SERIES

TECHnically Speaking

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Unwanted Currents Can Damage Electronic Equipment

"Technically Speaking" is a new regular series in Avionics News. *Peter Ashford, writer for the new series, has an extensive engineering background, including as an aircraft instrument/electrical engineer, quality assurance engineer, quality systems and regulatory lead auditor, and many other positions. His experience ranges from installing and maintaining ISO 9000 systems to writing quality procedures manuals and auditing quality systems internationally. He has worked for the NZCAA as an airworthiness inspector since 1998. Born and educated in England, Ashford served in the Royal Air Force. He has lived in New Zealand since 1971.*

The term ESD (electrostatic discharge) generally is used in the electronics industry to describe momentary unwanted currents that could cause damage to electronic (avionics) equipment.

Integrated circuits are made from semiconductor materials, such as silicon and insulating materials like silicon dioxide. Either of these materials can suffer permanent damage when subject to high voltages. As a result, there now are a number of antistatic devices to help prevent static build-up.

Causes of ESD

One of the causes of ESD is static electricity. This often is generated through tribocharging. Triboelectricity is electricity generated by friction. For example, combing hair with a plastic comb, descending from a car or removing some types of plastic packaging. In all of these examples, the friction between two materials results in tribocharging; therefore, creating a difference of electrical potential that can lead to an ESD event.

When two different materials are pressed or rubbed together, the surface of one material generally will steal some electrons from the surface of the other material. The material stealing electrons has the stronger affinity for negative charge of the two materials, and that surface will be negatively charged after the materials are separated. (Of course, the other material will have an equal amount of positive charge.) If various insulating materials are pressed or rubbed together and the amount and polarity of the charge on each surface is measured separately, a reproducible pattern emerges.

For insulators, the table on page 37 can be used to predict which will become positive versus negative and how strong the effect will be.

This table can be used to select materials that will minimize static charging. For example, if uncoated paper with a positive charge affinity value of +10 nC/J is squeezed by a pinch roller made of butyl rubber (@-135 nC/J), there will be about 145 pico coulombs of charge transfer per joule of energy (associated with pinch and friction). This is about 20 times more than 7 nC/J, which is the static charge per joule that results from squeezing paper with a roller made of nitrile rubber (@+3 nC/J). In general, materials with an affinity near zero (such as cotton, nitrile rubber, polycarbonate and ABS) will not charge much when rubbed against metals or against each other.

The table also can be used (with other

formulas) to predict the static forces that will arise between surfaces and to help select materials that will create an intentional charge on a surface. See further information on the interpretation table.

Symbols in the Table

Polyurethane (top) tends to charge positive; teflon (bottom) charges negative. The charge affinity listings show relative charging. Two materials with almost equal charge affinity tend not to charge each other much even if rubbed together.

Column 3 shows how each material behaves when rubbed against metal, which is much less predictable and repeatable than insulator-to-insulator rubbing. The charging by metal is strongly dependent on the amount of pressure used, and sometimes will reverse polarity. At very low pressure (used in this table), it is fairly consistent.

A letter "N" (normal) in this column means the charge affinity against metal is roughly consistent with the column 2 value. The letter "W" means weaker than expected (such as closer to zero than expected or even reversed.) The "+" or "-" indicates the polarity. In all cases where the polarity in Column 3 disagrees with Column 2, it is a weak (W) effect.

Limitations of These Measurements

Testing was done at low surface-to-surface force (under 1/10 atmosphere) using 1" strips of each of the insulators that are available as smooth solids. (Cotton, for example, could not be made into a solid strip.) The charge affinity ranking of non-smooth solids was interpolated by their effect on smooth solids, which had measured affinity values.

At this low surface force (typical of industrial conditions), the absolute rank-

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Column 1 (this col.): Insulator name. Col.2: Charge affinity in nC/J (nano ampsec/wattsec of friction). Col.3: Charge acquired if rubbed with metal (W=weak, N=normal, or consistent with the affinity). Col.4: Notes.	Affinity nC/J	Metal effect	**Triboelectric Table**
Polyurethane foam	+60	+N	All materials are good insulators (>1000 T ohm cm) unless noted.
Sorbothane	+58	-W	Slightly conductive. (120 G ohm cm).
Box sealing tape (BOPP)	+55	+W	Non-sticky side. Becomes more negative if sanded down to the BOPP film.
Hair, oily skin	+45	+N	Skin is conductive. Cannot be charged by metal rubbing.
Solid polyurethane, filled	+40	+N	Slightly conductive. (8 T ohm cm).
Magnesium fluoride (MgF2)	+35	+N	Anti-reflective optical coating.
Nylon, dry skin	+30	+N	Skin is conductive. Cannot be charged by metal rubbing.
Machine oil	+29	+N	
Nylatron (nylon filled with MoS_2)	+28	+N	
Glass (soda)	+25	+N	Slightly conductive. (Depends on humidity).
Paper (uncoated copy)	+10	-W	Most papers & cardboard have similar affinity. Slightly conductive.
Wood (pine)	+7	-W	
GE brand Silicone II (hardens in air)	+6	+N	More positive than the other silicone chemistry (see below).
Cotton	+5	+N	Slightly conductive. (Depends on humidity).
Nitrile rubber	+3	-W	
Wool	0	-W	
Polycarbonate	-5	-W	
ABS	-5	-N	
Acrylic (polymethyl methacrylate) and adhesive side of clear carton-sealing and office tape	-10	-N	Several clear tape adhesives are have an affinity almost identical to acrylic, even though various compositions are listed.
Epoxy (circuit board)	-32	-N	
Styrene-butadiene rubber (SBR, Buna S)	-35	-N	Sometimes inaccurately called "neoprene" (see below).
Solvent-based spray paints	-38	-N	May vary.
PET (mylar) cloth	-40	-W	
PET (mylar) solid	-40	+W	
EVA rubber for gaskets, filled	-55	-N	Slightly conductive. (10 T ohm cm). Filled rubber will usually conduct.
Gum rubber	-60	-N	Barely conductive. (500 T ohm cm).
Hot melt glue	-62	-N	
Polystyrene	-70	-N	
Silicones (air harden & thermoset, but *not* GE)	-72	-N	
Vinyl: flexible (clear tubing)	-75	-N	
Carton-sealing tape (BOPP), sanded down	-85	-N	Raw surface is very + (see above), but close to PP when sanded.
Olefins (alkenes): LDPE, HDPE, PP	-90	-N	UHMWPE is below. Against metals, PP is more neg than PE.
Cellulose nitrate	-93	-N	
Office tape backing (vinyl copolymer ?)	-95	-N	
UHMWPE	-95	-N	
Neoprene (polychloroprene, *not* SBR)	-98	-N	Slightly conductive if filled (1.5 T ohm cm).
PVC (rigid vinyl)	-100	-N	
Latex (natural) rubber	-105	-N	
Viton, filled	-117	-N	Slightly conductive. (40 T ohm cm).
Epichlorohydrin rubber, filled	-118	-N	Slightly conductive. (250 G ohm cm).
Santoprene rubber	-120	-N	
Hypalon rubber, filled	-130	-N	Slightly conductive. (30 T ohm cm).
Butyl rubber, filled	-135	-N	Conductive. (900 M ohm cm). Test was done fast.
EDPM rubber, filled	-140	-N	Slightly conductive. (40 T ohm cm).
Teflon	-190	-N	Surface is fluorine atoms-- very electronegative.

Tests were performed by Dr. Bill Lee, Ph.D. in physics, in 2009, at AlphaLab Inc., which also manufactured the test equipment used.

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ing of charge affinity of various insulating materials was self-consistent. Above about 1 atmosphere, surface distortions caused some rearrangements in the relative ranking, which are not recorded here.

Conductor-to-insulator tests were done as well, and contrary to prevailing literature, all conductors have about the same charge affinity. However, the metal-insulator charge transfer was strongly dependent on the metal surface texture in a way not seen with insulator-insulator. Metal-insulator transfer also was more pressure-dependent in an unpredictable way, so charge transfer has not been quantified for metal-insulator. The "zero" level in this table is chosen arbitrarily as the average conductor charge affinity.

"Slow conductors,"such as paper, glass and some types of carbon-doped rubber, had approximately the same affinity as conductors if rubbing was done very slowly. All tests were done fast enough to avoid this effect. Testing was at approximately 72 F, 35 percent RH, using an AlphaLab Surface DC voltmeter SVM2 and an Exair 7006 AC ion source to neutralize samples between tests. Resistivities were measured with an AlphaLab HR2 meter.

Applied frictional energy per area was 1 mJ/cm^2. Total charge transferred was kept in the linear range, well below spark potential, and was proportional to applied frictional energy per area. All samples needed to be sanded or scraped clean before testing; any thin layer of grease or oil (organic or synthetic) generally was highly positive and would distort the values.

Explanation of Units 'nJ/C' Used in the Table

The units shown here are nC (nano coulombs or nano amp sec) of transferred charge per J (joule or watt sec) of friction energy applied between the surfaces. The friction energy was applied by rubbing two surfaces together; however, "adhesion energy" might be substituted for friction energy when using the table.

For example, when adhesive tape is removed from a roll, a certain amount of energy per cm^2 (of tape removed) must be expended to separate the adhesive from the backing material. Although not yet fully verified, newly dispensed tape becomes charged approximately as is predicted by the table if the adhesion energy is substituted for friction energy. After verifying that charge transferred was approximately proportional to the frictional force (for a given pull length), the contact force was adjusted for each pair so the friction force was 25 grams on 2.5 cm wide samples. This is 1 millijoule (mJ) per cm^2. When a teflon sample (-190 nC/J) was rubbed in this way against nylon (+30 nC/J), the nylon acquired a positive charge and the teflon negative. The amount of transferred charge can be found by first subtracting the two table entries: 30 nC/J - [-190 nC/J] = 220 nC/J. In this case, using 1 mJ (0.001 J) of friction energy per cm^2, the charge transferred per cm^2 was 220 nC/J x 0.001 J = 0.22 nC.

'Saturation' or Maximum Charge That Can Be Transferred

Beyond a certain amount of charge transferred, additional friction energy (rubbing) does not produce any additional charging. Apparently, two effects limit the amount of charge per area that can be transferred.

If the spark E-field (10 KV/cm) is exceeded, the two surfaces will spark to each other (after being separated from each other by at least about 1 mm), reducing the charge transferred below 10 KV/cm. This maximum charge per area is about Q/A = 1 nC/cm^2, from this formula.

A second, lower charging limit seems to apply to surfaces with an affinity difference of < (about) 50 nC/J. Two materials that are this close to each other in the triboelectric series never seem to reach a charge difference as high as 2 nC/cm^2, no matter how much they are rubbed together. Although not yet fully verified, it is proposed that the maximum Q/A (in nC/cm^2) is roughly 0.02 x the difference in affinities (in nJ/C) if the two materials are within 50 nC/J of each other. Surfaces that cannot reach spark potential obviously cannot spontaneously dump charge into the air. Therefore, this is a good reason to select contacting materials such that their affinity difference is small.

Inaccurate Information About Air Being 'Positive'

A triboelectric series table has been circulating on the Internet, and it contains various inaccuracies. Although attribution is rarely given, it appears to be mostly from a 1987 book.

The table lists air as the most positive of all materials, polyurethane as highly negative and various metals being positive or negative, apparently based on their known chemical electron affinities rather than on electrostatic experiments. From actual tests, there is little or no measurable difference in charge affinity between different types of metal, possibly because the fast motion of conduction electrons cancels such differences.

In gaseous form, air generally is unable to impart any charge to or from solids, even at very high pressure or speed. If chilled to a solid or liquid, air is expected to be slightly negative, not positive.

There are three cases in which air can charge matter (in the absence of external high voltage):

- If contaminated by dust, high-speed air can charge surfaces, but this charge comes from contact with the dust, not the air. The charge polarity depends on the type of dust.
- If air is blown across a wet surface, negative ions are formed because of the evaporation of water. In this case, the wet surface charges positive, so the air becomes negative.
- If air is hot (above about 1000°C), it begins emitting ions (both + and -). This

is thermal in nature, not triboelectric.

Another cause of ESD damage is through electrostatic induction. This occurs when an electrically charged object is placed near a conductive object isolated from ground. The presence object creates an electrostatic field, causing electrical charges on the surface of the other object to redistribute.

The net electrostatic charge of the object has not changed, but now it has regions of excess positive and negative charges. An ESD event could occur if the object comes into contact with a conductive path.

Types of ESD

The most spectacular form of ESD is the spark. This can cause discomfort to people, severe damage to electronic equipment and explosions or fires if combustible gases are in the air.

The best known example of a spark is the lightning strike. This is when the potential difference between a cloud and ground or between two clouds is hundreds of millions of volts. The resulting current flow through the ionized air causes an explosive release of energy.

Because of the high temperatures reached, sparks can cause serious explosions.

A classic example was the Hindenburg disaster. This was attributed to a spark discharge igniting flammable panels, which burnt violently and quickly, and ultimately led to the ignition of hydrogen gas held in or leaking from the airship at the time. The ship had just passed through a thunderstorm and likely picked up a large charge. Discharge occurred when mooring ropes were dropped as it came in to land.

ESD Avoidance

Because ESD can occur only when different potentials exist, the best way to avoid ESD damage is to keep the ICs at the same potential as their surroundings.

The logical reference potential is ESD ground. There, the first and most important rule in avoiding ESD damage is to keep ICs and everything that comes into close proximity to them at ESD ground potential.

Other rules supporting this rule include:

• Any person handling ICs must be grounded by a wrist strap or ESD protective footwear, used in conjunction with a conductive or static-dissipative floor or floor mat.

• The work surface where devices are placed for handling and testing must be made of static-dissipative material and be grounded to ESD ground.

• All insulator materials must be either moved from the work area or be neutralized with an ionizer. Static-generating clothes should be covered with ESD protective overalls.

• When ICs are being stored, transferred between work stations or shipped to a customer, they must be placed in a faraday shield container for which the inside surface is static-dissipative.

Audit Compliance

Audits of ESD handling procedures and equipment should be carried out prior to any work being performed. This includes functional checks on wrist straps, heel-straps, ionizers, table mats and floor mats.

As an avionics engineer, would you like to be responsible for damaging or destroying a piece of very expensive avionics equipment? I think not. Therefore, follow the written procedures and ensure all staff members understand the consequences should they forget or ignore them. ❑