suitable for use in or on floors, table tops and clothing[1].

Conductive Material

Conductive materials are suitable for use in the construction of enclosures for storing or transporting power MOSFETs. Like static-dissipative materials, conductive materials are susceptible to triboelectrification but can easily be discharged to ground.

Plastic, though normally highly insulating, can be made conductive when manufactured from carbon or metal impregnated base material. Conductive tote bins and bags are constructed from these materials. Containers should be constructed such that the conductive elements will not separate, migrate, or otherwise contaminate the environment.

Power MOSFETs contained in closed conductive containers are safe from Corona Discharge as electric current is conducted around the container. The contents of the container are shielded.

Ionizers

In addition to passive static control by proper material selection, active controls may sometimes be necessary or advantageous. Ionizers are a form of active static control.

There are three basic types of ionizers: AC, DC, and Nuclear. Ionizers are intended to produce large and equal quantities of positive and negative ions. When used to neutralize a specific object, the object tends to attract only those ions necessary for neutralization. Excess positive or negative ions either tend to find each other or ground.

Nuclear ion sources should be avoided, if possible, because of real or imagined concerns of employees over radioactive contamination[2]. Although reported to be harmless, small amounts of Polonium used for static neutralization purposes can be shown to cause radiolysis in some organic materials in its proximity.

When using DC powered ionizers, use only the balanced type. Unbalanced DC ionizers can create imbalances in the amount of ions of different polarities, creating exactly the type of dangerous condition one is trying to eliminate.

Objects, and even the air, can sometimes acquire a charge from an ionizer. Also, they create minute but compoundable amounts of poisonous ozone[2,3], and ionic imbalances have been shown to create mild neurological and biological disturbances in humans[4]. Consequently, ionizers of any type should be avoided for general room area or direct personnel neutralization.

Never use ionizers where there is possible contact with moisture.

Facility Preparation

Floors

The foremost consideration is to prevent the generation of triboelectrically induced static charges in the first place. A good place to start is with the use of grounded static-dissipative floor coverings or treatments.

Conductive floor tiles are the most

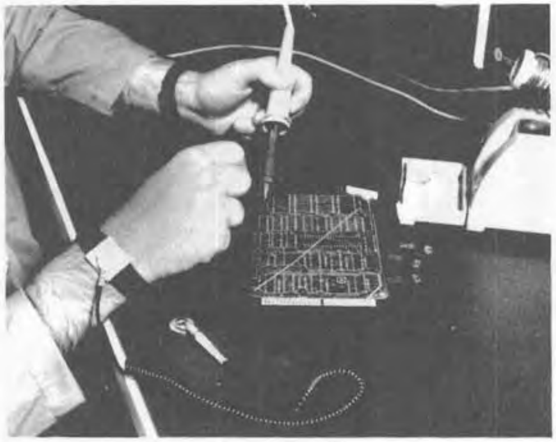

Figure 5a. Static dissipative table mat with typical wriststrap grounding. Always use a grounded soldering iron.

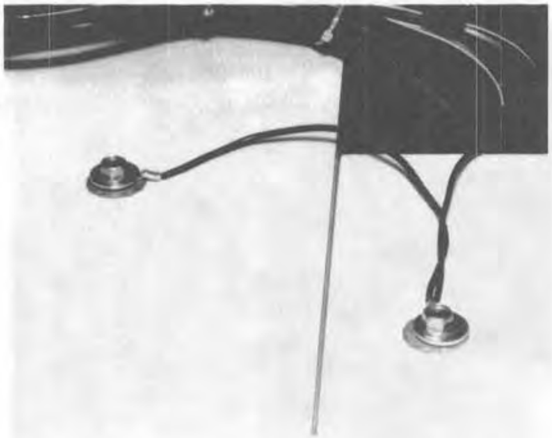

Figure 5b. Static dissipative tabletop laminate with typical grounding.

permanent solution, but their cost tends to be prohibitive unless the installation is on a new floor. Floor mats, conductive or static-dissipative, can be used but may constitute a safety hazard with curled-up edges or corners. One suitable and cost-effective method is to use a static-dissipative floor finish.

A static-dissipative floor finish can provide an aesthetically pleasing finish which has a surface resistivity that remains well within the static-dissipative range for about two months of normal pedestrian traffic. Grounding of a static-dissipative floor finish can usually be accomplished through incidental means. Since it is applied as a liquid, it tends to slosh into grounding rods or other static control ground points.

Tabletops

Grounded, static-dissipative tabletops should be used at every work station where power MOSFETs are handled, whether they are in or out of protective containers.

Two types of tabletop surfaces have been found to be effective by International Rectifier's Test Engineering Group. As with floors, the most permanent solution is static-dissipative tabletop laminant (see Figure 5b). New benches can be ordered with a static-dissipative surface, and old benches can be resurfaced. Alternatively, benches can be covered with soft, static-dissipative mats (see Figure 5a). Mats, however, should be avoided where they may be exposed to heat or chemicals.

Metal tabletops should never be used in place of static-dissipative ones, as they are far too conductive and therefore present a shock hazard where electrical equipment is used. The ideal work surface should fall within the static-dissipative range[1].

Containers

Power MOSFETs should always be stored and transported in *closed* conductive bags or containers. MOSFETs contained in anti-static tubes or bags should be stored and transported in closed conductive bags or containers. See Figures 6a and 6b.

If power MOSFETs are to be stored in a dry atmosphere, such as nitrogen (N_2), the gas should be ionized going into the bag or dessicator to prevent static build-up in the container.

Conductive bags and containers should never be opened except at a static-controlled work station and only after the bag or container has been placed on a grounded static-dissipative surface. See Figure 6c.

Personnel

Static protection as pertaining to personnel involves: prevention of static build-up, dissipation of existing static, and training.

Materials found in most outer garments constitute an ESD hazard. Typical lab coats of a cotton-polyester blend have been found to store charges of up to 5,000 volts. Static-dissipative lab coats or smocks should be supplied to employees, as this will shield the environment from personal clothing.

Gloves should be worn only when necessary for cleanliness, since the surface resistivity of the human body falls within the static dissipative or conductive range.

Removal of existing charges can be effected with wrist grounding straps. Grounded wrist straps should be worn whenever physically possible. See Figures 5a, 6c, 8b, and 9. Ground straps and grounded table-top surfaces should have at least 1 megohm of resistance to ground to prevent shock hazard.

Training personnel is essential to ESD control. Carefully installing the most expensive ESD protection available will be useless if employees are not educated in the necessity, and use of, ESD protective techniques. Also, a certain resistance to change must be overcome on the part of the employee. ESD demonstrations have proven especially helpful in gaining cooperation from those who handle HEXFETs at IR. Refer to the Document

Figure 6a. Anti-Static "DIP" tubes in a conductive bag.

Figure 6b. Conductive Bins

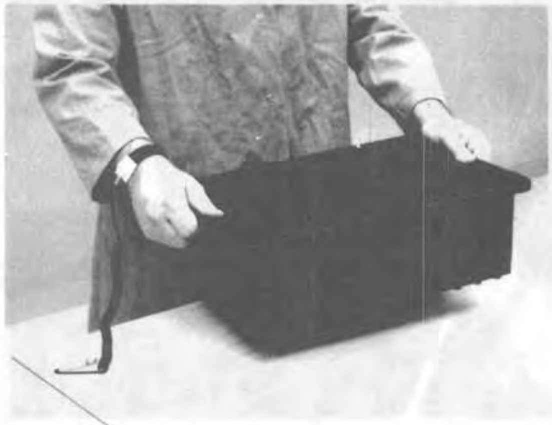

Figure 6c. Handling

Index for reference and reading material.

Grounding

Although grounding has thus far been only casually mentioned in conjunction with ESD protection, it is essential. Earth ground rods for ESD protection should be solid copper or copper-jacketed steel and should be driven six to eight feet into the earth beyond the building slab with approximately six inches exposed above the floor for making connections (see Figure 7). Dry soil conditions may require a copper sulfate drip. Electrical grounds should be isolated from static control grounds. Water pipes should *NEVER* be used to terminate static control grounds since they may not be connected to ground.

These grounding methods may seem excessive since the ground rod may be in series with 1 megohm or more of resistance. However, these techniques are for minimizing the difference of potential between separate grounds and not for reducing the ohmic resistance to earth.

Ionizers

Ionizers should be installed where necessary for dedicated applications. For example, it may be advisable to

Figure 7. Typical static control ground connection

Figure 8a. Automatic Tester for HEXDIPs using Anti-Static Feed and Bin Tubes.

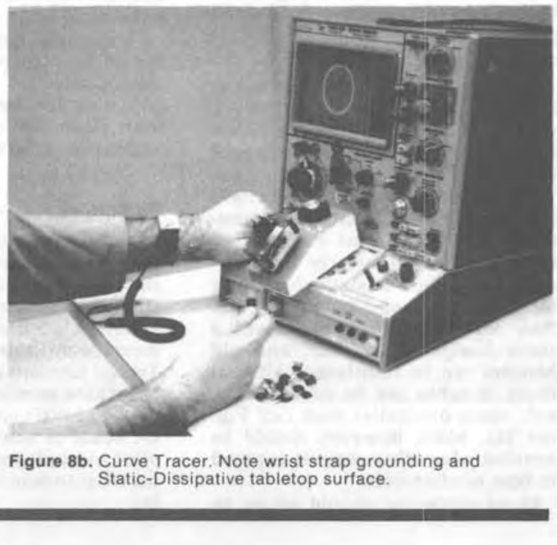

Figure 8b. Curve Tracer. Note wrist strap grounding and Static-Dissipative tabletop surface.

use an ionizer on PC boards where MOSFETs are to be mounted. Ionizers should be used for neutralizing any specific inanimate object in the environment which cannot be controlled by any other means.

Test Equipment

Test equipment should be placed on grounded static-dissipative floors or tabletops. Operators should wear a static-dissipative or anti-static garment and a ground strap at all times. Automatic testers and handlers should have anti-static feed paths and receptacles for MOSFETs (see Figures 8a and 8b).

Complete ESD Protection

The most effective protection from ESD occurs when the total environment is under control. Changing only the floors or just the tabletops is not enough. When all of the appropriate ESD protection devices are used simultaneously and in conjunction with trained personnel, ESD damage can be reduced to negligible levels.

Document Index

Text References

1. Fuqua, Norman B., "ESD Protective Material and Equipment: A Critical Review," Reliability Analysis Center State-of-the-Art Report, Spring, 1982, pg. 16.
2. Antonevitch, John N. and Blitshteyn, Mark, "Measuring Effectiveness of Air Ionizers," Proc., Reliability Analysis Center, EOS/ESD Symposium, 1983, pp. 77, 78.
3. Mykkanen, C. Fred and Blinde, David R., *The Room Ionization System: An Alternative to 40 Percent RH,* Evaluation Engineering, September 1983, pp. 86, 87.
4. Donsbach, Kurt, W. and Walker, Morton, "What You Always Wanted to Know about Negative Ions," The International Institute of Natural Health Sciences, Inc. Copyright 1981.

Recommended Reading Materials

1. Yenni, Jr., D.M. and Huntsman, J.R., "The Deficiencies in Military Specification MIL-B-81705: Considerations and a Simple Model for Static Protection," Proc., Reliability Analysis Center, EOS/ESD Symposium, 1979.
2. Military Specification MIL-M-38510, Revision E, Section 5.
3. Yenni, Jr., Don M., "Basic Electrical Considerations in the Design of a Static-Safe Work Environment," Presented at 1979 Nepcon/West Conference, Anaheim, California. Copyright ISCM, pg. 2.
4. Gruchalla, Michael E., "Electrical Grounding in Large Instrumentation Systems," Proc., Reliability Analysis Center, EOS/ESD Symposium, 1982.

Specification References

1. DoD-HDBK-263, 2 May 1980
2. DoD-STD-209
3. FED-STD-209
4. MIL-B-81705
5. MIL-M-38510, Revision E
6. MIL-M-55565
7. MIL-STD-883B
8. Defence Standard 59-98, Ministry of Defence, Crown, Copyright 1979.

Manufacturers' Index

The following incomplete manufacturers' index is given as a starting reference for procurement of ESD protective devices:

Charleswater Products, Inc.
93 Border Street
West Newton, Massachusetts 02165

Products:
STATGUARD® Floor Finish
MICASTAT® Amino Resin Tabletop Laminate
STATSHIELD® Conductive Transparent Bags
STATFREE® Conductive Foam

Semtronics Corporation
P.O. Box 592
Martinsville, New Jersey 08876

Products:
ENSTAT™ Ribbed Conductive Rubber and Vinyl Floor Mats

Vinyl Plastic, Inc.
P.O. Box 451
Sheboygan, Wisconsin 53081

Products:
Conductile™ Conductive Vinyl Tile

Simco Company, Inc.
2257 North Penn Road
Hatfield, Pennsylvania 19440

Products:
Electrical Source Ionizers

Static Control Systems/3M
22-2SW, 3M Center
St. Paul, Minnesota 55144

Products:
8200 series table mats
2068 series wristbands
2100 series conductive transparent bags
VELOSTAT™ conductive bags
Nuclear source ionizers
Conductive tote boxes
Conductive foam

Olympic Plastics Company, Inc.
5800 West Jefferson Boulevard
Los Angeles, California 90018

Products:
Protect-O-Stat™ conductive tote boxes

Meritex Plastic Industries, Inc.
3301 E. Randol Mill Road
Arlington, Texas 76011

Products:
Anti-static DIP and TO-3 tubes

ADE, Inc.
1560 East 98th Street
Chicago, Illinois 60628

Products:
Cancel-3™ anti-static cushioning material

Angelica Uniform Group
700 Rosedale Avenue
St. Louis, Missouri 63122

Products:
FREOSTAT™ smocks and lab coats
ASQ-100™ cleanroom garments

FLUORWARE
Jonathan Industrial Center
Chaska, Minnesota 55318

Products:
STAT-PRO™ 100 wafer carriers
STAT-PRO™ 150 chip trays