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ELECTROSTATIC DISCHARGE CONTROL FOR STDN STATIONS

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1.0 GENERAL.

This manual defines the requirements and control method necessary to minimize the effect of electrostatic discharges (ESD) that damage or destroy electronic equipment components (see figure 1). In addition, test procedures are provided to measure the effectiveness of the control method.

2.0 APPLICABLE DOCUMENTS.

The following documents, of the issue in effect on the date of publication of this document, form a part of this manual.

a. Appendix A, Electrostatic Damage in Hybrid Assemblies.

b. Appendix B, Additions to JPL Technical Information Bulletin 377S2-4E9.

c. DOD-STD-1686 Electrostatic Discharge Control Program excluding paragraph 2.0.

d. DOD-HDBK-263 Electrostatic Discharge Control Handbook, excluding paragraph 2.0.

e. JPL Technical Information Bulletin 377S2-4E9.

f. Appendix C, Electrostatic Damage to CMOS Analog Switch.

3.0 BACKGROUND.

3.1 Damage to components and assemblies which are electrostatic discharge sensitive (ESDS) has become a serious reliability problem for equipment users. The increased dependence upon highly complex and sensitive microelectronics makes entire systems vulnerable to damage. Various methods for controlling ESD have been developed. These include: internal device protection, installation of conductive floor mats, use of topical antistat liquid and/or spray, wearing of protective clothing, and the use of static-free packaging (see figure 1). Any control method may be worthless unless the user understands static electricity and ESD, and exercises proper precautions.

3.2 STATIC ELECTRICITY.

3.2.1 Static electricity is electrical charge at rest. The electrical charge is due to an imbalance of electrons within a body or between two bodies. A body having an excess of electrons is charged negatively; a body having a deficiency of electrons is charged positively. The magnitude of the charge is dependent upon such factors as surface cleanliness, relative humidity, amount of pressure, friction, and the size of surface area (see figure 2).

3.3 TRIBOELECTRICITY.

3.3.1 Triboelectricity is electricity generated by friction resulting from the mechanical separation of electrical charges of opposite sign by processes such as (1) the separation (as by sliding) of dissimilar solid objects, (2) interaction at a solid-liquid interface, and (3) breaking of a liquid-gas interface. Plastic, paper, textiles, and other materials are ordinarily electrically balanced. When two such

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Figure 1. Static-safe Work Station.

Table 1. Triboelectric Series

Positive (+)	Air
	Human Hands
	Asbestos
	Rabbit Fur
	Glass
	Mica
	Human Hair
	Nylon
	Wool
	Fur
	Lead
	Silk
	Aluminum
	Paper
	Cotton
	Steel
	Wood
	Amber
	Sealing Wax
	Hard Rubber
	Nickel, Copper
	Brass, Silver
	Gold, Platinum
	Sulfur
	Acetate Rayon
	Polyester
	Celluloid
	Orlon
	Polyurethane
	Polyethylene
	Polypropylene
	PVC (Vinyl) (Polyvinylchloride)
	KEL F
	Silicon
Negative (-)	Teflon

materials come in contact under pressure and friction, and are then separated, electrons are torn from the surface of one material and become attached to the other material. The materials then become positively or negatively charged.

3.4 TRIBOELECTRIC SERIES. (Refer to table 1)

3.4.1 The triboelectric series is a list of materials in descending order of positive to negative charging as a result of triboelectrification. When two substances are rubbed together and then separated, the substance higher on the triboelectric series list will lose electrons to the substance lower on the triboelectric series list, and thereby become positively charged with respect to the substance lower on the list. In addition to generating triboelectricity by rubbing two different substances together, triboelectricity may also be generated when two pieces of the same substance come in contact and are then separated. For example, separating the sides of a plastic bag.

3.5 ELECTROSTATIC DISCHARGE (ESD).

3.5.1 ESD is a transfer of electrical charge between bodies at different potentials. Destructive ESD may be delivered in the form of sparks passing between materials of different potentials. Metal, carbon, and human skin can pick up, store, and discharge potentially destructive sparks. The charge, generated by a shoe-sole separating from a carpet is induced and stored on the body's surface and clothing, and can then be discharged to another object. For example, a printed circuit board is an object to which a destructive spark may be discharged. If touched at a right point, the board may be damaged as the discharge passes through a sensitive component (see figure 3). Appendix A, Electrostatic Damage in Hybrid Assemblies, has photomicrographs of damaged devices and suggested preventive action.

4.0 ESD PREVENTION.

4.1 The following acronym SIGH should be used in the prevention of ESD:

a. Surround the device or assembly with antistatic materials.

b. Impound all plain plastics, textiles, foam, and cushions from near approach to ESDS items. Replace with approved antistatic types or treat with topical antistats.

c. Ground the skin of all item-handling personnel with safety resistive wrist straps. Where this is not possible or practical, use conductive floor mats or treat floor topically, and wear appropriate foot wear.

d. Hound personnel and management to see that above rules are observed, for without breaking one, it is virtually impossible to cause electrostatic damage.

4.1.1 An important idea presented by SIGH is that every one must become involved in prevention. To provide continuity in the protective chain, awareness and prevention of ESD must be part of:

a. The vendor

b. Shipping and Receiving personnel

c. Logistics/supply personnel

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Table 2. ESD Susceptibility of Various Electronic Devices
(Not limited to)

Device Type	Range of ESD Susceptibility (Volts)
VMOS	30 to 1800
MOSFET	100 to 200
GaAsFET	100 to 300
EPROM	100
JFET	140 to 7000
SAW	150 to 500
OP AMP	190 to 2500
CMOS	250 to 3000
Schottky Diodes	300 to 2500
Film Resistors (Thick, Thin)	300 to 3000
Bipolar Transistors	380 to 7000
ECL (PC Board Level)	500 to 1500
SCR	680 to 1000
Schottky TTL	1000 to 2500

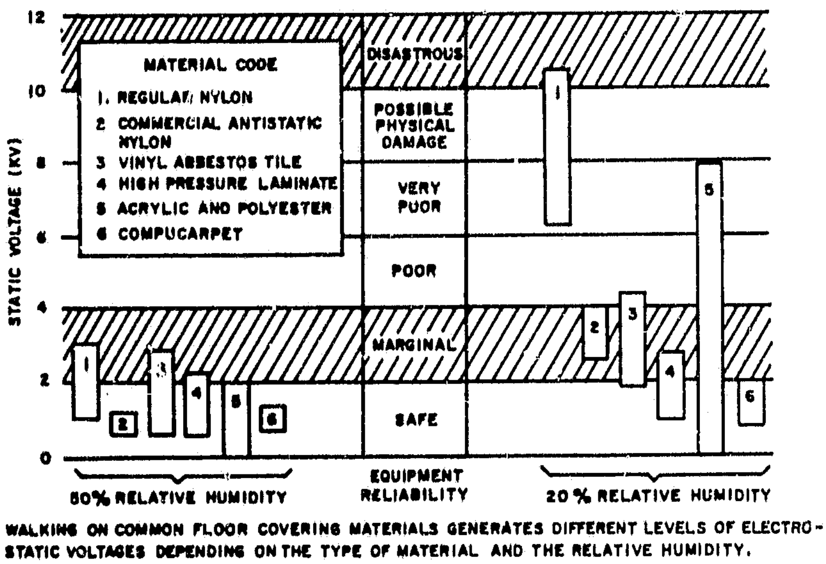


Figure 2. Voltages Generated by Walking on Common Floor Materials

d. The user

e. Maintenance/trouble-shooting personnel

To comply with the above, we have instituted a requirement to all vendors that those items listed in table 2 be supplied in a translucent antistatic container, labeled as shown in figure 4. Depending upon the item shipped, the containers may be protective bags, carbon-loaded plastic boxes or tubes, or conductive foam.

CAUTION

Packages labeled STATIC SENSITIVE are to be opened ONLY at a static safe work station.

4.2 THE USER. The user will use conductive floor mats or topically treated floors to discharge any electrostatic build-up before touching equipment. Tests reveal that an exposed panel-mounted LED can permit transmission of ESD to PC boards, resulting in failure of ICs and other semiconductor components (see figure 3). Laboratory tests have also shown that damage and resulting failure was sometimes due to accumulative shocks. Personnel working in operational areas should not wear shoes that have rubber or composition soles. If leather-soled shoes are not worn, it is necessary to attach conductive shoe straps or treat with a topical antistat. However, it should be realized that leather does not always provide an efficient discharge path, and that treatment with an anti-stat is advisable. The wearing of a laboratory coat is recommended. The laboratory coat should be treated with an anti-stat by spraying once a week, and treated with anti-stat in rinse water after washing.

4.3 BENCH TOPS. Because work benches become contaminated, they must be periodically cleaned with a topical anti-stat. The conductive bench mat must also be cleaned periodically. However, cleaning solutions can lower the conductivity of the conductive mat unless the mat sits long enough to absorb enough moisture to again become conductive. The process can be expedited by wiping the mat with a cloth dampened with a solution of equal parts of water and a topical antistat. To check the bench conductivity, see figure 5.

4.4 MAINTENANCE/TROUBLESHOOTING. This category requires much the same techniques as those described under "USER" (paragraph 4.2). In addition, this area demands more attention to preventing static build-up as more direct contact with discrete devices is probable. The maintenance area should have work benches with grounded floor, and bench mats with wrist straps. Conductive foam and antistatic plastic containers should be used to hold parts (see figure 1). The value of the series wrist-strap resistor (1 M) should be checked periodically. Also, visual check of the wrist strap, resistor, ground wire, table and floor mats, and floor-mat ground wire should be made for frayed insulation, loose connections, or other defects.

4.5 LOGISTICS/SUPPLY PERSONNEL. All personnel in the Logistics/Supply area should be aware that many electro-static protection devices are reusable. When returning sensitive devices for any reason repack in original packaging. All sensitive devices should also be stored in same packaging.

Reusable items include, but are not limited to: (a) PCB Edge Protectors; (b) Shielding Bags; (c) Caution Labels; (d) Conductive Foam; and (e) Shipping Tubes.

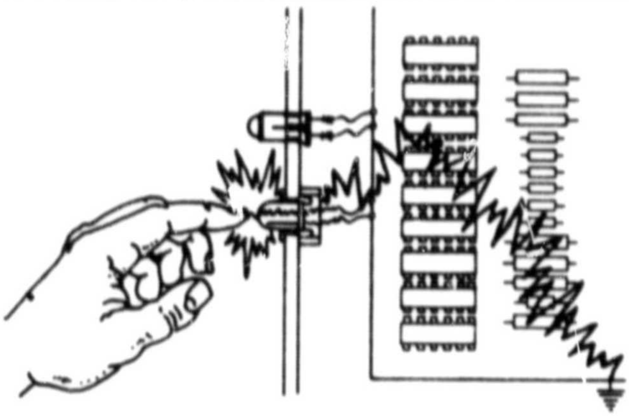


Figure 3. Transmission of ESD to PC Board Through Panel-mounted LED.

Figure 4. ESDS Device, Container Label.

WARNING

Maintain the integrity of the "soft" ground system, primarily for personnel protection.

4.6 SHUFFLE TEST. A portable static locator (electrostatic voltmeter) should be used to measure the charge build-up in all areas described in the preceding paragraphs. A very simple test can be conducted to determine the efficiency of the applied topical anti-stat. It is known as the "Shuffle Test" and is performed as follows:

a. Stand at any point on the carpet or floor area where the anti-stat is to be applied.

b. Turn on (electrostatic voltmeter) static locator, and record the reading.

c. Slide one foot back and forth over the floor.

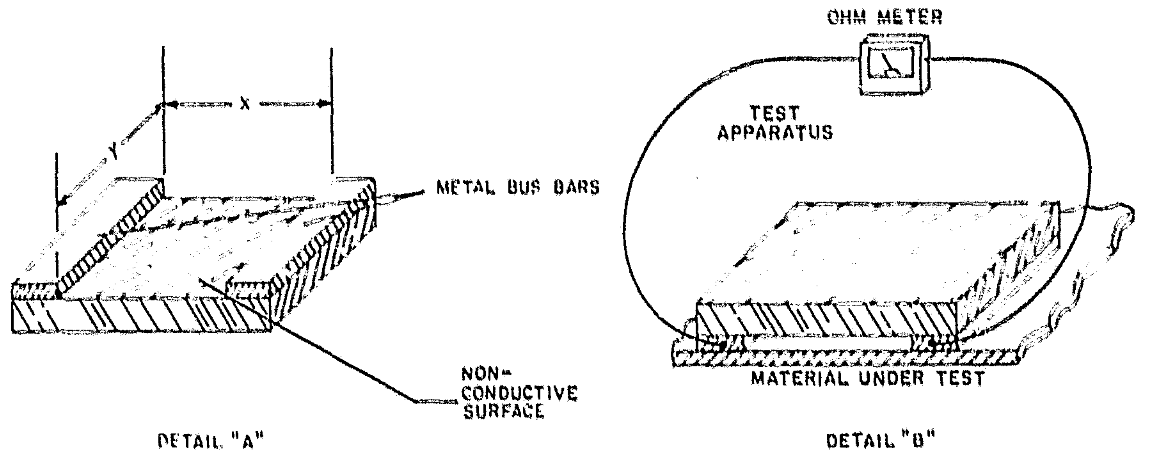
d. Lift foot off floor, and record meter reading.

e. Use same procedure after application of anti-stat.

The static locator can also be used to check the efficiency or the wrist strap by taking a reading of the bench area with the wrist strap off, and then attaching the wrist strap, and observing the change in the meter reading. The soft ground for the bench top can also be checked by touching the mat and again noting the meter reading.

5.0 CONCLUSION.

5.1 The foregoing general precautions apply to all activities in areas where ESDS components are located. Many things can impair the effectiveness of anti-static measures. The conductivity of floors, floor mats, work surfaces, etc. can be reduced by dirt or contamination. Ground connections can be broken by error, accident or by normal wear and tear. Those conditions are obvious, and can be easily corrected. Probably, the single most important factor is the awearness of all personnel of the damaging effects of ESD. Maintaining a static-free environment is virtually impossible; therefore, the handling of ESDS devices is of paramount importance.



NOTES

1 X DIMENSION EQUALS Y DIMENSION

2 X DIMENSION IS MEASURED FROM INSIDE EDGE OF METAL BAR

3 READING SHOULD BE ≤ 1000 X 10^6 OHMS PER SQUARE

4 MAINTAIN PRESSURE BETWEEN BUS BARS AND CONDUCTIVE SURFACE USING ADDITIONAL WEIGHTS IF NECESSARY TO ASSURE A FIRM AND STEADY CONTACT TO ENSURE ACCURATE AND REPEATABLE RESULTS PERFORM ALL TESTS IN THE EXACT SAME MANNER

5 INVERT TEST APPARTUS, AND USE AS SHOWN IN DETAIL "B"

Figure 5. Bench Mat Conductivity Check.

Appendix A

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Electrostatic Damage in Hybrid Assemblies

O.J. McAteer

Keywords: Electrostatic, Failure Analysis, Hybrid, Semiconductor, Transient.

Abstract

This paper discusses analysis of electrostatic damage to hybrid assemblies. Case histories of electrostatic discharge (ESD) problems on several different part types are described. In particular, subtle aspects of ESD failure analysis and part susceptibility are discussed. The results of these analyses are the development of a series of ESD corrective action measures to be considered by hybrid manufacturers and users.

Introduction

The electrostatic discharge (ESD) problem has been significantly publicized during recent years. However, most of this publicity has concerned ESD problems with discrete CMOS devices (Refs. 1,2), and very recently some acknowledgement of problems with other technology discrete devices (Refs. 3,4, and 5). The problems with the most severe consequences, and in many cases the highest probability of occurrence, are not at the discrete part level, but at higher levels of assembly.

Recent experience with hybrid assemblies has included ESD problems in numerous part types including bipolar devices, thin film substrates, ECL and CMOS devices. Examples discussed herein will illustrate certain subtle aspects associated with ESD problems along with corrective action considerations.

ESD Affects on Bipolar Devices

During lot acceptance tests on Westinghouse bipolar operational amplifier chips intended for hybrid usage, the most frequent failure mode was damage to the input transistor pair. In the most severe cases, the base emitter junction was degraded to a low resistance short or the reverse characteristic curve was shifted by several tenths of a volt. Physical damage typical of that observed is shown in figure 1. This failure mode was observed several years ago, prior to institution of extensive static prevention measures. The lot acceptance chips had been packaged in 14 pin DIP's for test purposes.

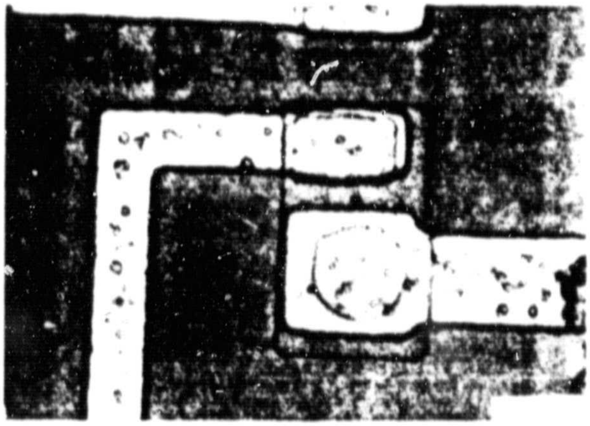

Figure 1. Bipolar Input Transistor Degraded by Severe ESD (2K X)

Since the failures were at the input transistors, the base junctions of which were tied to external pins, static electricity was suspected. This suspicion was fortified by occasional reverse voltage characteristic shifts observed during microanalysis.

Experiments were then conducted (in the month of February in Baltimore, Maryland, when the relative humidity is low) to attempt failure duplication via ESD. It was quickly found that the typical damage as shown in figure 1 could be inflicted by standing from the lab stool and touching the package lid. This motion built a sufficient static voltage on the body to destroy the device. The path of the transient was from the charged human to the package lid which is electrically tied to the package bottom and to the chip substrate. From the substrate the path was through a p-n junction to the collector of the npn current source transistor (Q14) to the emitter and then the base of the input transistor (Q1 or Q2). See figure 2.

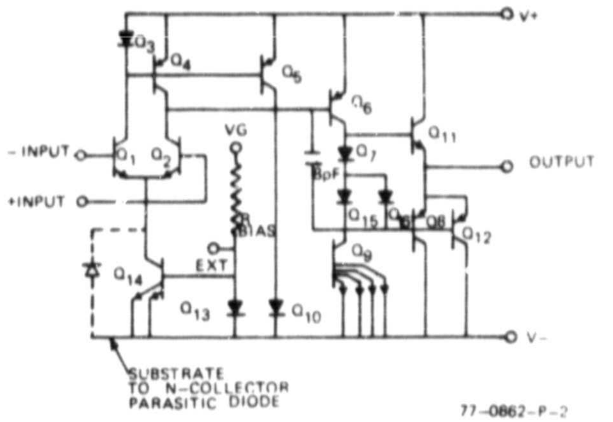

Figure 2. Bipolar Operational Amplifier Circuit Diagram

Subtle Bipolar Damage

During the same time period, there was another common failure mode where the "beta" of one of the input transistors would be "degraded" by 10% to 80%. The typical ESD physical damage was not observed.

Visible Damage Threshold Tests

The first phase of this investigation was to determine the threshold, if existent, where visible damage does not occur on statically destroyed devices. For this purpose an electrostatic voltmeter was utilized to measure the charge on a selected test person just prior to ESD through the package lid. To simulate actual test conditions, 100 ohms was tied between the inputs and ground. The pin-to-pin characteristic across the input pair was monitored before and after each discharge in order to get some idea of the extent of damage to the device. The results are given in table 1.

TABLE 1

ESD TESTS ON BIPOLAR DEVICES

Device	Charge (volts)	Initial Breakdown (volts)	Breakdown after Discharge (volts)
3–8	325	6.22	4.09
3–9	405	6.28	3.5
3–10	140	6.24	6.22
6–2	133	6.15	6.15
6–3	431	6.19	5.99
6–4	188	6.14	5.95
6–5	190	6.31	3.73
6–6	165	6.18	5.72
6–8	90	6.2	6.2
6–9	160	6.21	6.2
6–10	152	6.18	6.2

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Performance and pin-to-pin test data correlated very well with the degree of damage. Devices numbered 310, 602, 603, 604, 606, 609, and 610 showed no visible damage.

Beta Degradation Verification

In order to prove whether or not beta could be degraded by static discharge, another test was run. This time seven good devices were functionally tested, delidded, and retested to verify that there was no significant changes due to the delidding operation. The betas of the input transistors were then measured and the devices were subjected to static discharge to pin 6 (substrate) with an input pin tied through 100 ohms to ground. Results are given in table 2.

No visible damage was observed on devices 702, 704, 705, 706, and 708. Device 707 showed visible damage to Q2 but none to Q1. Transistor Q1 of device 707 became degraded even though the base of Q1 was not grounded. This phenomenon has been noted on other devices and is due to a relatively heavy charge, and the effective capacitive load caused by the leads and wires of the test box. Thus, a hard ground is not necessary in order to produce damage to these devices.

Physical Analysis

Detailed physical analysis on these subtle failures with no visible damage showed that after a partial silox etch, physical damage similar to that in figure 1 would become apparent (see figure 3). Thus, it was concluded that the physical mechanism was aluminum transport which begins at the silicon/silicon dioxide interface and thermally cracks the silox overcoat in the most severe cases.

TABLE 2

BETA DEGRADATION VIA ESD

Device	Charge	Initial Betas Q_1	Initial Betas Q_2	Final Betas Q_1	Final Betas Q_2
7–2	151 V	12	30	11	2
7–4	200 V	32	32	32	25
7–5	470 V	30	30	30	19
7–6	Not Measured	23	23	23	16
7–7	450 V	35	32	29	0.3
7–8	320 V	22	22	23	4.3
7–9	225 V	30	30	30	0.68

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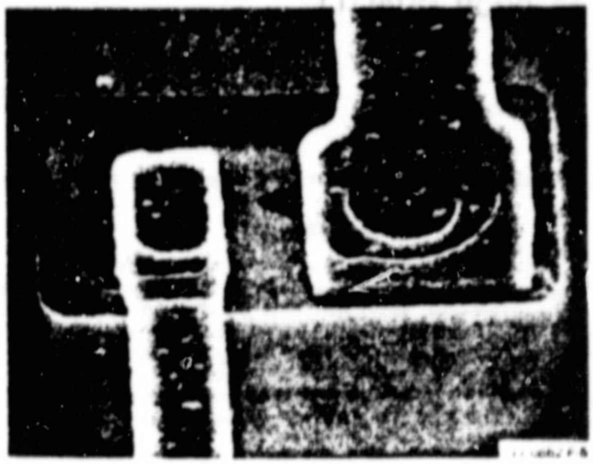

Figure 3. Bipolar Static Damage Made Apparent through Partial Silox Removal (2K X)

Shorted Substrates

A rather perplexing problem was experienced in hybrid units containing complex CMOS chips mounted on sapphire thin film substrates with two metallization intraconnect layers. In each case the shorts were isolated to scratched metallization crossovers on the sapphire substrates such as shown in figure 4. The CMOS chips were removed from the substrate shown in figure 4 to facilitate further analysis. After removal, the substrate was given an aluminum etch sufficient to remove any exposed second metal. Figure 5 shows the scratched crossover after this etch. Note that there appear to be cracks in the first silox layer that allowed removal of some first aluminum in addition to the second metal exposed by the scratch. The unit was then given a second aluminum etch to verify that the first aluminum was being etched through what appeared to be cracks in the silox. Figure 6 shows that the etchant did attack first aluminum at the crack locations.

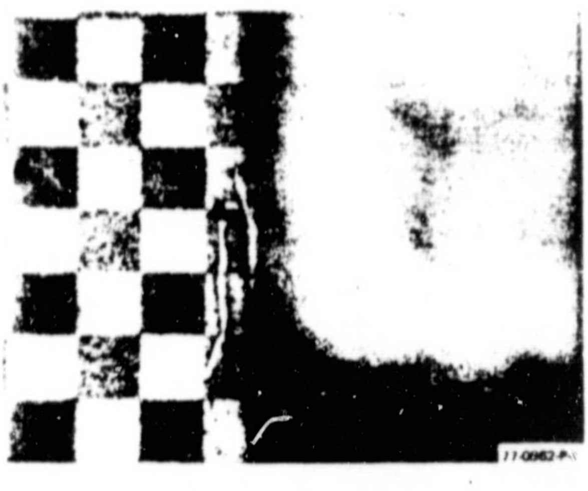

Figure 4. The Shorted Crossover (100X)

Figure 5. Shorted Crossover after Aluminum Etch (Note Cracks in First Silox (1000X))

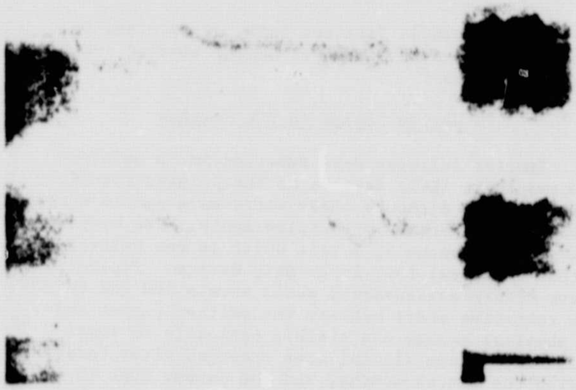

Figure 6. Shorted Crossover after Second Aluminum Etch (Note Increased Etching of First Aluminum through Cracks in First Silox (1000X))

The substrate was then SEM'd. The scratched areas and cracks are shown in figures 7 and 8. The quasi-square anomaly shown in figure 8 resembles the characteristic often observed after static discharge.

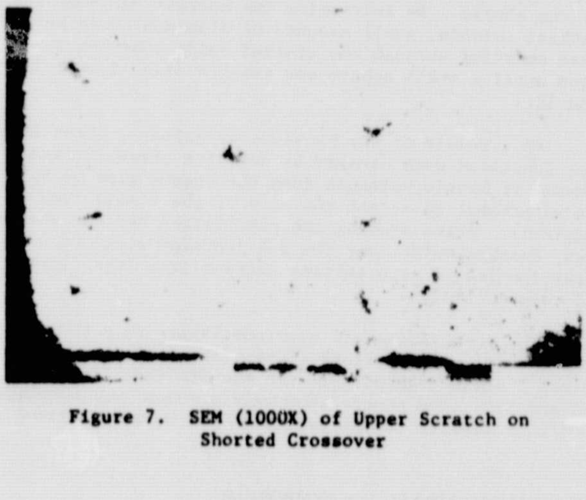

Figure 7. SEM (1000X) of Upper Scratch on Shorted Crossover

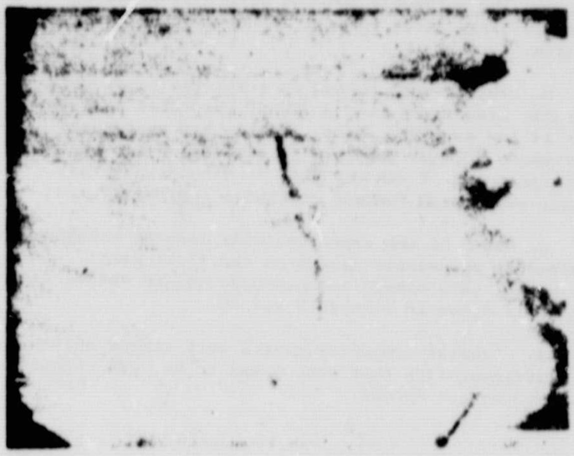

Figure 8. SEM (4K X) of Anomaly from Upper Scratch Resembling Static Damage

The four assemblies under investigation failed one week after the use of nylon coveralls and shoe covers was initiated. This led to a suspicion of static electricity.

Static Voltage Measurements

Measurements were made of static voltage levels in the assembly area under several combinations of footwear and outer garments. The following was concluded from the measurements taken:

a. The nylon shoe covers build very high (up to 20KV)* voltage levels on the person, especially when worn over shoes having gum type soles.

b. The coveralls tend to build high static charges (up to 20KV)* even without the shoe covers.

c. The ground straps are effective in bleeding off static potentials from a person's body.

d. The static build-up was generally low when conductive shoes were worn (0 to 250 V)*.

e. The conductive shoes were effective in bleeding off the body potential to a grounded floor plate.

f. Nylon overshoes with conductive shoes was a bad combination. The static potentials were high and did not bleed off.

g. The clean room garments can maintain a dangerously high potential even though the wearer's body is grounded.

---

* These measurements do not in any way indicate maximum levels for the clothing worn, but reflect the relative voltages after prescribed activity in the room atmospheric conditions on the day of measurement.

Failure Duplication

Experimental attempts to duplicate the short failures from scratches and subsequent static discharges were conducted in parallel with the physical substrate analysis. The substrate experiments gave the following results:

a. The purposely induced scratches produced cracks in first silox similar to those found in actual failures.

b. Shorts were formed in scratched crossovers by static discharges from a 200-pF capacitor at potentials as low as 150V. Note: In this and subsequent experiments, 200 pF was used to simulate human body capacitance and 1K ohm was used to simulate average contact resistance (unless otherwise indicated).

c. Some of the experimentally induced breakdowns resulted in observable damage to the first metal. In many cases, this damage had a pseudo-square shape. An example is shown in figures 9 and 10.

d. Several temporary shorts were formed during the experimentation that were found to be open circuited on subsequent checks.

Figure 9. SEM (450X) of Scratched Crossover Subsequently Damaged with 2 kV Discharge from ≈ 500 pF through 52K ohms (Note pseudo-square feature)

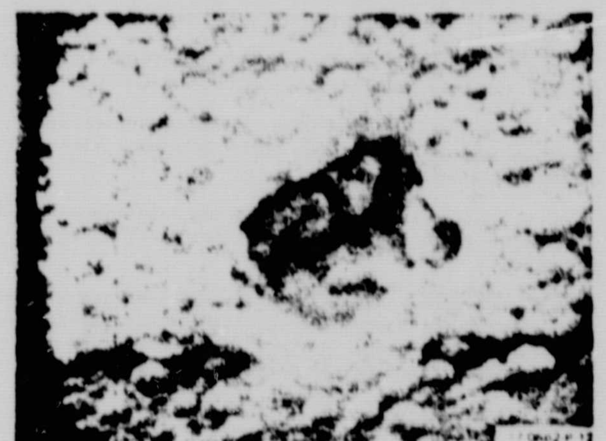

Figure 10. SEM (2.5K X) of Feature

CMOS Chip Experiments

The CMOS chips on the failed substrates were still functional even though CMOS devices are particularly susceptible to ESD. Experiments were conducted in order to verify that the CMOS chips would not fail when subjected to static discharges across the shorted substrate crossover nodes. The chips were given static discharges from 200pF in both polarities across these nodes on five different hybrid assemblies. The discharge levels were stepped in 20V increments from 40V to 200V, then in 50V increments up to 600V. The characteristic breakdown voltage across the two points in question was measured before and after each static discharge. A change in breakdown characteristic was considered to be a chip failure. The results were that for some polarity conditions, the CMOS chips withstood greater than 600V without damage. This proved that a scratched substrate could become shorted by ESD with no damage to the CMOS chips.

Conclusions

a. Scratches at crossovers can make the substrates very susceptable to damage from low level static electricity, transients, dc and/or ac voltages.

b. The hybrid failures analyzed were due to scratches at crossovers which became shorted due to static discharges.

Static Damage to ECL Devices

Similar failures were experienced on emitter-coupled logic (ECL) devices at the printed circuit board level. Although these parts were not in hybrid assemblies, the same principles apply. The symptom was several tenths of a volt shift in one emitter (or) output of a dual four-input gate device. Typically, curve tracer measurements would show a 100 ohm to 500 ohm resistive short between the emitter output and V_{cc}. No physical damage was visible optically on these failures. Since all failures occurred after handling during the winter months, and the output came to an external PC board jack, static electricity was the prime suspect. ESD tests revealed that a static discharge of approximately 500V from 200pF through 1K series resistance would duplicate these failures.

In order to isolate the physical site of failure two output E-B junctions of an electrically good device were damaged with a static discharge of 500V from 200pF while being observed with the SEM. A short of approximately 350 ohms was measured across each junction. SEM voltage contrast did not reveal the location of the shorts. By increasing the current to 250mA for several seconds, small amounts of aluminum could be seen emerging through the cracked oxide over the junction until a small sphere was visible (see figures 11 and 12.)

As a result of the previous experiment, three output junctions were damaged by applying three different levels of static voltages from the output pins to V_{cc} in an attempt to accent the site of the damage (see table 3). After etching the passivation and the aluminum, damaged oxide over the E-B junction could be seen near one end of each emitter contact area (see figures 13 through 15).

The passivation and aluminum layers were then removed from actual failure items. The devices were given a close examination with the SEM (see figures 16 and 17). The photos show emitter-base oxide damage which is similar to the damage on the devices inten-

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tionally overstressed with static discharge. This damage also begins from the same point in the emitter contact area as on the devices intentionally damaged with static discharge.

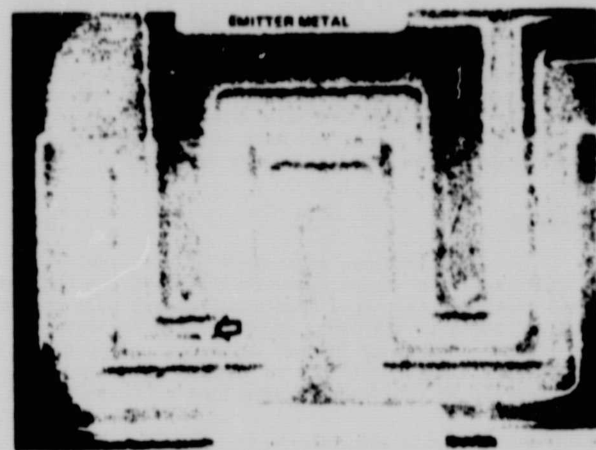

Figure 11. ECL Short Caused by Static Discharge (+500V, 200pF)

Figure 12. Enlargement (2.5K X) of Sphere in Figure 11

TABLE 3

ESD TESTS ON ECL DEVICES

Applied Voltage	Output Pin Shorted to V_{cc}	Resistance of Short to V_{cc}
+5000V	Pin 6	114 ohms
+2000V	Pin 2	211 ohms
+500V	Pin 7	300 ohms

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Figure 13. Output Transistor 2 After Partial Passivation Etch (600X)

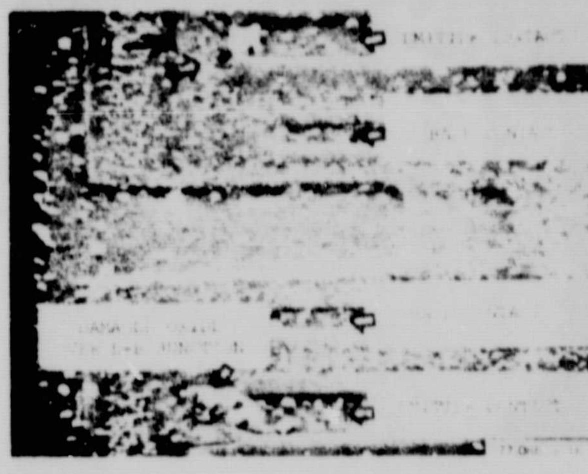

Figure 14. SEM Enlargement (1.5K X) of Transistor 2 in Figure 13 after Passivation and Metal Etch

Figure 15. SEM (5K X) of Damaged Emitter Finger Area in Lower Half of Figure 14 after a Partial Oxide Etch

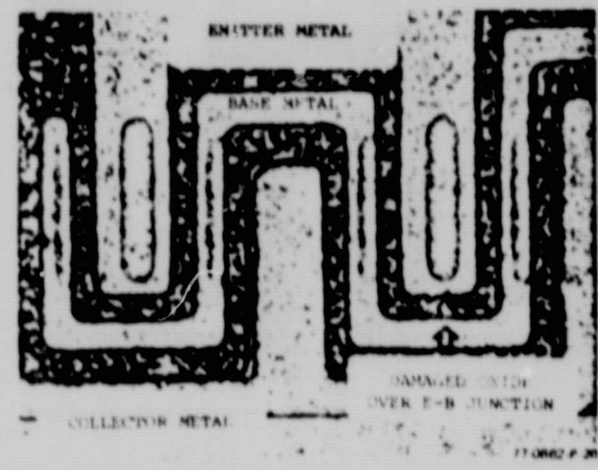

Figure 16. After Passivation Etch (700X)

Figure 17. SEM (7K X) of Emitter Finger Shown in Figure 16 after Metal Etch

Multiple Damage to ECL From ESD

A subsequent failure of this same device type occurred that had some different symptoms. Electrical pin to pin measurements with a curve tracer indicated an 80-ohm short from V_{cc} to output 1. Also, outputs 2 and 3 measured 7.5K-ohm and 4.5K-ohm shorts to V_{cc}. Output 4 showed a leaky reverse base-emitter characteristic. The device was then delidded and examined. Evidence of damage was seen only in the output 2 transistor emitter-base area (see figure 18). The damage occurred in both ends of the emitter fingers which is typical of static damage to this device. Characteristics of this failure which were not typical are the fact that more than one emitter-base junction was damaged and that the damage was visible without etching the passivation or aluminum.

A transient of a wider pulse width than a typical static discharge was considered as a possible cause of the visible damage. A sample output was pulsed with a one-shot, 400V pulse in steps from 60 nsec to 26 μsec where an open circuit to V_{cc} was detected. This device was then delidded and examined. It was seen that the emitter metalization had melted open (see figure 19). The electrical and visual characteristics were quite different from the actual failure, so a static charge of higher voltage was proposed as the cause of the failure. Three devices were damaged by ESD at levels of 600V, 5000V, and 10,000V with proper loads (300 ohms from each output through 0.33uF to GND; V_{cc} at GND) applied to the outputs. The electrical results (see table 4) show that more than one output emitter-base junction can be damaged or degraded when only one of the outputs is hit with a static voltage. Microscopic examination of the output hit with 10,000V shows damage at both ends of the emitter fingers (see figure 20).

Conclusion

Because the previous experiment closely duplicates the electrical and visual characteristics of the failure, it was concluded that this device failed due to a static voltage (+5000$_V$ to +10,000$_V$, 200pF) coming in contact with output 1. This is further supported by the fact that similar damage could not be induced with slower transients or by long term reverse bias or forward bias tests.

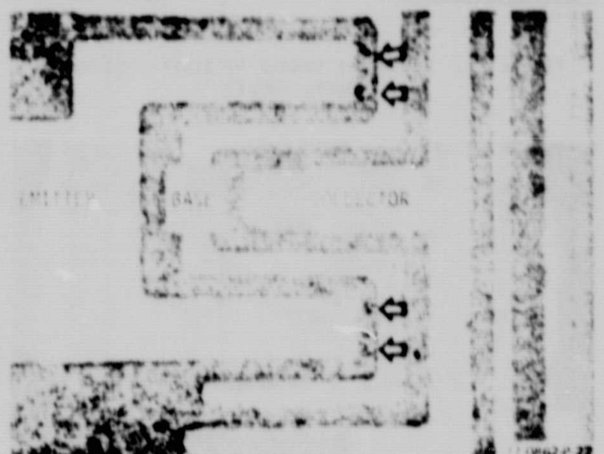

Figure 18. Damaged Oxide Over Emitter Base Junction (700X)

Figure 19. Output Transistor Open Emitter Metal (400V, 26 μsec) (300X)

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TABLE 4

ESD EXPERIMENTS ON ECL DEVICES

Device No.	ESD from 200 pF (Through 1K Ohm)	Output Pin Damaged	Result of Damage (to V_{cc})
1	+800V to Pin 2	Pin-2	370-ohm short
2	+5000V to Pin-2	Pin-2 Pin-3 Pin-6 Pin-7	115-ohm short 2 Meg short Increase in reverse leakage Increase in reverse leakage
3	+10,000V to Pin-2	Pin-2 Pin-3 Pin-6 Pin-7	130-ohm short 280-ohm short 410-ohm short 280-ohm short

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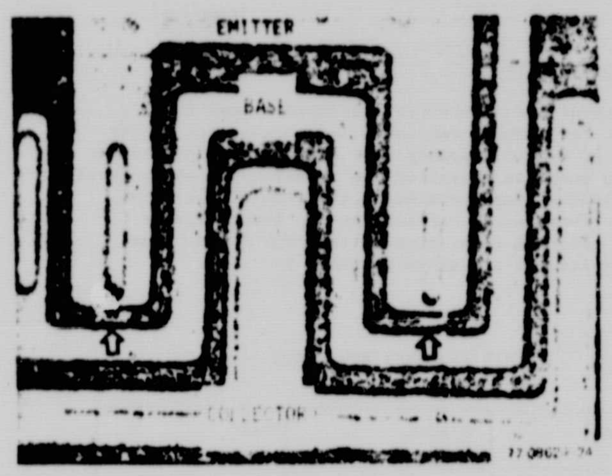

Figure 20. Damaged Oxide Over Emitter Base Junction (800X)

CMOS Failures due to ESD

Immediately following installation of a new electrical test station, there were numerous failures of a large hybrid assembly. Fault isolation indicated that a very complex CMOS chip was the failed device. Delicate electrical microprobing could usually further isolate the problem to a short between two nodes of the CMOS chip. However, the shorted nodes would commonly have approximately 50 CMOS gates in parallel. Since there was no visible defect, the exact gate at fault was not known. It might have been possible, albeit impractical, to find the failure site by sequential chemical etching and microscopic/SEM examination.

This is an excellent example of the value of the cholesteric liquid crystal method whereby the exact short site was located prior to etching. Sequential etching of layers then reveals the physical anomaly for further study (see figures 21, 22, and 23). For comparison, an example purposely damaged by 190V ESD from 200pF is shown in figures 24, 25, and 26.

Experiments were conducted in order to determine static susceptibility of these CMOS devices under different loading conditions. The hypothesis was that a device would be most susceptible to static with one or more nodes tied to a good ground; least susceptible with nothing attached to any nodes; and that the susceptibility would vary with the amount of stray capacity tied to nodes in any other "ungrounded" conditions. This hypothesis was supported by experimental results as shown in table 5.

Figure 21. Shorted CMOS Gate (1K X)

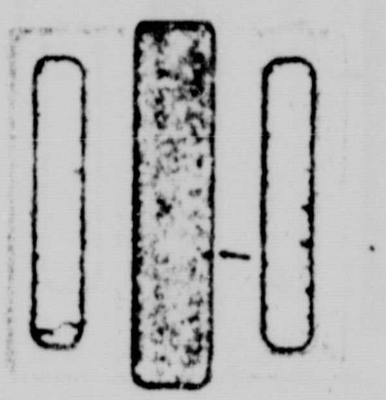

Figure 22. Shorted Gate, after Removal of Silox and Aluminum, Located by Liquid Crystals (1K X)

Figure 23. SEM View of Defect (13K X) (Note Hole)

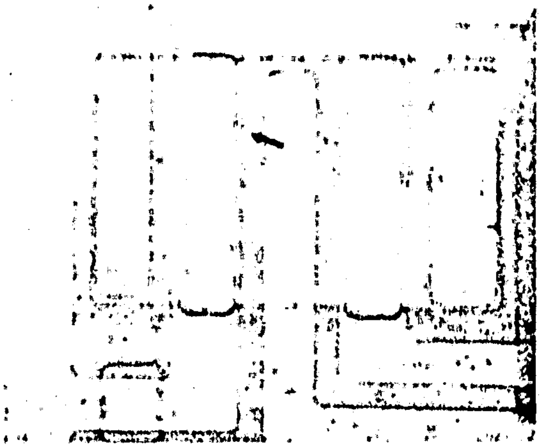

Figure 24. Shorted Gate after Silox Removal and Liquid Crystal Detection (700X)

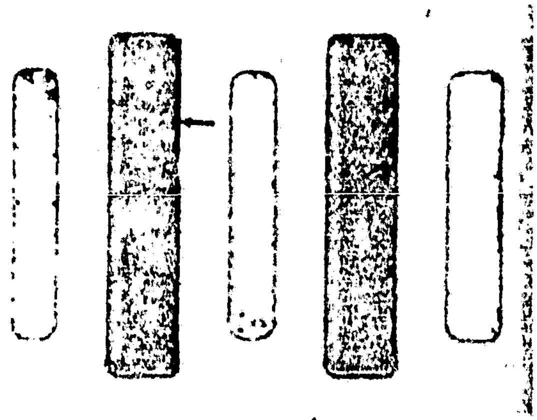

Figure 25. Shorted Gate after Removal of Aluminum (800X)

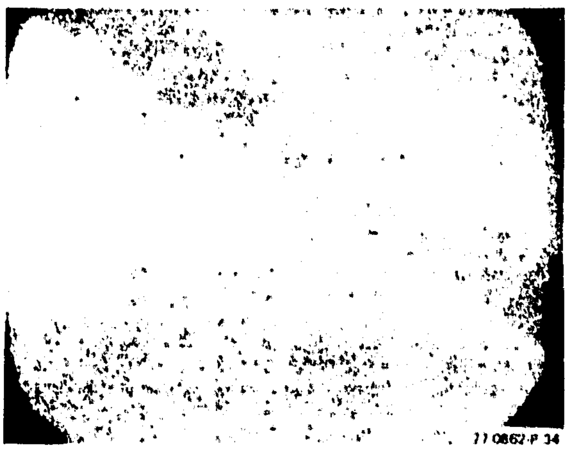

Figure 26. SEM of Defect (18K X)

TABLE 5

LOAD CONFIGURATION EXPERIMENTS

STATIC POTENTIAL REQUIRED to damage device (discharge from 200 pF capacitor applied to Pin 1)	LOAD CONFIGURATION ON PIN 2
≈3000 V	9-inch, 30-gauge wire (hanging in mid-air)
≈500 V	9-inch, 30-gauge wire plus 3 feet 20-gauge wire (hanging in mid-air)
>100 V, >600 V (2 cases)	9-inch, 30-gauge wire tied to ground
≈600 V	9-inch, 30-gauge wire in grounded chassis
≈1000 V	9-inch, 30-gauge wire in ungrounded chassis

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Hybrid Assembly Tests

Observations of the test operations lead to a series of tests under realistic load conditions likely to occur at hybrid assembly test stands. The particular hybrid in question contained two insulated 30-gauge wires, about 9 inches long, epoxied to the side of the metal package. These wires carried the two input signals from the external input pins to the CMOS chips. The tests and results are given in table 6.

TABLE 6

HYBRID ASSEMBLY ESD TESTS

Configuration	STRESS Test	Result
One input floating One input connector to center conductor of 1 foot RG59 coax cable (shield grounded)	ESD applied to power ground pin	CMOS with input tied to coax cable failed at >750 V
Power ground applied All other inputs floating (no cables, lines or other loads)	a) ESD applied to floating metal package (from 200 pf through 1.K). b) ESD applied from human body	CMOS device destroyed at >700V CMOS device destroyed at >1000V. (See note below.)
All inputs floating	ESD applied to floating metal package	No damage at o KV from 200 pf (capacitor voltage limit)
All inputs floating	ESD applied to package from ≈ 20 pf Van de Graff generator	CMOS failed at ≈ 60 KV

Note: This test indicated that the human body simulation model used (200 pf through 1K) was quite good.

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Conclusions

a. The hybrid assembly failures investigated were caused by static discharge. This is supported by very close correlation of actual failures with experimentally induced failures, both in defect location and appearance. The fact that multiple failures occurred on the failed hybrids is also characteristic of static damage. Multiple failures occurred on several of the static discharge experiments as well.

b. CMOS chips can be particularly susceptible when assemblies are connected into test fixtures. The primary hazard at these stations is capacitive coupling a discharge from the chassis to internal wires or other conductors.

Corrective Action Considerations

There exists already a good number of articles discussing detailed ESD corrective action measures. Therefore, this discussion will be limited to highlighting items for consideration

An effective ESD prevention program should include the following:

a. Personnel Electrostatic bleed-off apparatus (*See Note below)

(1) Conductive ground straps (with series resistance of ≈ 1 Meg ohm) for personnel at stations requiring little or no operator movement.

(2) Grounded floor mats and conductive shoes for stations requiring considerable operator movement.

(3) Ground work surfaces, such as table tops.

(4) Grounded tools and handling instruments such as wire cutters, tweezers, etc.

(5) Ionized blowers at critical stations where ESD problems exist from insulating materials such as clothing, tapes, plastic, etc; or where other personnel or equipment grounding methods are impossible or impractical.

Note: All grounding apparatus for ESD avoidance, especially direct personnel grounding equipment should be reviewed by the Safety Department for possible hazards.

b. Equipment Electrostatic Bleed-off Apparatus

(1) Grounded equipment such as test and assembly chassis, wire bonding equipment, including capillaries, cleaning nozzles, microscope stands, microprobe stands, soldering irons, and any other assembly holding or tooling apparatus.

(2) Ionized blowers are recommended at bonding stations.

c. Clean Room Considerations

(1) Elimination of nylon overshoes.

(2) Regular periodic checks and controls or anti-static treatment of clean room garments. (Ionized blowers may be necessary if effective garment treatment can not be obtained).

d. Hybrid Assembly Consideration

(1) Comprehensive ESD avoidance procedures.

(2) Shorting bars for external leads.

(3) Special grounding connectors for susceptible outputs at PC board or other higher assembly levels.

(4) Ionized blowers during sensitive subassembly handling.

(5) Conductive transport containers.

(6) Specified wire-bonding order.

e. Special Considerations

(1) Multi-metallization pattern devices must have strict inspection criteria for physical damage applied to crossover regions.

(2) Where possible, electrical isolation tests at several hundred volts should be performed on multilevel substrates.

f. General Considerations

(1) Training of personnel in ESD awareness.

(2) Elimination, as possible, of notorious static generators such as plastic envelopes, nonconductive tapes, and other plastic, nylon and rubber paraphernalia.

(3) Engineering must be static - conscious and consider ESD avoidance as a design parameter when incorporating new designs, tests, or procedures, or modifying existing ones.

(4) It is extremely important to take appropriate static precautions during failure analysis, so that new problems are not introduced.

Comment

The considerations recommended herein are believed to contain the elements of adequate and effective precautionary procedures. However, the possibility of human error remains, such as not properly attaching the wrist strap. This problem can be reduced by utilization of redundant measures such as grounded floor mats in conjunction with wrist straps. Each facility must be tailored to the needs with consideration for safety, cost, yield, ESD sensitivity, and other factors.

References

1. D. Lyons, "Protect Your MOS Devices for Better Reliability", Quality Management and Engineering, April 1973.

2. Joe Kroeger, Bruce Threewit, "Heed the Limitations of MOS I/O Circuitry", Electronic Design 10, pp 82-88, May 10, 1974.

3. T.S. Speakman, "A Model for the Failure of Bipolar Silicon Integrated Circuits Subjected to Electrostatic Discharge," 12th Annual Proceedings, Reliability Physics, pp 60-69, April 1974.

4. E.R. Freeman and J.R. Beall, "Control of Electrostatic Discharge Damage to Semiconductors," 12th Annual Proceedings, Reliability Physics, pp 304-312, April 1974.

5. R.P. Himmel, "The Effect of Static Electricity on Thick Film Resistors", Insulation/Circuits, pp 41-44, September 1972.

Biography

Owen McAteer received his BSEE and MSEE from the Johns Hopkins University in Baltimore, MD. His Reliability Engineering career at Westinghouse began in 1964 after several years in circuit design. In June of 1973 he became a Supervisory Engineer responsible for organizing and directing the Microanalysis Laboratory at the Westinghouse Advanced Technology Laboratories. Since June of 1976 he has been an Advisory Engineer. In this position he retains direction of the Microanalysis Laboratory and is technical consultant to the Reliability Engineering group on Reliability Physics matters. Much of his recent experience has been on hybrid assembly problems.

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Appendix B

Additions to JPL Technical Information Bulletin 377S2-4E9.

1.2.2 Recent studies and analyses of failed components indicate the following devices should be added to the list:

(e) Film resistors (thick & thin)
(f) Operational Amplifiers
(g) Bipolar Transistors
(h) SAW

2.1.8 An antistatic laboratory coat which uses a metal-fiber impregnated cloth (manufactured by Simco company) has been proven effective.

Figure 3. Avoid the connection shown to the metal frame, since it could result in a hard ground.

2.1.16 The edsyn "Silverstat" solder-sucker is static free and can be safely used at work stations.

2.1.28 Use a topical anti-stat such as Analytical Chemical Laboratories, staticide, or Richmond Resque.

2.1.29 All work stations should be provided with an electrostatic meter, and an ohms-per-square measurement must be made periodically. See figure 5 of the manual.

2.2.2(c) Because protective networks do not always provide adequate protection from electrostatic discharge, and could give a false sense of security, the items listed under paragraph 4.1 of the manual should be observed.

2.2.3(c) Leather-soled shoes or conductive shoe bags should be worn. Straps should be worn over composition or rubber soled shoes. In any case shoe soles should be treated with Topical Antistat.

2.4.8 Insulate all fixtures, test equipment, and associated apparatus from the ESD conductive cover, see figure 3 of the manual.

3.1.2 Metal sheets should not be used for a work surface because they do not provide a soft or slow drainage of static charges (≈.06 second). Also, the work surface cover should not be grounded to the bench frame (see figure 2 of DOD-HDBK-263). It is not necessary nor desirable to fasten the conductive mat to the work bench, because most mats have a non-skid backing. The attaching screws could interfere with the conductive path through the mat scrim.

3.3 Change to 3M type 2100, or equal, protective bag. Though there is some controversy among manufacturers, the type 2100 is generally considered to be a superior design compared to the "poly" type.

TYPEFACE SPECIMEN SHEET

The following typefaces and type sizes were utilized in preparing copy for this technical manual.

Marginal copy, Table Titles, Heads for Table of Contents, List of Illustrations, List of Tables, Subordinate Sideheads, Text and Tables	- Xerox 850 Page Display Word Processor with an Elite 12 Printwheel
Primary Side Heads	Bold Feature on Xerox 850 with Elite 12 printwheel

EQUIPMENT DOCUMENTATION

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Sheet ___ of ___

APPENDIX C

ELECTROSTATIC DAMAGE TO CMOS ANALOG SWITCH

The following photos show the physical damage suffered by two CMOS Analog Switches Type 7511DIJN. This particular switch is used in the STDN Voice Communications System (VCS) Solid State Matrix Card #1386408 as U14 through U22.

These particular cards were shipped to a station without ESD protection and were damaged in handling. The protective measures outlined in Paragraph 4.0 ESD Prevention were implemented following the discovery of the ESD damage. No reports of a similar failure have been received since the outlined procedures were followed.

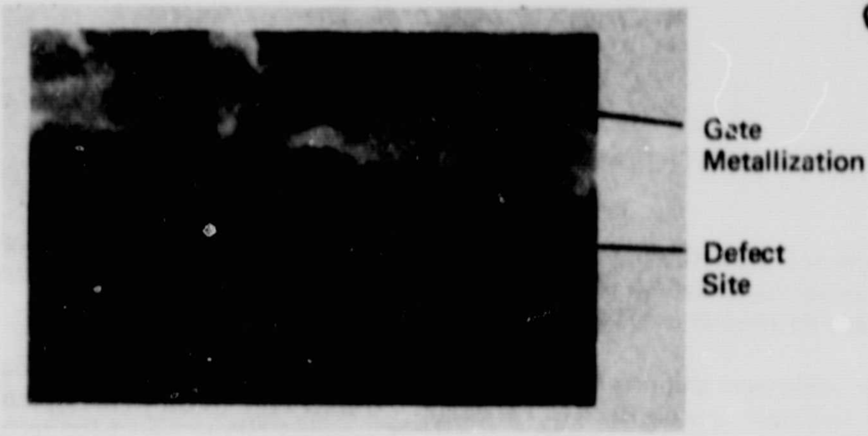

Figure 6a. SN1. 800X

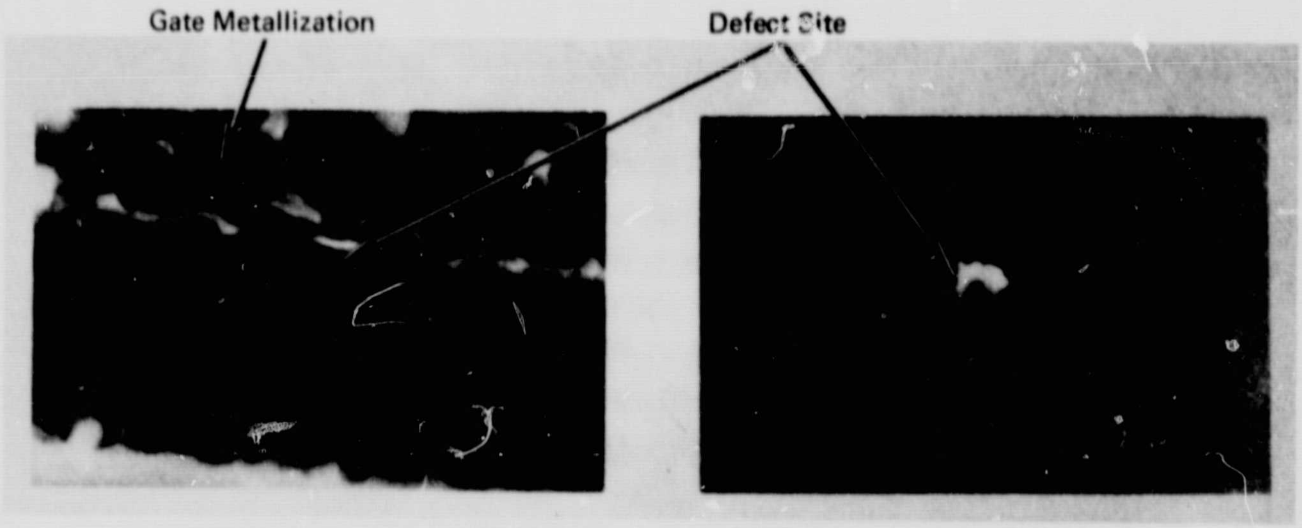

Figure 6b. Views of the gate overstress before and after removal of the gate metallization in SN3. 500X

Figure 6 Photomicrographs of the gate electrical overstress sites in two Micro Power Systems microcircuits.

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APPENDIX D

STATIC CONTROL USING TOPICAL ANTISTATS

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SUMMARY

Triboelectric static charges can be prevented by using properly selected topical antistats. Utilizingthe concept of Environmental Static Control (ESC), the burden of a company's overall static control program can be shifted from the line employee to a management team made up of operations and maintenance personnel. If proper instrumentation is employed, constant performance feedback and detailed analysis are available. As a result, the optimal return in static prevention, at the lowest possible cost can be achieved.

INTRODUCTION

For years industry has focused its efforts in dealing with static as the cause of its problems rather than treating it as the symptom of a more serious, underlying problem. We have created ionization and new packaging materials, discovered grounding, and employed these techniques as means to suppress the effects of static in our environment. These efforts have been positive and worthwhile; however, static remains a problem. It is time to deal directly with the causes of static rather than its effects. The question becomes, "If static is a natural phenomenon, how do we deal with the causes? We cannot change nature any more than we can change the weather." This paper presents a practical rather than theoretical approach to this problem, utilizing topical antistats as the controlling media. We will introduce a concept of Environmental Static Control (ESC) and present the role of topical antistats in this approach. The various factors of problem cause, functions of topical antistats, selection and application factors will be explored as they relate to industry in general, and to electronic environments specifically.

THEORY

Other than chemically and electrically induced charges, common static as we know it is created when materials separate; one material strips electrons from the other, leaving it positively charged. The host material then becomes negatively charged. Rubbing is multiple separations. The result is known as a triboelectric charge, a charge caused by friction or separation.

The Triboelectric Series (Table I) shows the charge relationships of many materials. Note that COTTON is identified as a reference material being at mid-point of Table I. It tends to absorb moisture, thereby rendering it somewhat conductive. However, when COTTON is rubbed against another material, it has the ability to produce a static charge.

TABLE I

Triboelectric Series	References
AIR	1
HUMAN HANDS	1
ASBESTOS	2
RABBIT FUR	3
GLASS	2,3,4
MICA	3
HUMAN HAIR	2
NYLON	2,4
WOOL	2,3,4
FUR	2,3,4
LEAD	2
SILK	2,3
ALUMINUM	2,4
PAPER	2,4
COTTON	1,2,3,4
STEEL	2,4
WOOD	3,4
AMBER	3
SEALING WAX	2
HARD RUBBER	2
NICKEL COPPER	2,3,4
BRASS SILVER	2,3,4
GOLD PLATINUM	3
SULFUR	3
ACETATE RAYON	2,4
POLYESTER	4
CELLULOID	3
ORLON	2
SARAN	2
POLYURETHANE	1,4
POLYETHYLENE	2
POLYPROPYLENE	1,4
PVC (vinyl)	4
KEL-F (CTFE)	4
SILICON	2
TEFLON	2,4

ELECTROSTATIC OR TRIBOELECTRIC SERIES REFERENCES

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2. Keers, J.J. and Kunz, R.J., "Nuclear Static Eliminators, Their Development and Uses", Nuclear Products 3-M Company.
3. Sarbacher, R.I. ScD, Encyclopedia Dictionary of Electronics and Nuclear Engineering, (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1959) p. 449

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4. "Triboelectric Series" MIL-HDBK-XXX(NAVY). Project RELI-No. 12. 15 November 1978. Table 1 p. 7.

Materials listed above COTTON tend to assume a positive charge by giving off electrons in a friction/separation situation: while those listed below COTTON become negatively charged by acquiring electrons. When any two materials experience separation or rubbing, the material listed highest on the table will become positively charged, and the lower listed material will accept the negative charge. (See Table I)

For the sake of simplicity, let us define the cause of common static as the FLOW OF MATERIALS AND PEOPLE WITHIN AN ENVIRONMENT. Materials include all components, packaging and other raw materials which make up our finished goods. People carry and generate charges, and it all takes place within a defined environment made up of facilities and equipment. The environment is not limited to a plant, but can be defined as a package, or many plants as in a transport situation.

Static, as it manifests itself in our environment, is actually a symptom. If we can impose control on the elements which create static as an end result, we can control the generation of a myriad of problems caused by static.

Topical (surface coating) antistats have proven their effectiveness in imposing control in static generation as it relates to triboelectric charges. When properly selected and applied to environmental factors, materials and personnel clothing, a measurable degree of static prevention and control can be accomplished.

WHAT ARE TOPICAL ANTISTATS?

Topical antistats have been known by industry as sprays. We look at them with jaundiced eyes - we do not understand their functions, potential contamination, or how long they last in a given application. The fact is, much like the Electronics Industry, topicals have evolved and grown to very sophisticated levels of function and performance so that we can no longer ignore their presence or potential.

Topical antistats are generally liquids which when applied to a surface or material renders it static controlled. They usually consist of two basic components:

1. CARRIER - The vehicle that transports the antistatic mechanism. It acts as a solvent and can be water, alcohol or other solvent.

2. ANTISTATIC MECHANISM (OR ANTISTAT) - The primary material which when deposited on a substrate performs some static control or charge prevention function.

It is the carrier which allows us control of the amount and application of the antistat. The antistatic mechanism determines the method of static control, longevity characteristics and net performance of the material. Major types of organic antistatic agents include quaternary ammonium compounds, amines and their derivatives, phosphatic esters, fatty acid polyglycohol esters and even polyhydric alcohol derivatives such as glycerine and sorbitol.

Overall, topicals are designed to MINIMIZE CHARGING AND DISSIPATE A GENERATED CHARGE BEFORE IT BECOMES A DESTRUCTIVE OR OBJECTIONABLE FACTOR. They function in three ways in order to provide maximum performance.

First, TOPICAL ANTISTATS REDUCE MATERIAL COEFFICIENT OF FRICTION by increasing surface lubricity. This tends to reduce the maximum potential charge that can be generated in a frictional or triboelectric situation. This is the first step in dealing with the cause of the charge. Even though we limit the maximum potential, static can and will continue to be induced in the material; where the limited charge will go and how quickly brings us to the second topical antistatic function.

TOPICAL ANTISTATS INCREASE SURFACE CONDUCTIVITY on virtually any material. Normally, most man-made materials tend to be non-conductive and therefore do not easily pass, or dissipate a charge. For example, a polymer with a normal surface resistivity of 10^{14} to 10^{18} ohms/sq. can be modified with a topical antistat to a resistivity of 10^{6} to 10^{11} ohms/sq.. In fact a quality topical will provide controllable conductivity; one may select the degree of conductivity desired by increasing or decreasing the amount of carrier. Once the material is surface conductive and can dissipate a charge, where that charge is conducted is another matter; which brings us to the third function.

TOPICAL ANTISTATS INTERACT WITH ENVIRONMENTAL FACTORS to dissipate generated charges. Though grounding is a normal procedure with conductive materials, it is not always required when the material is treated with a topical antistat. Because of this third function, grounding is optional depending on the application. Some topicals absorb moisture from the ambient air and form a conductive vapor layer on the material's surface. This layer not only allows a material to pass a charge to ground, but also can more readily conduct a charge to ambient air with adequate relative humidity. As some of you have already discovered for yourselves, some antistats are subject to poor performance as the relative humidity falls below 35 to 40 percent. Modern topical antistats are not so humidity dependent as their forebears and function in a more reliable manner.

Today's topical antistat has the ability to help prevent a significant charge from being generated during the friction or separation process. Two schools of thought have emerged regarding this phenomenon. The first, is the increased conductivity of the topical antistat allows the two materials to more readily exchange an appropriate amount of electrons during the generation process. In this manner, the materials maintain or acquire a sufficient electron balance so that the triboelectric effect is minimized, and the resulting charge is either non-existent or very small. If a charge exists after this initial exchange, the topical antistat conducts it across the material's surface to the various edges and points for dissipation to the ambient air.

The second school of thought describes the modern topical antistat as having the ability to introduce an abundance of positive and negative ions across the material's surface in a balanced manner. Therefore, when a triboelectric charge is being generated at a given point on the surface, the ion inventory is more than adequate to neutralize a great portion of the charge; and can also dissipate a charge to the ambient air through a form of ion exchange. In this latter effect the topical antistat theoretically interacts with ambient free ions which are in the form of non-particulate radiation, thermal neutrons and the like to neutralize the material's charge.

Regardless of the theory one chooses to identify with, the efficient topical antistat performs very well in preventing static charges. In addition, the modern antistat has the ability to perform with surprising effectiveness at and below, 15 percent relative humidity.

ENVIRONMENTAL STATIC CONTROL (ESC): THE BASICS

As we have defined, common static comes from the FLOW OF MATERIALS AND PEOPLE WITHIN AN ENVIRONMENT. People carry and generate charges within a defined environment made up of facilities and equipment. Though the environment is not limited to a plant, for our purposes let us utilize the production facility as the environmental model.

The work environment consists of floors, walls, ceilings, fixtures and certian large pieces of equipment. All of which contribute to the generation of triboelectric flow across them. All of these environmental surfaces can be treated effectively with topical antistats to minimize static generation. Except in those cases where cleanliness and total control is absolutely required, most facilities implement their first ESC step by treating floors.

Facilities with sealed wooden or cement floors, or carpeting and non-conductive tiled floors have an especially difficult time with static charges. These materials are non-conductive by nature and will help develop and hold harmful triboelectric charges very easily. Though most people would not feel the result of these charges, sensitive components and assemblies are plagued in these areas. Regardless of the type of floor, proper treatment can eliminate these charges and the resulting effects. Application is fast, easy, very inexpensive and relatively long-lasting, in every case.

Hard floors without carpet, may be treated during the normal maintenance operation of washing. Simply add a cup of quality antistat concentrate to the bucket of wash water. With this one act, charges normally generated when people, materials and equipment pass across the floor can be prevented. Carpets can be sprayed with a high friction resistant antistat formula and provide the same results. One treatment can last for months depending on traffic conditions. All treated areas should be monitored with appropriate static instruments to determine optimal treatment frequency.

Before a company invests large sums of money for modifying common floors with special tiles, pads and other devices, they should clean and treat their floors with a topical antistat. A controlled test should be made of the antistat's performance against plant requirements. In most applications, modifications will no longer be necessary. Previously modified floors must be properly maintained to provide optimal performance and the use of a topical antistat will maximize results.

Basically, the first step in Environmental Static Control (ESC) is to treat the key factors in the environment, and those are:

FLOORS

FLOOR MOUNTED FIXTURES & MAJOR EQUIPMENT

ESC options are for those who must maintain maximum dust/particulate control. These options include:

WALLS & CEILINGS

LIGHT FIXTURES & HANGING EQUIPMENT

VENTILATION SCREENS

Practical test applications have proven topical antistats to be very helpful in controlling dust and particulate attraction to environmental surfaces. In the case of fluorescent lighting fixtures, an antistat was applied to the tubes and the fixtures. Except for natural gravity fallout, no dirt has attracted, resulting in brighter light with lower maintenance costs. Office environmental tests on all paneling over a five year period indicates that no static dirt attraction occured on treated panels.

A most difficult case involved unpainted

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cinder block walls in a Johnson and Johnson Baby Products Company fiber grinding operation. Airborne fibers first became physically attached to the cinder blocks' extremely rough surface. Secondly, static charges on entrapped fibers attracted other airborne fibers and subsequently formed fiber strands as long as ten inches. The net effect was a moss like wall coating which floated and moved with the air current in the room, giving the appearence of an eerie underwater scene.

After cleaning the thirty foot high walls, alternating treated and untreated sections were designated. The treated sections were coated with Regular STATICIDE^{TM} antistat using a common paint roller. After several weeks, a typical accumulation of fibers developed on the untreated wall sections. Panels coated with the topical antistat showed evidence of individual fibers being physically attached to the rough cinder surface. However, there was no static attraction of additional fibers. As a result, the treated sections looked clean and remained free of stringers and fiber accumulation. Subsequent maintenance cleanup cost savings exceeded treatment costs by a ratio of 30 to 1.

The application of topical antistats to the optional environmental surfaces allows the facilities air filtration system to perform its job more efficiently. No longer attracted to surfaces, the particulate remains airborne and is part of the air flow. It is then filtered out of the environment by the air processing equipment. Gravity fallout of particulate is dealt with using normal maintenance techniques.

PEOPLE

When surveying personnel skin charges, one finds that the bulk of their charge is created when crossing the floor as they move to, from, and at their work stations. Though a proper floor treatment will eliminate the triboelectric charge generated between a person and the floor, employees' clothing creates its own charge. It is difficult at best to control what an employee wears as under and outer garments; most of you have faced this delicate challenge at one time or another with varied results. A quick self-application of a non-toxic, non-staining, non-hazardous topical spray can eliminate this problem. An interesting fact about self- treatment is that all garment static cling is eliminated. As a result, blouses and slacks look and feel better; slips and skirts do not cling. Subsequently, most employees use the antistat willingly. In addition, the same antistat is normally used for work station cleanup.

For optimal results, each work station should be equipped with a refillable applicator of approved antistat for personnel use.

MATERIALS

Virtually any material can be rendered safe for use in a static sensitive environment with topical antistats; these include tapes, labels, films, foams, trays, carts, paper, textiles, plastics, containers used for packaging and handling, cabinetry, masks, shrink wrap, lenses, structural components, certain boards, rails, harnesses and cable runs, CRTS, and tools. Once treated with a quality long-lasting antistat, these materials become an integral part of your static prevention program.

A series of wool rub tests and electrostatic decay tests indicate that topical antistatic coatings will control static charging on most materials. Table II summarizes specific antistatic performance of individual materials commonly found throughout industry before and after antistatic treatment.

All materials were acquired from distributors, or directly from manufacturers where distributors were not available. Samples were allowed to condition in ambient at approximately 32% relative humidity and 72°F for a minimum of 24 hours prior to testing.

Initially, each sample was either tested with laboratory instruments or subjected to a wool rub test prior to treatment to establish control reference data. Where a material had very poor electrostatic decay properties, as in the plastic samples, only a wool rub test could be used to determine control data.

After initial testing, each sample was treated with a General Purpose STATICIDE^{TM} antistat formula or high friction formula (where indicated by an asterisk), allowed to dry, and retested. Electro-Tech Systems, Inc. Static Decay unit Model 406B was used for all decay time measurements.

Each sample was installed between electrodes enclosed in a Faraday cage. An initial charge of 5000 volts was applied across the sample and the test material allowed to charge to a full 5000 volts. The sample was grounded, power removed and the time to discharge was measured in hundredths of a second.

Several static decay measurements of each sample were made to determine the times required to discharge the sample from 5000 volts to:

1. 2500 volts (50%)
2. 500 volts (10%)
3. zero volts (0)

All samples except the carpet were treated using a DeVilbiss TGA spray gun, equipped with the DeVilbiss #944 nozzle. Air pressure was regulated to 35 lb., and the material flow valve was set at one quarter turn open. Carpet samples

TABLE II

MATERIALS	WOOL RUB	SECONDS DECAY	STATIC DECAY TIME IN SECONDS FROM 5000 VOLT CHARGE — BEFORE ANTISTATIC APPLICATION: decay to 50%	decay to 10%	decay to 0	AFTER ANTISTATIC APPLICATION: decay to 50%	decay to 10%	decay to 0
GROUP I								
Acetal	1000	100	NOT APPLICABLE			0.09	0.45	1.05
Acetate Film	1800	100	NOT APPLICABLE			0.04	0.12	0.25
Acrylic	5000	100	NOT APPLICABLE			0.02	0.05	0.19
Industrial (Rigid) PVC	4200	100	NOT APPLICABLE			0.02	0.05	0.10
Closed Cell Pkg. Foam	3600	100	NOT APPLICABLE			0.03	0.10	0.40
Mylar	1800	100	NOT APPLICABLE			0.02	0.04	0.06
Nonwoven Pulp/Rayon	10,000	100	NOT APPLICABLE			0.02	0.04	0.06
Oilon PV80	1200	100	NOT APPLICABLE			0.05	0.21	0.55
Phenolic	300	100	NOT APPLICABLE			0.03	0.13	0.81
Polyamide (Nylon)	3750	100	NOT APPLICABLE			0.02*	0.05*	0.07*
Polycarbonate Coated	4250	100	NOT APPLICABLE			0.02	0.05	0.09
Polycarbonate Uncoated	2250	100	NOT APPLICABLE			0.02	0.04	0.07
Polyethylene	6500	100	NOT APPLICABLE			0.04	0.14	0.81
Polyethylene Film	3200	100	NOT APPLICABLE			0.02	0.04	0.09
Polyurethane Foam	1100	100	NOT APPLICABLE			0.02	0.04	0.09
Polystyrene (high Imp.)	4400	100	NOT APPLICABLE			0.02	0.03	0.06
Expanded Polystyrene	6500	100	NOT APPLICABLE			0.02	0.03	0.06
Polyvinyl Chloride	200	100	NOT APPLICABLE			0.03*	0.12*	0.33*
Styrofoam, Molded	1100	100	NOT APPLICABLE			0.02	0.03	0.05
GROUP II								
a. 70% Acrylic 30% Nylon Jute Backed, Mothproofed	N/A	N/A	0.81	18.30	180.04	0.11*	0.56*	1.39*
b. 100% Acrilon Acrylic, Jute Backed	N/A	N/A	0.20	1.81	106.90	0.07*	0.41*	0.84*
GROUP III								
Card Stock (Bristol)	N/A	N/A	0.65	3.21	8.61	0.05	0.21	0.61
Corrugated	N/A	N/A	0.21	1.17	2.61	0.04	0.20	0.61

* Treated with Regular High Friction Antistat

were treated with the high friction Regular STATICIDE™, using a standard quart container equipped with a manual trigger sprayer.

In all cases, the topical antistat increased a sample's ability to completely dissipate an induced static charge in a minimum amount of time. The average decay times for various treated materials are as follows:

		Average Decay Time in seconds: to 50%	to 10%	to 0
Group I	Synthetic Sheets & Film	0.03	0.09	0.27
Group II	Carpets	0.09	0.62	0.27
Group III	Paper Products	0.05	0.21	0.61

Figure I illustrates the various types of water based antistatic formula applications. Though brands of antistats vary, this scale provides an insight as to the relative strength and intended use of topicals.

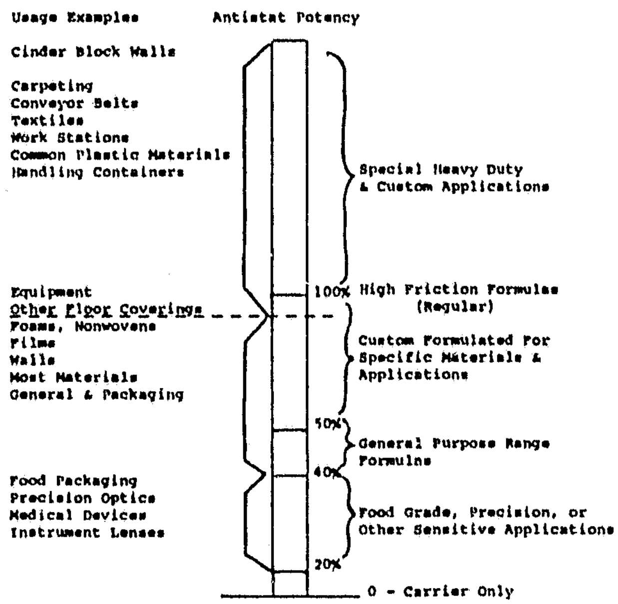

FIGURE 1
Formula Application Guide

CONSIDERATIONS IN SELECTING TOPICAL ANTISTATS

The ESC concept is based on proper treatment of people, materials and environment. In order to create the most effective prevention program using topical antistats, you will need to be able to evaluate the proper antistat for your particular application.

The development and evolution of today's topical antistat has made selection rather simple but a tremendous amount of work has been invested into R & D in every industry and it would be advantageous to build criteria for topical antistat selection to suit particular applications.

The following are the major considerations which should be reviewed when selecting a topical antistat.

1. PERFORMANCE COMPATABILITY WITH SUBSTRATE (MATERIAL)

Certain materials are extremely difficult to control. Vinyl and Mylar are excellent illustrations. The antistat that is not compatible will not bind itself to these materials resulting in little or no protection. The key to compatibility is testing. Usually environmental chamber tests will accelerate any negative affect a topical will have on the substrate. Also controlled friction tests will indicate binding capability of a topical to a substrate.

2. CONTAMINATION FACTORS

Materials which introduce large amounts of conductive salts or silicone can provide significant problems. Salt contamination with temperature and relative humidity can cause electrolysis and degradation of metals. Silicone can inhibit solderability which in turn creates additional production and quality control problems. Heavy or greasy residues can also provide negative affects.

3. LONGEVITY & WEAR CHARACTERISTICS

The materials ultimate usage goals determine the proper topical for a given application. Packaging materials such as covaluted foam, corrugated paper, closed cell packaging foams, foam "peanuts", chips, etc., are designed as disposables and should be treated as such. In these cases short term useful life indicates that a diluted antistat which is rather inexpensive is appropriate. Usually the topical coating will outlast the useful life of the disposable material, even in abusive applications.

In situations where the substrate's life is several years, the use of that material determines the life of the topical antistat. Friction is the key. For example, a lens which is subjected only to air friction and treated on the inside surface will remain antistatic for years. We have seen treated locomotive speedometer lenses remain virtually static free (on the inside surface) for over twenty years.

On the other hand, a high friction surface such as that of a conveyor or carpet may require treatments with a high friction topical antistat once every 3 - 12 months. Carpet treatment longevtiy depends on traffic intensity, material density and the amount and formulation of antistat used.

In cabinetry, topicals can last from months to years depending on application and end use. Computer cabinets and peripheral equipment are usually cleaned and dusted (inside and out) on a routine basis. A topical can be used for this application for both cleaning and long term antistatic protection. On components which are not exposed to significant friction or handling, longevity of protection is usually measured in years.

Trays, racks, rails, and other production aids are usually treated on a periodic basis, for example, once every 4 - 6 months depending on handling and activity. Work stations are cleaned daily for the sake of organization and cleanliness; however, one application will normally last several weeks. A spray and wipe is all that is needed.

Conversely, a quality topical should be removable if desired. Water alone should not remove it. Soapy water, and scrubbing, or firm wiping with a solvent like alcohol should remove the coating.

4. DECAY PERFORMANCE & CONTROLLABILITY

Quality topical antistats can easily comply with any current electrostatic decay specification on any material. The beauty of the topical is that one can select the decay performance required. By concentrating or diluting the topical solution prior to application, one can control the amount and dispersion of the antistatic mechanism across the materials surface. As a result not only can one select the rate of decay best suited to his needs, but can also select surface conductivity within the range of the combination of material & topical coating characteristics.

5. EASE OF APPLICATION

A topical should be compatible with process constraints. It must be flexible so that application can be by wipe, dip, spray, roller coat, flexographic or other coating operation. If your facility spray paints, spraying antistatic coatings would be very compatible with your process. If wiping a part, lens or cabinet is a normal function, wipe on your antistat. Using a wire mesh basket and dipping many small components into a tub of antistat may be the answer to a particular problem.

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In high speed gravure or flexographic applications, the topical antistat must be designed or diluted for these processes. Solids content (Antistatic mechanism) and solvent (Carrier) should be carefully reviewed for the best results. Along with roller coating and spraying, these methods of application are the most efficient and least expensive for high volume situations.

6. COST EFFECTIVENESS

To calculate and compare topical antistatic costs a few elements must be considered. They are:

1. COVERAGE (USUALLY IN SQUARE FEET/GALLON
2. LENGTH OF TIME OF PROTECTION
3. COST PER READY TO USE GALLON

For example, an, antistat which costs \$3.00 per gallon, covers 1500 ft^2 and lasts about 10 weeks is more expensive than one which costs \$5.00, covers 8000 ft^2 and lasts 40 weeks in a given application.

Consider this formula as a guide for cost evaluation:

$$\frac{\text{COST/GALLON}}{\text{COVERAGE}(\text{FT}^2)/\text{GALLON}} \times \frac{\text{PERFORMANCE DURATION}}{\text{1 YEAR(WKS, MOS)}} =$$

COST OF EFFECTIVENESS/FT^2/YEAR

If used for our example:

Item A

$$\frac{\$3.00/\text{GAL}}{1500\ \text{FT}^2/\text{GAL}} \times \frac{10\ \text{WK}}{52\ \text{WK/YR}} = \$.01/\text{FT}^2/\text{GAL}$$

Item B

$$\frac{\$5.00/\text{GAL}}{8000\ \text{FT}^2/\text{GAL}} \times \frac{40\ \text{WK}}{52\ \text{WK/YR}} = \$.00046/\text{FT}^2/\text{YR}$$

You can readily see in this situation that Item B costs only 4.6% of what Item A would cost in the same application, a difference of more than 21 times. When the cost of labor, potential down time and damage is taken into consideration, the difference is more dramatic.

7. PRINTABILITY, LAMINATION & SCREENABILITY

In an application where a material must be static protected, and is also expected to be printed upon, painted, silk screened, or enter a lamination process, selection of an appropriate antistat is critical. In this situation, almost any antistat can meet the longevity requirements because the time between production functions is relatively short. However, some antistats will not permit proper bonding of inks, paint or other laminated coatings. There are a few that meet bonding requirements and have been in use for several years. If bonding is a requirement, one can circumvent a lot of headaches by selecting a material that has either been previously used in these applications, or perform a basic strip test to determine the suitability of the antistat.

A strip test is done by applying the antistat as the manufacturer directs, performing the bonding operation over the antistat, then applying a tacky tape to the laminate or ink. Pull the tape off; if the laminate or ink is easily removed with the tape, the antistat should be replaced or modified. If all stays in place, you have a winner.

8. POTENTIAL MICROBIAL ATTACK & DEGRADATION

Topicals are compatible with most material. However, certain antistats can cause crazing or fogging on acrylics. Discoloration can also be induced by using a material which allows bacteria to breed on the substrate. It is microbial attack promoted by some antistats and the environment, which causes crazing, some forms of discoloration and degradation. A quality antistat can assist you in eliminating this type of problem if it is designed to prevent bacteria growth.

Antistats which control bacteria growth are called bacteriostatic, and must be registered with the Environmental Protection Agency in order to legally make the bacteriostatic claim. Somewhere in the literature or on the product label should be an EPA registration number indicating that the product has been fully tested and complies with EPA'S requirements for bacteriostatic material. For environmental static control applications, this feature can be an added benefit to your organization's health and safety program.

9. CONDUCTIVITY IN CRITICAL APPLICATIONS

Highly conductive materials which come in contact with critical components are often detrimental to the operation of certain assemblies. A circuit which requires a board impedance of 10^8 ohms per square in order to function properly without significant leakage, cannot be made too conductive without destroying its function. A topical antistat which functions well without lowering surface conductivity below required limits should be sought in this situation.

Most quality topical antistats can be adjusted by dilution with an appropriate solvent. By increasing the dilution we can reduce the amount of antistat applied to a surface. The antistat can maintain surface resistivity of the material above minimum limits and at the same time perform its antistatic function in relatively low or high humidity.

Proper dilution and application techniques to achieve conductivity control can be determined quite easily in the test lab. Using a sample of the production material in question, coat the sample with the antistat per instructions, test for conductivity then test for electrostatic decay. Modify the antistat dilution and repeat the tests as necessary. An investigation in this area can be enlightening, and it is a good procedure for determining the optimal dilution for a particular application.

10. LUBRICITY REQUIREMENTS

As we have said, lubricity does help to reduce the magnitude of triboelectric static charges. Today, the question of lubricity is not so great a factor in the electronics industry as it is in the textile or non-woven fabric areas. However, it does concern us in the handling and conveying of materials. Testing for lubricity is oriented to measuring and comparing the coefficient of friction of a treated material to that of an untreated material. However, the most important lubricity caution is whether the material is oily or greasy to the point that it isn't practical to use. If dilution or application techniques cannot control residue, the supplier should be contacted for instructions or another formulation recommendation.

11. SAFETY TO PERSONNEL & ENVIRONMENT

As we have become more sensitive to controlling contamination in our environment, so too. have we become more concerned with the safety and well being of our employees. For these reasons many antistat manufacturers have gone to great lengths to make non-hazardous materials. Those manufacturers who have been successful in their efforts can provide antistats which are: non-flammable; non-toxic by inhalation, ingestion or skin contact; non-sensitizing; and biodegradable. Most suppliers can provide toxicity and material safety data sheets to verify product safety.

APPLICATION & COVERAGE OF TOPICAL ANTISTATS

After selecting the best antistat for your needs, how is it applied to material? Basically, apply your antistat in the best way that works for you in your facility. An acceptable antistat may be readily applied in any number of ways including:

A. WIPING

B. SPRAYING

C. DIP PROCESSING

D. ROLLER OR GRAVURE COATING

E. PRINTING USING A FLEXOGRAPHIC PRESS

The application best suited to your process and material is the most desirable. Volume is also a major consideration when selecting application technique.

A component which normally would not be dipped can be sprayed with a highly atomized mist. In this manner the solvent is dispersed to atmosphere while the antistatic molecules are directed to the substrate's surface. In fact, if properly applied, the material or component never becomes obviously damp. If you held one hand 14 - 18 inches from the spray nozzle you should feel nothing but air. Yet, this technique will eliminate an existing charge and prevent charge accumulation for months or years, depending on the material's use.

Method of application determines effective utilization and coverage of topical antistat (refer to figure 2). A heavy spray used for carpeting would yield 1500-3000 ft^2 of coverage per gallon. A wipe application would provide 5000-11,000 ft^2, whereas a fine spray would yield 11,000 to over 50,000 ft^2 per gallon. Life and coverage depends on the material used, the application technique and the end use of the treated material or component.

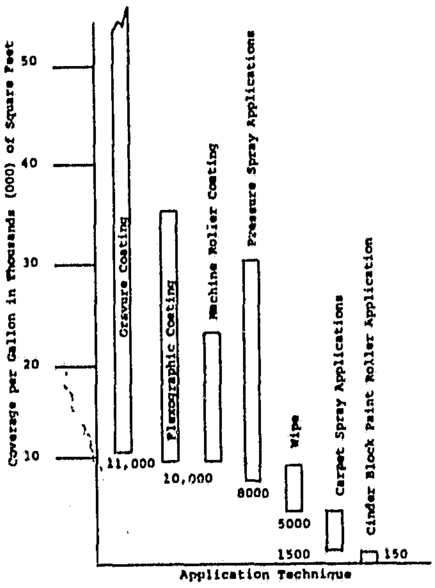

FIGURE 2
Topical Antistat Coverage/Gallon

MEETING SPECIFICATIONS

The two most frequently requested specifications that topical coating manufacturers are asked to meet are the National Fire Protection Agency (NFPA) Code 56A and MIL-81705B.

NFPA requires a material to have the specific electrostatic material decay characteristics which require a 5000 volt charge to dissipate to 500 volts within 0.05 seconds when grounded.

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This particular specification is designed for materials intended for use in hospital operating theaters and in areas where combustible gases or other hazardous materials may be present.

MIL-81705B which currently allows 2.0 seconds for a 5000 volt charge to dissipate to zero, refers most specifically to barrier materials used in packaging static sensitive electronic components. However, at present, electrostatic criteria outlined in this specification are often used for non-barrier packaging materials as a guideline for electrostatic performance. For example, certain cushioning materials, trays, foam containers which contain sensitive components, must have excellent static protection characteristics. Once this is accomplished with topical antistats, the whole package is protected by a barrier material from moisture, dirt and extraneous static charges.

Regardless of specification performance goals, quality topical antistats can provide exceptional electrostatic decay times on virtually any material that can be coated. Military specification electrostatic decay performance at 15% relative humidity with total dissipation in less than a few hundredths of a second is not unusual. Even difficult materials like rubber, concrete, polycarbonates (Lexan), Mylar, Vinyl, ceramics, glass, any polymer (plastic) can be rendered static-controlled quite easily.

THE FINAL STEP: APPROPRIATE INSTRUMENTS

A good procedure or system provides useful feedback as to its effectiveness. ESC is no exception. Initial users employed hand held survey meters to evaluate their environment, and sent materials to outside laboratories for precise electrostatic decay evaluation. This has been and will continue to be an effective means to evaluate problems. For this reason, several good instruments are now available for constant environmental survey, measurement, and materials & component analysis.

For continuous evaluation of the overall environment, systems employing stratigically located sensing heads feeding a master base unit monitor all area static on a second to second basis. When a level exceeds the preset point due to a "hot" material, process or person, an alarm is sounded automatically. Some units have a secondary alarm if no action is taken and levels continue to increase. A strip chart records the actual static level for each sensing channel. Several base units can be used independently, each covering several areas, or all connected to a mini computer system for constant overall evaluation. If properly set up, the actual route of an unacceptable material can be traced and monitored throughout a facility.

In the past, most laboratories created their own electrostatic decay measurement systems utilizing several different components. Usually each system varied from the others depending on component selection and how they were used. Rarely could the test results of one system be duplicated on the same or another system with a different operator. Now a complete unit designed specifically for material ESD analysis is available in compact form and provides remarkable consistency. This unique system can show static decay time to 0.03 seconds, ± 1% accuracy regardless of the operator. Consistency from unit to unit has been proven in multicompany projects where accuracy and consistency was a requirement.

An interesting new development in material static prevention is an Electrostatic Overstress Simulator for the evaluation of the electrostatic discharge characteristics of semiconductors. The system incorporates a "worst case" human model test circuit, and has the capability of simulating situations whether the component is installed in a circuit or not. This new system provides the capability to help differentiate between electrostatic destruction and EMI destruction of the device.

IN CLOSING

High performance topical antistats are now available which can readily perform on any material against the toughest electrostatic decay standards. They are inexpensive, easy to use, and safe for personnel and the environment. Thus existing materials, tools, containers, etc., do not have to be replaced, only properly and periodically treated with a quality antistat to insure their safe, continued utilization.

The alternative is to continue dealing with the symptom: Static, after it is generated. The battle will be constant and expensive, the problem will remain, losses will continue to grow during a recessionary period, and require the purchase of more equipment and devices to fight static. Now, a viable solution exists and has demonstrated its potential to help prevent the problem. We would be remiss if we did not place it on trial and let it prove itself.

APPENDIX D

Editor's Note:

Since this article was written a new product has been introduced by Charleswater Products, Inc. This product is called "Statguard" and is used as a conductive floor finish on any hard surface or sealed floor material. This would include vinyl, vinyl asbestos, linoleum, rubber, asphalt, sealed or painted wood, and terrazzo and concrete which has been previously sealed. "Statguard" is not a topical anti-stat but using this product will provide a finished floor with no static charge generation. It also provides a bright glossy finish. "Statguard" may be ordered through normal logistics channels.