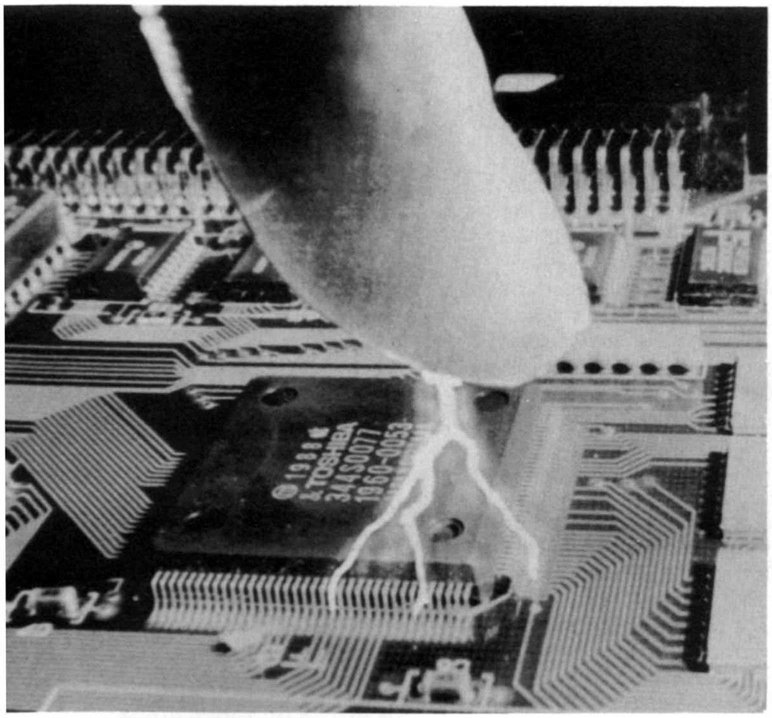

ESD—Electrostatic Discharge—*Part 1*

Here's how electrostatic discharges are generated, how they affect electronic equipment, and what steps you can take to minimize ESD damage.

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Until about 10 years ago, any discussion of safety precautions to be observed when working with amateur communications equipment was typically centered around how to prevent serious personal injury from high-voltage power supplies. To the contemporary technician working with today's low-voltage, high-density, solid-state components, safety precautions now also bring to mind static-dissipative floor mats, grounding wrist straps and conductive circuit-board carriers. These safeguards are all designed to protect sensitive electronic components from the effects of electrostatic discharge (ESD), a phenomenon to which some authorities attribute between 5 and 25 percent of all device failures.[1]

ESD Generation

Static electricity is a normal part of our environment.[2] Anyone who has been shocked when reaching for a metal doorknob after walking across a carpet on a dry, crisp, winter day has experienced an ESD first-hand. Whenever a charged object approaches or passes near another object (triboelectric charging), or when two objects contact, rub together, and separate, there exists the possibility of an electrostatic discharge and its associated damage. ICs, transistors, and other electronic devices may become charged when they slide through nonconductive plastic storage tubes onto a conductive surface where they suddenly discharge—an ESD event.

When the relative potential difference between two surfaces is discharged (as when the two oppositely charged surfaces are brought into contact with each other), the electrostatic energy is transformed into heat, sound and broad-spectrum electromagnetic energy (the upper-frequency limit can easily exceed 1 GHz). The bright flash of lightning, the crackle of static heard on radio frequencies during a lightning storm, and the occasional fires caused by lightning strikes are all evidence of this energy transformation.

Relative humidity—the ratio of moisture actually in the air to the moisture it would hold if it were saturated at the same temperature and pressure—has a significant effect on charge accumulation (see the sidebar, "Humidifiers and ESD").[3] Because a high relative humidity can render plastic films, polyurethane foams, and other insulators partially conductive, maximum electrostatic potentials in the 65% to 90% relative-humidity range are significantly below those possible in low relative-humidity environments. Radio amateurs in New Orleans, Louisiana, and Tucson, Arizona, will therefore have strikingly contrasting perceptions of—and attitudes toward—the potential for ESD damage. As

[1]Notes appear on page 21.

Humidifiers and ESD

Although a high relative humidity (on the order of 65 to 90%) can reduce typical electrostatic potentials from tens of kilovolts to one or two kilovolts, many semiconductor devices can be destroyed by only a few hundred volts. A conventional room humidifier should therefore be considered as only part of your anti-ESD arsenal—at best.

Home humidifiers are promoted as a means of avoiding drying of the skin and throat during the low relative humidity that's common indoors during cold weather. If you suffer from allergies, however, a humidifier can actually be *harmful* to your health, because house dust mites and molds (common allergens) thrive in humid conditions. In addition, conventional humidifiers can spray mold and bacteria into the air, resulting in frequent respiratory ailments.

Recently, ultrasonic humidifiers have become popular. Instead of relying on a mechanical agitator or drum to create a mist, ultrasonic humidifiers use a rapidly vibrating disc or nebulizer. Because this transducer is excited at 1 to 2 MHz, there is considerable risk of RF interference. (I have found, though, that the RF noise generated by the motor-speed controls of conventional humidifiers is worse than that generated by the ultrasonic transducer-drive circuitry.)

Although ultrasonic humidifiers generally kill any molds and bacteria in the water, they also eject dissolved minerals into the air. These minerals, predominantly calcium carbonate, settle on surfaces as a white dust. Harmless to humans, the dust can ruin VCRs, computers, and other electronic circuitry. Therefore, unless you can afford to fill an ultrasonic humidifier with several gallons of distilled water daily, keep it away from your amateur gear.—*NU1N*

I'll discuss later, perceptible discharges of several kilovolts are not necessary for significant ESD damage to occur, especially with the more-sensitive semiconductor devices. Even if you live in a climate with a very high relative humidity, you should not assume that your equipment is immune to ESD-induced damage.

Manifestations of ESD Damage

Walking across a carpet on a dry day (relative humidity of less than 20%) can generate an electrostatic charge approaching 20 kV, but many semiconductor devices can be damaged by far lower potentials. Gallium-arsenide (GaAs) devices can be damaged by a discharge as low as *5 V*. Even the more-robust bipolar transistor, with a minimum ESD failure voltage of approximately 300, can be damaged by the charge (up to 18 kV) generated by someone sitting on a polyurethane-foam-padded chair. MOSFET and CMOS devices can fail at ESD voltage levels of 100 and 200, respectively. Passive components, such as resistors, capacitors, and inductors, are also susceptible to ESD damage.

Gallium-arsenide devices can be damaged by a discharge as low as 5 V.

In assessing the threat of ESD-induced failure, you must consider not only the amplitude of the electrostatic voltage, but also the rise time, duration, and peak current of the discharge; the source impedance of the discharging body; the circuit characteristics and whether the charge enters the circuit via conduction or radiation. A person can be charged up to 20 kV, with a peak discharge current of about 20 A.[4] By comparison, metal furniture can be charged up to only about 8 kV, but peak discharge currents can exceed 150 A! Although radiated coupling (as when the electromagnetic field produced by an ESD is coupled into a circuit via cables) results in temporary circuit upset, permanent circuit damage is most likely with conductive (direct-contact) coupling.

The heat associated with an electrostatic discharge (as well as dielectric breakdowns caused by the high voltage differentials) are the major threats to semiconductor devices, such as high-density RAM and ultracompact microprocessor ICs. Even relatively low-voltage electrostatic discharges within a semiconductor device can produce sufficient heat to vaporize semiconductor material and the metal or polycrystalline silicon traces connecting them. The transients associated with ESD are of such brief duration (on the order of 100 ns or less) that heat cannot rapidly escape the immediate area of the semiconductor junction where the power is being dissipated, so part of the junction vaporizes. The power required to vaporize or otherwise destroy a semiconductor junction varies inversely with the pulse duration.

High voltage differentials can cause semiconductor junctions to *reverse avalanche*, a process in which electrons, accelerated by the fields associated with the high voltage differential, collide with atoms, thereby releasing more electrons, which repeat the sequence. The resulting current heats the semiconductor material, lowering resistivity, resulting in a concentration of current flow and localized heating. The semiconductor material melts along the high-current paths, leaving low-impedance shunt paths across the junction, rendering it useless. The larger the junction region, the higher the power level required to raise the local temperature to the melting point.

Insidiously, ESD-related failures are not always total or catastrophic, but can be partial or intermittent (see note 1). An intermittent failure can occur when a tract within an IC is only partially vaporized, and the device is operated such that the damage causes localized heating in the chip. Many apparently nonrepeatable failures of computer-based equipment have been attributed (rightly or wrongly) to ESD-related damage. Although ESD-induced failure can be verified by examining electronic components via electron microscopy, or by using liquid-crystal thermography to identify hot spots in functioning components,[5] such postmortem studies have little practical value to the amateur. What's more important is how to prevent damage from occurring in the first place.

Preventing ESD Damage

ESD damage can be avoided by eliminating potentially dangerous electrostatic buildups, by preventing the coupling of ESD-induced energy into sensitive circuits and components (see the sidebar, "Combatting ESD"), and by increasing the noise immunity of devices and circuits. Individual components and complex circuits can be designed to maximize noise immunity through the use of clamping elements between critical points and ground, and the judicious placement of traces on PC boards that may act as antennas for ESD-generated fields. Similarly, cables, circuit enclosures and power supplies can be configured to minimize noise pick-up. Software can also be designed to recover gracefully from ESD-induced errors. That is, programs should be designed not to allow wait states of unlimited duration or lockup.

Storage Precautions

Before considering ESD storage precautions, it's important to understand the terminology manufacturers use to classify materials designed for ESD work. Many materials are graded according to *surface resistivity,* measured in ohms/cm^2. Surface resistivity can be thought of as the surface resistance between two electrodes forming opposite sides of a square. Electrically conductive materials, sometimes marketed as "ESD shielding materials," have a surface resistivity of less than 100 kΩ/cm^2. *Static-dissipative* or "ESD antistatic" materials (which are somewhat less effective than electrically conductive materials for protecting circuits against

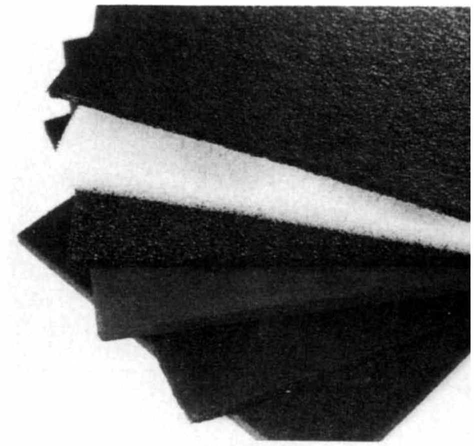
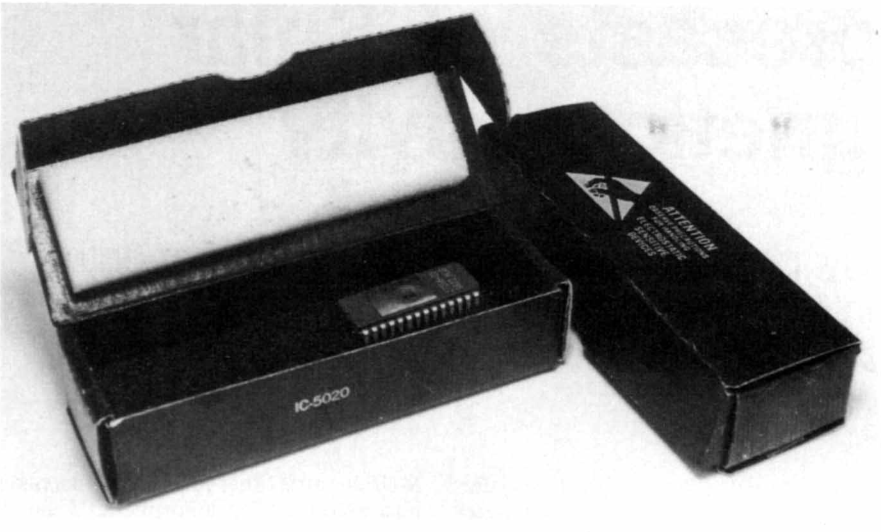


Fig 1—Conductive foam is produced in a variety of thicknesses, colors, densities, and surface characteristics.

Combatting ESD

Here are some steps that you can take to reduce the risk of ESD-induced damage:

- If you live in a dry environment, don't suffer from allergies or other respiratory ailments, and your house construction is sound, then consider using a room humidifier to increase the relative humidity to 65% or higher.
- Use grounded wrist straps when handling ESD-sensitive devices.
- Use grounded, anti-ESD work mats when troubleshooting sensitive circuits. One alternative to a commercial anti-ESD mat is to cover your work surface with a grounded metal sheet, but I feel uneasy about working with any type of circuitry near a low-resistance path to ground. Inexpensive anti-ESD coatings and paints may also be used to convert an otherwise insulating table top into a static-dissipative surface (assuming that you don't use your dining room table for a workbench).
- Use antistatic containers for storing and transporting static-sensitive components and circuits.
- Use a grounded soldering iron and antistatic tools when repairing and assembling static-sensitive circuitry.
- Connect the chassis of all of your electronic equipment—computers, transceivers and test instruments—to a good earth ground.
- If you spend a significant amount of time working with static-sensitive components, consider purchasing a desktop antistatic air ionizer to help remove static charges from tools, components, and other insulators on your workbench.—*NU1N*



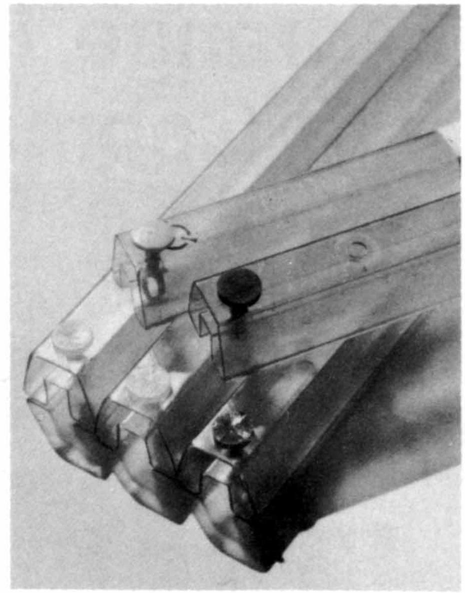


Fig 2—The lightweight and sturdy containers shown here are designed for mailing and storage of static-sensitive components.

some types of ESD-induced damage) have a surface resistivity of between 100 and 1,000,000 MΩ/cm².

Although an insulating barrier, such as a rubber or plastic film, can protect circuitry from the conductive coupling of an ESD, a conducting barrier, such as a metallized-plastic film, must be used to prevent the radiated coupling of ESD energy to a circuit or component. Storage precautions therefore include the use of conductive foam, circuit-board carriers, bins, storage cabinets, circuit-board racks, antistatic and shielding bags, and antistatic caps and plugs for nonterminated connectors, all appropriately connected to ground.

Anyone who works with solid-state components has seen the black, carbon-impregnated foam used for the storage and transport of transistors, ICs, and circuit-board assemblies (see Fig 1). Carbon impregnation reduces the resistance of the foam, effectively eliminating the possibility of interlead static accumulation. In addition to carbon, other elements and compounds can be used to reduce the resistance of antistatic foam.

Because both conductive and nonconductive foam are available in colors other than black, it's best to verify the conductivity of any foam that you plan to use to store static-sensitive components. With your VOM electrodes inserted into conductive foam (using an interelectrode spacing of an inch or so), the resistance reading should be about 20 kilohms or less. For conventional foam, the resistance ranges upward from tens of megohms. The point is: *Don't go by the color or texture of the foam to determine its antistatic properties*! When in doubt, use your VOM. Conductive foam is both an effective and inexpensive ESD storage precaution. A 2 × 3-foot sheet of ¼-inch-thick foam (a lifetime supply for most amateurs) sells for about $30.

Both electrically conductive and static-dissipative component storage bins, IC carriers (see Fig 2), and cabinets are constructed of carbon-impregnated plastic, painted cardboard, or metallized plastic. Although few of us are likely to have the volume of ICs and other solid-state devices needed to justify the cost of a static-dissipative cabinet, IC carriers have a place in almost every amateur's workshop. Inexpensive IC carriers, while providing ESD protection, also serve to protect the IC leads from bending and other physical damage, and provide a compact storage unit.

Fig 3—Static-dissipative circuit-board packaging makes use of a variety of materials. The padded circuit-board envelope (foreground) is constructed with a heavy, carbon-impregnated vinyl lining that is covered by a protective layer of air-filled cells. The three circuit-board jackets (background), while providing minimal padding, are also constructed of static-dissipative materials. The highly reflective metallized jacket (top left) provides a complete electrostatic shield, at the expense of poor circuit-board visibility. The jacket with the dark grid pattern (top center) formed by conductive traces impregnated into the otherwise nonconductive clear plastic, provides less-complete electrostatic shielding, but allows easy inspection of the enclosed circuit board. The nearly transparent jacket (top right), provides less electrostatic shielding than the other designs, but also minimally impairs visual inspection.

Antistatic and shielding bags (Fig 3) are an inexpensive (approximately $20/100 bags) and effective means of protecting circuit-board assemblies from static discharge. Because few board manufacturers ship unmounted boards without antistatic or shielding bags, they're relatively easy to collect. Though specifically designed to protect circuit-board assemblies from static discharge, these bags can also be used to hold discrete components. You can usually distinguish between antistatic and shielding bags by their opacity. The more-heavily-metallized shielding bags permit very little light to pass; antistatic bags are nearly transparent.

Next month, I'll have more tips on how to avoid ESD damage, tell you what tools you'll need for an ESD-safe workbench and where you can buy those tools.

Notes

[1]R. Antinone, "How to Prevent Circuit Zapping," *IEEE Spectrum,* Apr 1987, pp 34-38.

[2]On an ordinary day, going upward from the surface of the earth, the static electric potential increases by about 100 volts/meter; see R. Feynman, R. Leighton and M. Sands, "Electricity in the Atmosphere," *The Feynman Lectures On Physics* (Reading, MA: Addison-Wesley, 1977). Although this atmospheric static electricity is seldom noticed, discharges of static electricity from other sources are difficult to avoid.

[3]D. Hollander, "The Hidden Dangers of Electrostatic Discharge—ESD," *QST*, Mar 1987, pp 38-40.

[4]W. Boxleitner, "How to Defeat Electrostatic Discharge," *IEEE Spectrum,* Aug 1989, pp 36-40.

[5]M. Brenman and J. Mejerovich, "The Hedgehog Shape of ESD Failure," *Microelectronics Journal,* Mar 1989, pp 39-41.