

# Static Control in the Factory

By Glen Dash

Note: Material may be dated.

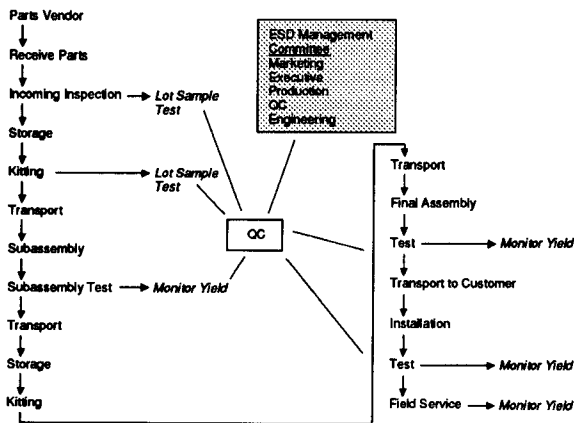
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**A** knowledge of what causes electrostatic discharge (ESD) and a plan to control it are vital to efficient manufacturing and to product reliability. Electrostatic discharges can damage sensitive parts, leading to low manufacturing yields, high rework costs, and poor product reliability.

Electrostatic problems are generally caused by triboelectric--or frictional--accumulation of excess charge. Nearly all electronic parts are susceptible to ESD. Moreover, most semiconductors can be damaged by discharges which are below the level of human perception, which is approximately 3 kV. During the manufacturing process, and during field service, components are unprotected and particularly vulnerable to discharges. The effects of a discharge may be obvious or insidious. An ESD event may produce outright component failure, or worse, result in "latent" damage which causes the affected part to fail soon afterwards in the field. This ESD-caused infant mortality can be especially expensive to repair.

The benefits of a static control program far outweigh the costs. For these benefits to be realized, however, the program must provide door-to-door protection from the receipt of components to the shipping of the finished product. Each stage of the manufacturing process must be inspected for potential ESD hazards. Protection measures include special materials, packaging and handling procedures, control of static buildup in the environment, and the use of ESD-protected work areas.



**FIGURE 1:** In designing a static control plan, ESD is a factor at every stage of the product's life.

## How ESD Damages Components

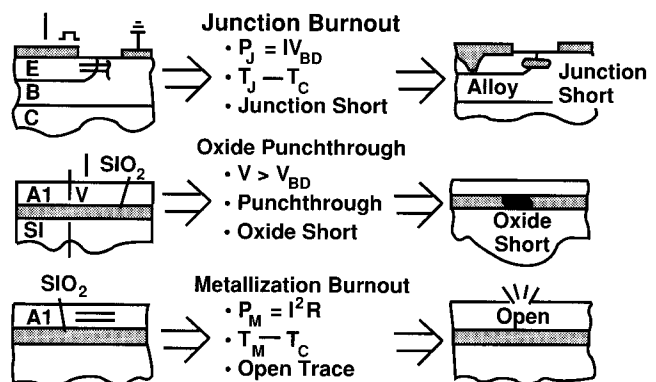
Electrostatic discharge damage can be understood at macro- and microscopic levels. At the macro level, we are concerned with the manner in which damage-causing charges may be delivered. There are four categories, or "models":

- **Field-induced model:** This model applies when damage is caused by intense external electric fields. The fields, due to charge concentrations in the environment, induce asymmetric charge distributions on the target components. Only the most sensitive components tend to be damaged this way.
- **Human body model:** Damage is caused by discharge from a worker. To a first approximation, the worker can be modeled by a bulk capacitance of 100 to 150 picofarads, with a discharge resistance of several hundred ohms.
- **Furniture discharge model:** Caused by the movement of furniture. For example, equipment carts can build up charge through the friction of their tires. If a discharge from such a cart occurs, it will be very brief and extremely intense.
- **Charged device model:** This mechanism describes self-damage by charged components. Consider an integrated circuit acquiring charge upon sliding out of its storage tube. If that device falls on a large conductive surface, the charge will quickly transfer, and device damage can occur.

All of these events can occur in the workplace. Fortunately, their prevention rests on a common principle. Charge buildup should be controlled, and any charge concentrations that do accumulate should be dissipated gently.

At the microscopic level, three primary damage mechanisms have been observed. *Junction burnout* occurs when a semiconductor junction carries high current. If the current density is high enough, thermal secondary breakdown will occur, destroying the junction by melting (see Figure 2). This failure mode is common to bipolar (TTL) devices. Bipolar junctions are especially sensitive to reverse bias surges.

*Dielectric breakdown* occurs when potentials are strong enough to punch through the insulating silicon dioxide layer which isolates the gates of FET-type semiconductors. Although silicon dioxide



**FIGURE 2:** Electrical-overstress-induced failure mechanisms (courtesy of D.G. Pierce).

has a high dielectric breakdown, the layers are extremely thin, and punch-through voltages will sometimes be under 50 volts.

A further mechanism, *metallization melt*, can occur when high currents cause bond wires or metallization barriers to act as fuses.

### Protection Through Packaging

Protective packaging of components during transport is an integral part of static control. Packaging materials come in many forms. Included are films, bags, rigid and flexible foams, and tote boxes. The packaging material is evaluated for two types of

performance. First, its resistivity must be neither too high nor too low. An insulator will not dissipate charge, while a highly conductive material may actually promote ESD damage by allowing high current discharge to occur. Second, a material's triboelectric properties must also be considered.

The Electronic Industries Association (EIA) standard, EIA-541, "Packaging Material Standards for ESD Sensitive Items," categorizes materials by their resistivity. Most commonly used materials are in the dissipative range. Some less conductive materials, popularly known as antistatic, fall in the range of  $10^{12}$  to  $10^{14}$  ohms. While antistatic materials are favored by some, recent industry practice has tended to favor materials in the dissipative range. At the other end, we have highly conductive materials. These materials are capable of providing shielding from external fields as well as charge dissipation but, as noted, high conductivity packaging materials have their limitations.

A material's resistivity can be expressed on a volume or a surface basis. For uniform sheet materials, surface resistivity, expressed in ohms per square is a convenient and easy-to-measure parameter. One method for measuring surface resistivity utilizes the concentric circular probe described in ASTM-D257. Two circular electrodes are pressed on the sample and attached to a high impedance ohm meter. It is important to remember that surface resistivity is a valid characterization only for uniform materials. Some materials are inherently non-linear and behave differently as current densities change. Other materials are physically nonhomogeneous. Still other materials may be nonhomogeneous because of a laminated construction. Here too, surface resistivity measurements may give misleading results.

A material's resistivity tells us how rapidly it dissipates accumulated charge, but that is only half of the story. Other measurements focus on the material's propensity to acquire charge by triboelectric action. There is little correlation between a material's resistivity and this propensity when subjected to friction with itself or other materials. The amount of charge that builds up is highly sensitive to the materials involved and the details of their physical interaction. EIA-541 suggests several application-specific tests. To prevent charge device model (CDM) damage, the test device is slid from its holder and dropped into a Faraday cup attached to an electrometer, and any acquired charge is measured. Protective bags can be subjected to a "bag shaker" test. Test disks of quartz and teflon are subjected to a cycle of 30 shakes and the accumulated charge on the disk is measured in a Faraday cup. This yields a material figure of merit expressed in units of charge per unit area.

This figure can be used to compare different material types and extrapolated to estimate the protection afforded to typical electronic components.

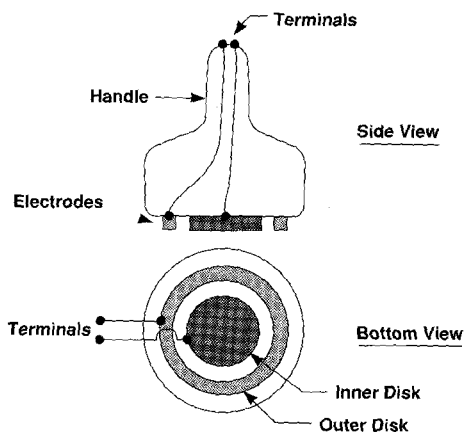
Other measures of a material's ESD protective ability look at its dynamic resistivity characteristics. One method, modeled on Federal Test Method 4046, checks to see if a material exhibits non-linear behavior. A material sample is charged to 5 kV and then allowed to discharge. The potential of the sample is monitored with a non-contact electrometer. The goal is to detect deviations from purely resistive behavior, such as low level charge retention.

### Controlling the Environment

Protective materials are needed for safe transport. However, components will be moved from that protection during the manufacturing process. In an unprotected environment, there are numerous ESD hazards. Humidity is one major environmental factor that can easily be controlled. Water vapor gives rise to ions that partially neutralize charged surfaces. Raising the relative

|  |                              |                             |  |
|--|------------------------------|-----------------------------|--|
| <b>Antistatic Properties:</b> All Materials Characterized by Faraday Cup Triboelectric Tests |                              |                             |  |
| <b>Resistivity Properties:</b>   |                              |                             |  |
|  | <b>Dissipative Materials</b> | <b>Conductive Materials</b> | <b>Electrostatic Shielding Materials</b> |
| Volume Resistivity (Ohm-cm)  | $10^4 - 10^{11}$             | $< 10^4$                    | $< 10^3$                                 |
| Surface Resistivity  | $10^5 - 10^{12}$             | $< 10^5$                    | $< 10^4$                                 |
| Secondary Tests (Optional)   | Static Decay                 | —                           | Electrostatic Probe Test                 |

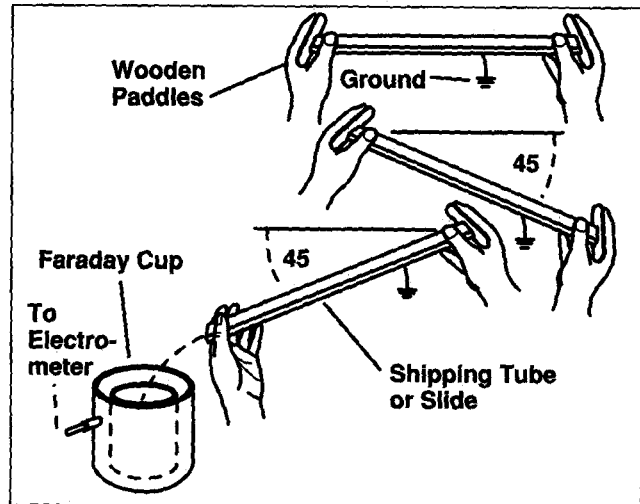
**FIGURE 3:** Material resistivity is a major classifying factor for static protective materials.



**FIGURE 4:** Design of the concentric ring probe of ASTM Standard D-257 used for measuring surface resistivity. A calibration factor corrects for the circular geometry.

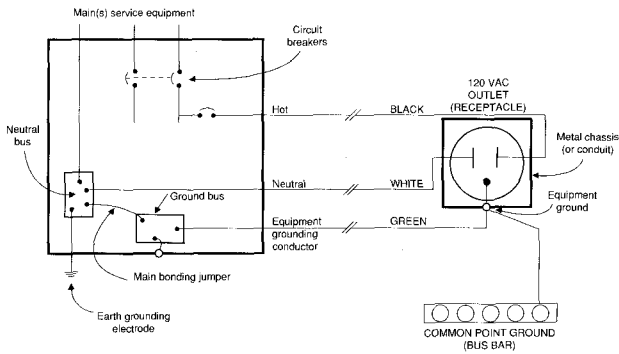
humidity to 40% or 50% is an effective first step for controlling ESD.

Often, humidity control alone will not suffice. A higher density of ions can be introduced with air ionizers. These ionizers can be found in static, electric, or radioactive varieties. Static ionizers



**FIGURE 5:** Component magazines are tested by measuring the charge picked up by a test device after six slides.

ESD/Immunity Reference



**FIGURE 11:** Ground and neutral wiring is supposed to be kept separate, with interconnection occurring at the service box. This schematic shows the wiring that would be typical of a 117 VAC circuit. Note that the equipment ground is connected to the ESD workstation common point ground.

ground from the hand opposite the wrist strap should not exceed 9 megohms. It is best to check this resistance frequently at the actual workstation where the wrist strap is used. Some manufacturers have installed common wrist strap continuity testers where workers check in on a daily basis. This is less satisfactory than checking in situ, as the ground connection through the workbench is not verified in a remote test.

The workstation itself is also of paramount importance. The centerpiece of an ESD workstation is the grounded static dissipative work surface.

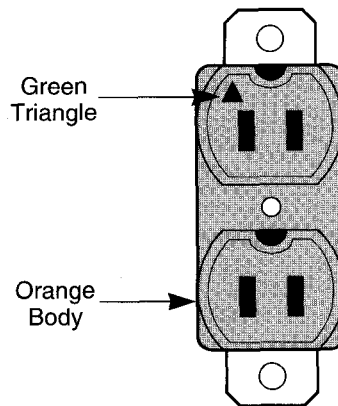
EOS/ESD Standard 4.1 provides a good guide to work surface evaluation. It is essentially a resistance-based method. Resistance measurements are taken on prepared work surface samples using a pair of 2.5" diameter electrodes weighing 5 pounds. The standard provides standardized procedures for qualifying new materials, qualifying new work surfaces and performing ongoing validation of existing installation. The resistance of a series of well-defined surface-to-surface and surface-to-grounding point paths must be between 1 megohm and 10,000 megohms.

EOS/ESD Standard S6.1-1991, "Grounding--Recommended Practice," outlines the details of grounding workstations and linking them together to form a facility ESD ground. The key idea is that a reliable, "hard" ground of less than 1.0 ohm should be used. This is not at odds with the prescription to use resistive grounding for ESD control. It simply places the burden for providing a resistive path on the protective equipment, rather than sharing it with the facility ground system. This yields better definition of the actual ground path resistance.

To ensure a robust ground, S6.1-1991 recommends the use of a single point ground connection at workstations (Figure 10). A typical ESD-protected area will have a variety of protective devices requiring ground connection. Since the resistivity of ESD protective materials is moderately high, the exact details of the grounding are not usually critical. Still, careless technique, such as the serial connection of several high resistance protective devices, can seriously erode the ESD protection afforded by the grounding system. The use of a single point workstation ground lets each protective device function as intended.

Each ESD protected work area is then connected to the facility ground, which serves as a large charge reservoir. In fixed installations this will be an earth ground; in vehicular equipment it will be the vehicle ground.

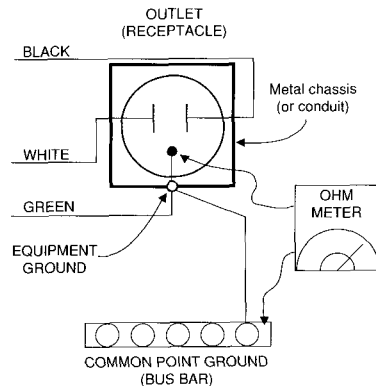
In a building, the default ground is the electric power ground. In addition, auxiliary ground connections may be available, and can be connected in parallel if desired. All connections should have a resistance under 1.0 ohm. Figure 11 shows the schematic of hot/neutral/ground wiring in a 117 VAC circuit. Neutral and ground wires are kept separate, and are returned to their own buses inside the service box. Inside the service box, they are connected together via the main bonding jumper. Under normal conditions, current does not flow in the ground lead. Power flows through the hot lead and returns via the neutral. The separate ground lead absorbs leakage and fault currents, and is also used for making the ESD ground. The standard notes that isolated ground receptacles should not be used to derive an ESD ground, as such use may degrade the isolated ground's performance.



**Notes**

1. Not to be used to derive an ESD ground
2. Receptacle body and triangle colors may vary

**FIGURE 12:** The standard advises against using the ground in an isolated circuit for ESD grounding purposes. Isolated receptacles are marked with an identifying triangle.



**FIGURE 13:** The basic test of a connection's quality is its resistance. It should also be mechanically strong and secure.

For safety reasons, it is important to check that the ESD ground is not connected to the wrong leads. Before connecting the ESD ground, verify that:

- Neutral and equipment grounding wires are present and separate in the outlet
- Hot and neutral wires are not reversed
- Hot and ground wires are not reversed (unlikely, but dangerous!)

Once wiring has been verified, the power and workstation grounds may be connected. Resistance is then checked using a meter capable of measuring from 0.1 ohm to 1 megohm. If a ground impedance meter is used, it should be capable of measuring up resistances below 1.0 ohms.

ESD protection does not merely stop with the wrist strap and work surface. ESD protective tools are also available. Soldering irons, desoldering tools, equipment racks, and tape dispensers are all available in static-protected form. In extreme cases, such as clean rooms, where ESD must be held to very low levels, it may even be necessary to clothe workers in static dissipative garments.

### Team Effort is Required

An ESD control program can yield large benefits. ESD control is based on the simple principle that charge generation should be controlled whenever possible, and dissipated gently when necessary. The program must be thorough to be effective. All aspects of the manufacturing process should be investigated for potential ESD hazards. It is also important to realize that ESD control is an ongoing process. Equipment must be maintained, and personnel must be trained in the why and how of its use. An ESD program that is put in place and forgotten is a program that will soon lose its effectiveness. An ongoing ESD committee should be established to monitor the program. Auditing of worker technique is recommended, as is ongoing training. Yield sampling throughout the production process provides valuable feedback. Sudden yield deteriorations may have many causes, but ESD will always be one of the usual suspects.