Four Approaches to

Controlling Plastics ESD

HOW THE CAPACITY OF (PLASTIC-MOLDED) COMPONENT HANDLING SYSTEMS

TO HOLD AN ELECTROSTATIC CHARGE MAY BE DISSIPATED

OR MITIGATED FOR SAFE PROCESSING AND SHIPPING.

By: Mark T. Banks

Static electricity is a little like a bomb waiting to explode. Its energy, therefore, must be managed. The relevant question is: How can a material respond to electrical energy as a shock absorber reacts to mechanical energy? Or, foam rubber to audio energy? Or, more specifically, how far should resistance to electron flow be lowered?

Nature seems to have cast the *midrange* as best for buffering: Earth and water are good lightning absorption materials. Wet tree trunks range from 10^{10} Ohms to about 10^5 Ohms, damp ground is 10^5 Ohms to 10^6 Ohms and ponds and puddles are about 10^3 Ohms to 10^4 Ohms (see sidebar). For the same purpose, the designers of wrist straps for electrostatic discharge protection selected a 1M Ohm (10^6 Ohm) resister for insertion in the wire between the operator's wrist and "ground."

Figure 1. (above) A two part package: carrier tape and memory module trays. Parts are humidity independent, transparent, clean and washable.
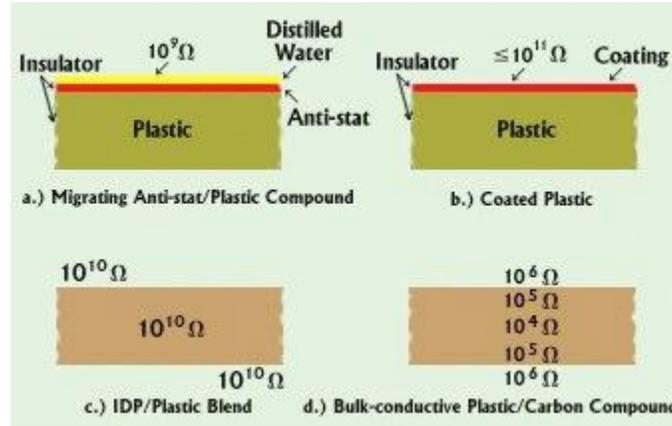
FOUR APPROACHES TO CONTROLLING PLASTICS ESD

Figure 2. Four ways to change ohmic value in plastic sheet include migrating antistatic/ plastic compound **(a)**, coating the plastic **(b)**, using an IDP/plastic blend **(c)** , and/or a bulk-conductive plastic/carbon compound**(d)**.

Four Solutions

Table 1 looks closer at the electron movement in the upper midrange of resistance. Electrons begin flowing slowly around 10^{13} Ohms and moves faster as the ohmic value drops. Many specifications require 5,000 V to drain off of a test surface in 2.0 seconds or less, and the specs often have a "relative humidity" aspect because water is the conductor in some "antistatic plastic" approaches. Accordingly, 10^{11} Ohms is the highest practical resistance in most "conductive" plastic applications, such as in device- or wafer-handling trays and reels (Figure 1). Plastics, or insulators, in that range and down to 10^6 Ohms are typically called "static dissipating," while lower ohmic material is generally termed "conductive." As is seen, there is no dramatic change at the intersection of the categories, but some distinction is made between "relatively slow" and "relatively fast." But, these are really only subcategories of the *buffer zone of resistivity* in the middle range of ohmic values **(Figure 2)**.

1, Pure Water. Some antistatic qualities are compounded into and slowly migrate out of plastic. Some are sprayed onto a plastic surface where they must "capture" a water network from the air.

TABLE 1

Electron Movement Increases as Resistance Drops

Ohms	5kV	Change Decay Rate
10^{18}	(Electret)	Never: ~ ∞
10^{16}		Forever
10^{14}		"Too Long"
10^{12}		~10 sec
10^{11}		~2 sec
10^{10}		~1 sec
10^{9}	(Distilled water)	~0.5 sec
10^{8}		~0.01 sec
10^{7}		~0.005 sec
10^{6}	("Natural" water)	~0.0001 sec
10^{5}		~0.00005 sec
10^{4}		~0.000001 sec
10^{-6}	(Gold)	"Very Fast"
$10^{-\infty}$?	(Absolute Zero)	Speed of Light, "C"

When compounded into plastic, the antistatic's migration time to the surface is often a function of the stress within the polymer, which varies with the production process (extrusion, injection molding, thermoforming or roto-molding). Once on the surface, however, the antistatic captures a distilled water molecule from the atmosphere where it is held when the ambient air dries.

Over time, as more and more water molecules are captured, a connecting network is formed and surface resistivity gradually declines to about 10^9 Ohms, the resisitivity of pure distilled water.

Occasionally, the captured distilled water molecules will attract "dirty" conductive water molecules which produce a surface below 10^9 Ohms. The water network can only be acquired from the air because liquid water strips the antistatics and delays the blooming process (i.e., antistatics migrating from the polymer matrix and onto the surface). The affinity between antistatics and water molecules is such that the presence of the latter on the surface will help the migration process.

2. Other Coatings. The coatings need not be antistatic; it can be a conductor other than water (metal, carbon, etc.). Applications usually dictate the suitability of a coating selection. Part geometry and mass-production techniques also are important considerations because the thin coating must conform to the part shape.

Shallow-draw thermo-forming is a common technique for coating plastics. Rolls of plastic sheets are uniformly coated, then thermos-formed so that the coating is shaped together with the plastic. The limitations of the process typically arise in the thin corners of a thermo-formed part such as a tray for QFPs: Thinning typically causes the resistance of the coating to rise, and is more than 10^{12} Ohms, the area could hold a static charge. Conversely, coatings are often the only way to get resistances below 10^{12} Ohms and retain clarity. A two-piece assembly can help manage this limitation.

3. Dissipative Polymers. Another approach is to compound a plastic with a special intrinsically dissipative (10^{10} Ohms) polymer , or IDP. Done correctly, the resultant blend is 10^{10} Ohms in three dimensions, i.e., electrons do not have to travel only on the surface of the plastic, and the chances of creating "hot spots" - possibly when coatings are stretched too thin by the thermo-forming process - are minimized. Because the IDP can be compounded into various base polymers, specific blends can be tailored to the application. (Some compounds are even sufficiently transparent for some see-through applications.) As with all compounds, the final blend has unique physical and mechanical properties. One of the primary attributes is that they do not contain carbon powder, which is not tolerated in some applications such as those in clean rooms.

4. Bulk-conductive Compounds. The oldest approach to rendering plastic less resistive is by compounding carbon powder into the polymer in amounts sufficient to achieve desired ohmic values. This produces a black plastic; hence, other additives are usually required to offset the physical property degradation caused by the carbon. Accordingly, the physical and mechanical properties of the base polymers are usually significantly different from those of the conductive compounded version of the polymer. Called bulk-conductive plastics, they have an unusual feature caused by the microscopic size of the carbon powder and the low thermal conductivity of plastic: the *ohm gradient.*

With bulk-conductive compounds, stress translates into ohms in the production (molding) process. The area near the gate of an injection-molded piece will be less conductive than an area further away where cavity melt pressure is lower. For example, the stretched sides of a thermo-formed tray are less conductive than its unstretched (thicker) flange, The tray side, which cools rapidly against tool steel, will be less conductive than the side that cools slowly in the ambient. As the "skin" of the bulk-conductive plastic, the exceptionally low thermal conductivity of plastic causes it to be the least conductive part of the piece.

The material *beneath* the skin, however, cools slower and is less stressed, i.e., it is more conductive and forms intrinsic ohm gradients. Thus, with the slowest cooling center of the plastic part the most conductive (because it is more annealed than the material surrounding it), an electron on the surface of a bulk-conductive part will gravitate to the lower-ohmic center, passing through the skin again if and when the part is "grounded." In effect, the ohm gradient creates a turbulent electron flow, permitting the electrons to be passively controlled. Interestingly, a hot-air gun can be used to "fix" the resistivity on the surface of a bulk-conductive part via careful annealing.

Wider ICP Application

New ICP technology has been making slow progress and most potential applications are precluded by very high cost and/or mechanical property limitations. These materials can be as low as 10 Ohms and can lead to an ingenious uses as economic considerations moderate.

While ICPs are not all suited to structural applications such as component trays and boxes, they do have promise as ESD coatings for other plastic materials. Some coatings employing ICP technology are transparent, humidity independent, clean, washable and light green (at 10^9 Ohms) or darker green (at 10^6 Ohms). This is the typical ohms/clarity trade-off of coated sheet for thermo-formed applications, and the ICP solution carries a very steep cost vs. ohmic-value relationship. The

thermo-formability of coatings is also at issue.

Carbon fibers may be compounded into plastics (usually high temperature thermoplastics) for conductive injection-molded applications. Fiber compounds are unsuitable for typical extruded/ thermo-formed applications because the fibers tend to align like logs in a river, causing both mechanical and electrical properties to be distorted by axis. The resistance of a carbon fiber/ plastic compound are very dependent on the length of the fiber in the part, and the conductive network mechanism is different from that formed by carbon powder. It is doubtful these compounds form ohm gradients because the fiber length is assumed to be uniformly distributed throughout the plastic matrix. Hence, resistance is uniform, as in the IDP compounds.

Static management can sometimes mean combining materials, as seen in Figure 2d. This two-piece package, having a clear 10^{10} Ohm lid and a bulk-conductive bottom, is a packaging scheme in which the bottom, with a 10^6 Ohm skin, will tend to draw any dust-collecting charge off of the clear lid. The charge on the 10^{10} Ohm lid will spread out slowly, then more quickly when it reaches the more conductive bottom. Logically, in time, the entire charge will drain from 10^{10} Ohm surface toward the 10^6 Ohm surface, and then into the bulk-conductive plastic. A package that draws electrons into its core material is obviously a better protector of static damage than one leaving the danger on the surface and near the contents of the package. This approach has the benefits of transparency, the buffering resistance of water and an ohm gradient to help manage the energy.

Conclusion

The wide use of plastics as insulators and carriers of sensitive components presents the concomitant problem of controlling static electricity. Because plastics have compelling economics in mass production, the best solution seems to be modification of its compounds so that the basic benefits are maintained while the problem of ESD is addressed. Some solutions now exist and improvements are being sought.

The Nature of the Problem

Static electricity is nonmoving electrons. This is an unnatural state: Electrons want to move because they repel each other like two magnets with the same polarity. However, movement is resisted by the material on which the electrons sit. Some materials resist movement slightly (e.g., carbon), some very slightly (e.g., copper) and some "totally." DuPont's Teflon, for example, can be called an "electret" - a material holding a permanent electrical charge.

Plastics are insulators of electron movement, a property highly instrumental in getting electronic systems safely into the hands of consumers. However, this is the same property permitting plastics to hold electrical static on their surfaces. Given an "opportunity, a "corona" or "electrostatic discharge" resembling a miniature lightning bolt can emit electromagnetic radiation over a wide frequency range, potentially to wreak serious damage and/or destruction on sensitive components and assemblies. The task then is to manage static electricity to prevent such discharges.
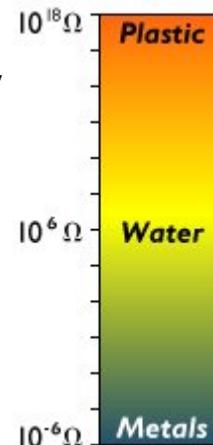
A pile of electrons has another dangerous side: Its voltage is higher than that of nearby materials. Thus is a static-sensitive device (passive or active component) bridges the space between the electron pile and uncharged material, it "sees" the potential difference. Result: Part of the static pile surges through the device and burns it in an instant. This event, which is usually silent and invisible, is capable of destroying many devices. Even worse is residual damage, which can cause device failure later in the field.

In nature, units of resistance to electron movement have a 24-decade range: from one millionth of one ohm (10^{-6} Ohms) for a conductor (copper) to a billion billion ohms (10^{18} Ohms) for a (plastic) insulator (diagram). Water, as an element, is about 10^6 Ohms. At the extreme ranges are "super insulators" (electrets) and the "super

conductors," the latter theoretically features zero resistance to electron movement.

In dealing with electrostatic discharge, plastic is the problem. Because the material resists the movement of current, the electrons can dangerously pile up. The solution is to let the electrons move away from each other. If resistance to electron movement is lowered, they will migrate toward areas of lower resistance, pushed by other electrons. However, if resistance is excessively reduced, a pulse of electrons will surge through the material and lead to damaging corona discharge and electromagnetic radiation. The "natural" range of ohmic values. Resistively and conductivity may be seen as the same, depending on whether viewed from above or below.

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