Moment of Truth in ESD: Conductor Contact

This is ESD: the extremely rapid equalization of charges between conductive surfaces.

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INTRODUCTION

Whenever two conductive surfaces first meet, or very closely approach one another, an ESD spark or electrostatic discharge passes between them. If they are at about the same polarity and degree of charge, the ESD will be so small as to be generally undetectable. But in the vast majority of such first conductor contacts, an ESD spark results.

Today, an extensive array of products - conductive chairs, floors, garments, workstations, protective packaging, and ionizing systems - are offered to prevent ESD damage to electronic components and assemblies. All have the same simple goal: *to ensure that conductors have the same charge level when they meet.* This is ESD prevention in essence. There must be no spark.

Assuring that all conductors are at exactly the same polarity and degree of charge at the meeting moment is extremely difficult. Therefore, the simplest approach is to see that they never meet *except when they must*, such as during assembly and test. Any other time, devices should touch only static dissipative, antistatic, or even nonconductive materials, none of which can discharge fast enough to produce the dreaded ESD spark at the lead, from where it echoes within the device according to the "chain of capacitors" effect, and results in damage or degraded performance in the chip.

This is ESD: the extremely rapid equalization of charges between conductive surfaces. It produces heat, light, sound, and electromagnetic radiation ranging through the entire spectrum. This ESD spark sets fires, fogs film, shocks personnel and ignites explosives. Blasting its way from one tiny conductor to another through the intervening insulative gate oxide layer of a semiconductor chip, ESD melts a hole in the glass-like oxide, vaporizes metals and causes shorting. Worse, ESD can cause latent failures so that components pass tests, but later fail in use.

CONDUCTORS

The common and overlooked factor here is that the *conductors* did the damage. For the tiny amount of electrostatic energy involved to produce the heat necessary to cause melting and vaporization of metal, the discharge must be extremely rapid; it must give no time for heat to dissipate. Only conductors can discharge so rapidly. All ESD damage is done by conductors. With insignificant exceptions, these conductors are *metal*, metallic *carbon*, and the *sweat* layer on the human hand.

Recognition of the *charged device model* began with Burt Unger's experiments at Bell Labs, which involved sliding dual in-line packages (DIPs) down grounded black conductive shipping tubes. This charged their nonconductive portions so that the devices became harmlessly and uniformly charged.

Not until the device left the tube and contacted the conductive wall of a Faraday cup did damaging discharge occur. In short, *only contact with a conductive material can damage a charged device. Damage is maximized if that conductor is a grounded one.*

STATIC DISSIPATIVE AND ANTISTATIC PLASTICS

For this reason, conductive packaging and handling materials throughout the electronics trade are being replaced or covered with non-sparking static dissipative or antistatic plastics. The slower discharge of static to or from these plastic materials is safely sparkless. The often criticized slower bleed-off of such surfaces when artificially charged and then grounded is the very thing that makes them safe to touch with other, faster conductors!

Moreover, when rendered antistatic or static dissipative by topical or internal treatments which cause them to hold invisible layers of moisture to their surfaces even at zero relative humidity, such materials neither charge nor spark, and so are incapable of causing ESD damage. They are now in ever-growing demand and wide use, and available from countless sources. They have surface resistivities from 10^6 to 10^{12} ohms/square and, ideally, neither charge on separation nor spark on contact.

Regardless of surface resistivity measurements, before any material is labeled "antistatic" or "static dissipative" *it should be tested and certified to possess the quality of sparklessness.* It must be unable to damage a charged device on contact. This is rarely, if ever, specified, but should be.

The first material to demonstrate these characteristics of ESD prevention was Richmond Technology's RCAS 1200, the first "pink poly." Prior to its development as a static-safe non-sparking spacecraft drape in 1966, static dissipative or antistatic films were not generally known or available. The choice lay between common plastic films which charged, and conductive carbon-loaded or surface-metallized films which sparked at a touch. The new pink poly did neither, and was therefore employed as a drape around spacecraft, along with an antistatic orange nylon called RCAS 2400 to give better abrasion resistance and fire-retardancy.

The need for sparklessness was real, for in 1964 a rocket had been inadvertently ignited by ESD. The static charge from a plain polyethylene drape had been induced on the conductive aluminum case of an igniter squib. The case discharged an ESD spark at the carefully grounded bridgewire inside it. The resulting ignition of the solid propellant was disastrous.

Attempts to use carbon-loaded black conductive poly and metallized films to make a safe cover came to naught. Both shed conductive particles when flexed or abraded, lacked transparency, and caused direct electrolytic corrosion when contacting other metals. They also sparked when touched for the first time by fingers or any other conductor. The RF pulse from the resulting spark could be picked up by a cheap AM transistor radio. The effect of such sparks in the vicinity of a spacecraft antenna capable of picking up broadcasts 250 million miles distant need only be imagined. Data, being binary-based, can be drastically altered by the effect of a single spark, from ESD or any other source.

ESD DETECTORS

The fact that ESD sparks produce RF pulses to cheap AM radios (together with heat, light, sound, UV, VHF, UHF, etc.) means radios are handy, cheap, and accurate ESD event detectors, which can also evaluate EMI shielding or Faraday Cage effects.

It is generally conceded that Faraday Cages, like his original tinfoil covered room-within-a-room, will inhibit a radio's reception of broadcast signals. Thus, any bag or box which is called a Faraday Cage should be able to demonstrate its ability to hush a radio enclosed in it. Surprisingly, no transparent static shielding bag does so, nor do black carbon-loaded bags or boxes. Only containers having solid foil layers or heavy wire mesh (massive enough to be a foil layer if beaten flat) attenuate RF to any significant degree. Radios play on with undiminished volume when placed in any bag or container which is transparent. If light penetrates, so does RF, except in the case of wire mesh, which is not widely used in any commercial shielding bags. This simple test has rudely shocked some bag buyers.

As an ESD event detector, the same AM radio will "hear" a spark and give out a "zap" or click sound in response to it. Any safe static dissipative work surface should demonstrate that a charged fingertip or tweezer-point touched to it will not make a nearby radio respond with a "click." For if it does, any charged component or circuit card whose lead touched the surface could also produce an ESD spark, potentially damaging devices.

GROUNDING

However, most present work surface evaluations depend on surface resistivity measurements which are not related to sparklessness, the true essential property for ESD safety. Instead, they are based on complex "path to ground" or resistance measurements *made with continuous current*, none of which are related to the real problem of sparklessly bringing everything on the table to the same polarity before conductors meet. Indeed, some surfaces use carbon filaments scattered widely enough to provide resistivity measurement in the range called static dissipative, but if locally touched will still spark. Those organically destaticized, like some soft vinyl mats, do not spark, but give the same resistivity readings. In reality, any surface other than metal or carbon will be ESD safe, unless it is so dry that anything rubbed on it produces huge charges. Even this is easily handled by simple antistat wipes. The only dangerous work surface is one which is sparkingly conductive, and which could destroy a charged device which touched it, particularly if grounded.

There are however, two occasions in the life of a component or PCB in which conductor contact is unavoidable: *assembly* and *test*. Under the heading of assembly is included simple plugging of boards, cables, connectors and the like. For in all electronic work, joints must be soldered, or probes and test connections made; thus these conductor touches are unavoidable.

In these operations, however, the conditions can be tightly controlled, so that:

- personnel are commonly grounded (sweat layers are at neutrality);
- plain plastics and chargeable materials are excluded from the work areas;
- only sparkless dissipative work surfaces are used; and
- humidity and ion content of the air are regulated.

Any other first contact with conductors must be avoided because it can produce ESD. Engineers are learning, slowly, to cover or paint conductive "doorknobs" to keep the spark from happening, to safely slow down the discharge of charged devices to sparklessness. Charged conductors touching dissipative surfaces become equalized in charge without sparking, and may then safely be assembled. Before cables are plugged in, a piece of pink foam or similar antistatic plastic placed between them will safely drain off any charge, after which they may be connected with impunity.

Having ensured that the work surface is non-sparking, and has no exposed metal or metallic carbon, one has to consider that components, whether charged or not, are safe on it until their leads touch other conductors, including the skin of the operator. Ironically, a charged device produces its most intense or damaging spark when it touches a grounded conductor!

Thus the DIP semiconductor which slides down a dry conductive carbon shipping tube becomes charged, but undamaged. But when it leaves the tube and one lead meets a conductor, that lead only goes to another charge level, or ground, so swiftly that a spark results, and is echoed inside the device. A finger generally produces a "single shot" discharge so that skin must be recharged by more footwork to get another spark of equal intensity, while charged devices have many leads and can produce diminishing sparks from many or all of them on subsequent conductor contacts.

Gloves or finger cots should be worn when working on individual components for the same reason; if the device is charged, it can spark to the sweat layer, and more so if one is grounded. This concept should be more fully explored; sometimes grounding can be dangerous and can intensify ESD. The careful use of wrist straps to ground the skin prevents workers from being the source of a spark but not from receiving one from a charged device!

Black conductive foam, often used to shunt the leads of DIP semiconductors and similar components, can give precisely this same damaging result if devices are even slightly charged when first plugging into it. Antistatic foams are cheaper and noncorrosive and do not cause galvanic effects if exposed. Most important, they have in their favor the quality of sparklessness when touched by charged device leads. Shipping and handling tests using both materials have shown no damage to devices caused by the "pink foams," which are ever more widely used. Old habits of conductor use are hard to break, and the "sparkless" restriction has not yet been placed on the conductive black foams.

STATIC SHIELDING

Despite the long track record of antistatic plastics or static dissipative bags, wraps, foams, bubble cushionings and the like in preventing ESD damage to their contents, the major proponents of conductive black bags fostered, beginning about 1978, a real or imagined need for something called "static shielding." Using exaggerated demonstrations not supported by real-life ESD failures, they reintroduced to the trade the concept of exposed metallization on the outer surface of bags. The bags were lined with "a material similar to pink poly," to quote an early ad. It makes little sense to place a metal-faced sparking bag on such a sparkless table top where a device or assembly touching it can spark; the doorknob is back! One of these concepts clearly is wrong. If ESD sparks are not to happen on contact with charged devices, the "shielding" metallic layer in any bag or box must be covered just as the conductive layer in the table mat is covered.

Competitive static shielding bags with buried metal layers instead of exposed metal or carbon appeared. All these gave equal "shielding" (read discharge re-routing) properties against real life charged fingers or charged plastics, but did not easily spark on contact or offer shock hazard to personnel who contacted live circuitry with the bags. Most, if not all, such static shielding bags were lined with "pink poly" type antistat-impregnated polyethylenes, or covered with topical antistats. Most such antistats were amine based, and while non-corrosive and generally harmless, were found to cause "crazing" in stressed polycarbonate plastic items stored in contact with them. Since the antistats were never designed for use with polycarbonate (unique in its sensitivity to amine based wetting agents) the antistat manufacturers have found new, equally effective, "amine-free" antistats. Of course, wherever polycarbonate is not involved the old ones are quite safe.

The need to "bury the metal" in shielding bags (and work surfaces, cartons, shipping tubes, etc.) to prevent sparks caused by exposed conductors has led to the expressions "metal-in" and "metal-out" bags. The former are those with exposed metal or carbon exteriors (sometimes very lightly lacquered); the latter have the metal or carbon safely buried within the bag wall, leaving no exposed sparking surface. Buried metal bags proved to be just as static shielding as exposed metal types, without the hazard of shedding, sparking, or shock to personnel. All real-life "zapping" of components through the walls failed.

ESD TESTS

The principal metal-out advocate then devised a probe test generally accepted by the EIA and the military, in which the bag would be tested by placing it between metal plates and discharging some 1500 volts between the plates, while a probe within the bag would show any charge difference in the bag's interior walls. This, of course, shorts the plates when the metal is external, while showing poorer performance with buried metal types. If the metal-out bag is first wrapped in poly for the test, it scores much worse, which should give some indication of the fairness of the test. This and most other tests have never been correlated against real component damage in comparative shipping and handling tests using real-life hazards, and thus are meaningless.

To check for metal-in or metal-out bags, one simple test is to place a white card in the bag and, with a pencil eraser, abrade the exterior over the card. The removal of particles becomes obvious, and in the case of exposed metal-out bags, prevents the lighting of a multitester at the abraded area. The pocket multitester lights up when touching exposed metal, carbon or skin, the only practical sources of ESD sparks. Any surface which lights a multitester is too conductive to ever come into contact with a charged device; ESD can result. With almost no exceptions this means metal, carbon or sweaty skin.

Before any ESD tests or demonstrations are accepted, they should be correlated with real-life damage, and a radio should stand by during each test to check for sparks, and their suppression.

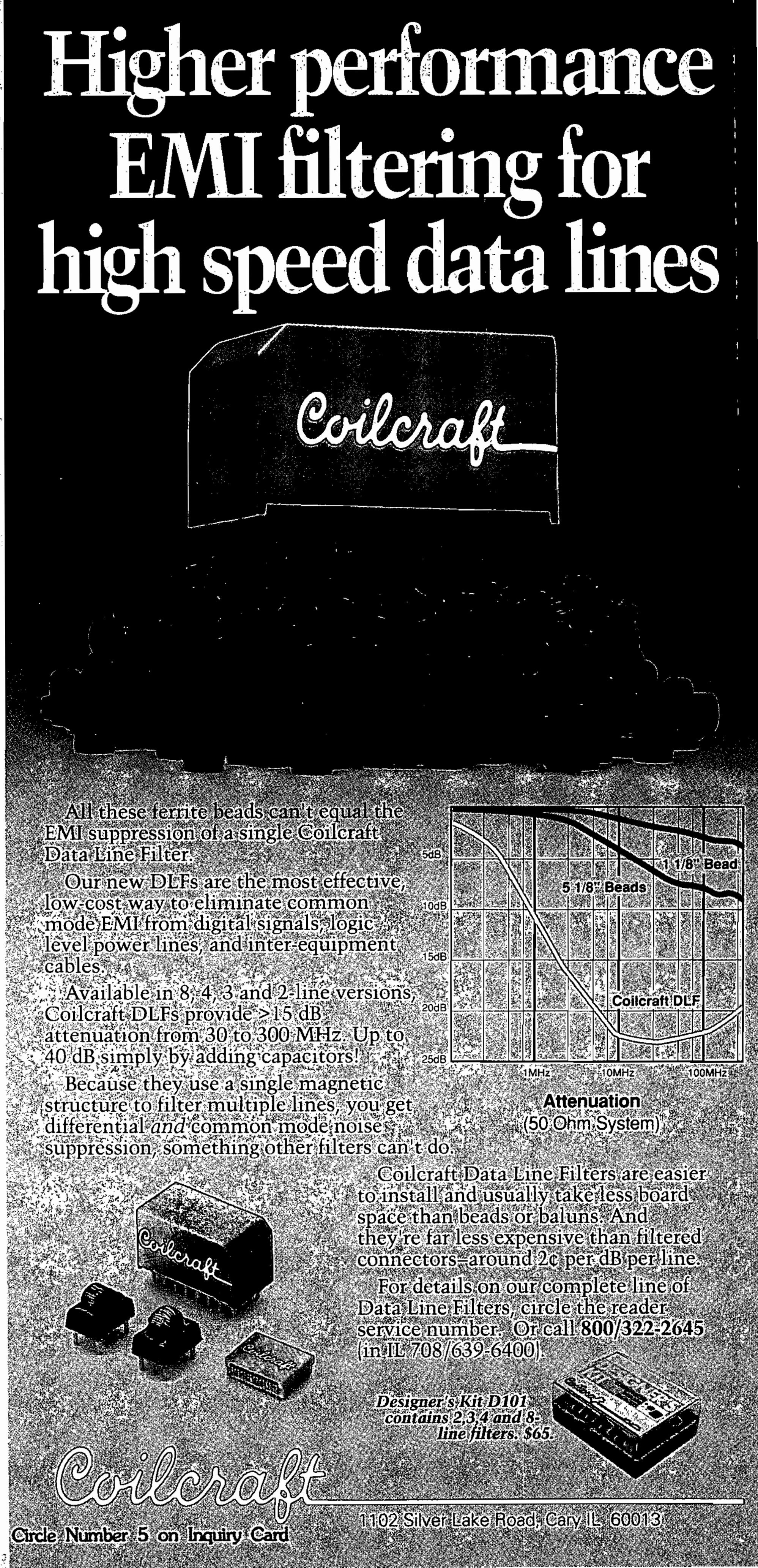
In real life, the worst ESD threats are a 25,000-volt finger (which could reach such a level of charge only if its owner crossed a very dry carpet at a run) or a nearby highly charged large plastic surface. Any package whose contents are not harmed by either is adequate protection from ESD damage by *charged bodies*. The *charged device model* is safe from anything but conductor contact.

ESD discharge simulators, corona-emitting ionizing pistols and the like produce sparks a cheap AM radio can hear, even when the pistols are fired at the wide world. Neither a charged finger nor the charged plastic will produce this spark alone. They require, respectively, a conductive target or a floating conductor which can accept an induced charge and discharge it at another conductor. Packaging to defend against body-discharge simulating zappers is overkill - a cure for which there is no real disease. "Static shielding" is a coined misnomer, and is not needed at all if sufficiently thick antistatic plastics, foams or cushionings are used.

Real shielding, however, is also available if it is needed. Foil-bearing bags, always with the foil buried under non-sparking layers, abound and truly shield against ESD, EMI and even moisture vapor and other external contaminants. Desiccants must be used even in these, however, to maintain dryness of the inner air or nitrogen. A properly made antistatic liner will still function satisfactorily in such a desiccated bag. Complex attenuation tests are performed on such bags as MIL-B-81705 type I barrier materials with buried foil layers as part of their qualification, and any bag which will not silence an AM radio will not pass these tests either. Thus the simple radio is a good screening test for candidate bags, or shielding of any kind, and may be followed with more complex tests only if the radio is silenced by the bag.

The radio can make ESD audible; making ESD visible is also easy with an NE2 or NE2H neon bulb with spread leads, to simulate the wiring runs of a PCB or the leads of a common resistor. By holding one lead, and touching the other to metal, carbon or other person's skin, the bulb will flash if a discharge of 90 volts takes place while the nearby radio announces the zap of the single-shot discharge. Touching static dissipative or antistatic surfaces produces no flash or zap; the target must be a conductor, and the larger and better grounded it is, the stronger the spark as the charged skin fires at it. The spark within the bulb is an echo of the one at the lead as it contacts the conductor. It is the *chain of capacitors* effect that causes the tiny destructive spark within semiconductors as their leads touch conductors of slightly different charge levels.

The skin, or the component lead, may safely and sparklessly be discharged or brought to the same charge level by touching static dissipative or antistatic surfaces prior to touching each other. Being flooded with sufficient ions from a flame or radioactivity just prior to contact will bring them both to



neutrality. Corona-emitting ionizers can charge or zap PCBs or components brought too near. The only duty of such benchtop ionizers is to slowly neutralize charges on plain plastics, or metal items charged by plain plastics. For cleaning air, at safe distances from boards or components, ionizers of the corona-emitting (read spark-emitting) type are of unquestioned value in precipitating airborne particulate matter. However, at work stations they can be actively dangerous, emit RF, and charge nearby conductors. Worse, they often lull users into false security, so that common chargeable plastics or tapes are brought to the area in the vain hope that the ionizer will prevent their charging. But a plastic must first be charged to attract the neutralizing ion, and ionizers can rarely keep up with the generation speed of nearby rapidly separated plastics in time to stop damage.

Today, plain plastics are kept from work areas, lest they charge and induce their charges on devices, which then die as they touch conductors, grounded or not. Thus, only "pink poly" or other antistatic or static dissipative types of plastic are allowed near the items to be protected. No rack or box with external carbon or metal sparking surface should be in such a work area either, unless its contents are safely bagged and never touch the black or metal surface. Chromium or nickel-plated metal racks or shelves are far safer if enameled, or covered with antistatic foam or sheets, so that no device may touch them. Carts ought also to have all metal covered or enameled for the same reason.

CHARGED DEVICE MODEL

Lately the *charged device model* has been found to be the major cause of ESD damage. In essence, this means that rather than a charged finger touching a doorknob, the doorknob became charged and touched a grounded finger.

Inductively charging a board or component by exposing it to a charged plastic or other electrostatic field will simply and slowly charge the whole device or board commonly, and only when touched by a conductor at some localized point will the ESD result. Touching it with anything else is safe.

Touching the charged board or device to antistatic materials will safely and sparklessly bring its charge to zero, or equal to that of its container wall. Or, just before the naked lead is touched with a conductor, both can be neutralized with a flood of ionized air from flame or radioactivity. Left alone, the item attracts enough ions of opposite polarity to neutralize it. For this reason, things long at rest have no charge.

Corona style ion emitters used to speed up this natural neutralization process can often charge or destroy sensitive components brought too close to them. Their emitters should be kept at a safe distance from components or assemblies. An AM radio can be checked for RF from such devices and their corona emissions, which are, after all, sparks. Or an ESD damage simulator can be held near an ionizer, and its neon bulb checked. Discharges able to light neon bulbs can destroy most ICs.

Pure (galvanized) iron foil, instead of aluminum foil as the buried shielding layer in a bag, box or other container gives better RF attenuation in some ranges, and shields against ordinary magnets as well. This is excellent for floppy-disc and data protection, and for magnetic-patterned credit cards and the like. In no case, however, is it necessary to expose the shielding layer, which could make ESD sparks. A radio in a closed tin can is shielded and silenced, but painting the can inside and out does not alter the shielding effectiveness; it simply prevents the surface sparking. Thus the modern computer rarely exposes metal in front.

Black tote boxes, trays, rails, shipping tubes, formed black materials used in surface-mount tape-and-reel packages, and even black conductive foams have all been found to share this dangerous property of zapping slightly-charged devices at a single sparking touch. All of these need to be replaced with static dissipative varieties, or at least covered with non-sparking layers if, at any time, they can touch devices or assemblies.

One well-known producer of carbon-lacquered corrugated containers subtly acknowledged this *cover-the sparker* philosophy by bringing out a static dissipative transparent coating over the exposed carbon of his containers. The additional premium for this more effective package might have been avoided by using plain corrugated alone, with perhaps a buried foil layer between its plies for true shielding and no exposed sparkers. At least, the coating over the carbon prevents easy sparking when charged devices touch it.

SUMMARY

To prevent damage to charged devices:

- All work surfaces, packaging, bags, boxes or handling materials which may at any time contact components or assemblies must be incapable of sparking on contact.
- Those with exposed metal or

carbon must be replaced, or be coated with non-sparking layers before they are safe for use in preventing ESD damage.

- If the shielding is required, the shielding layer is buried so that it cannot spark on contact with charged devices.

Well-intentioned scientists often succumb to the lure of complexity in figuring out *paths to ground* and other abstruse measurements, while the simple avoidance of exposed conductor contact would do the job simply and safely. The expensive test techniques required today often lead to overkill and a great deal of underkill. Many are badly conceived, and meaningless for ESD, which is never a continuous current, and has unique characteristics.

Dan Anderson, President of Anderson Effects, is credited with the development of antistatic packaging films (notably RCAS 1200 pink poly and RCAS 2400 antistatic nylon) first for clean room and spacecraft drape use, and later for the protection of static sensitive electronics. Mr. Anderson is a prolific writer and frequent lecturer on ESD. (714) 794-3792.