Trends In ESD Test Methods

by
Stan Weitz
Electro-Tech Systems, Inc. (ETS)

(Materials Testing Section of the ETS Testing Laboratory)

When asked, "What's new in ESD Test Methods" the answer is plenty. Over the past decade the static control industry has come a long way. As new technologies develop, ESD susceptibility levels drop (in the hard drive industry ESD susceptibility levels are down to an incredible 5 volts).

Electrostatics is as old as time itself. It was not until 600 *B*C that *Thales* of *Miletus* began conducting basic experiments with static electricity that involved charging Amber by rubbing it with a piece of fur and observing the attraction of lightweight objects such as fur, feathers, etc.

Serious work in the field of electrostatics began during the Renaissance when Gilbert published *DeMagnete* in the year 1600. Over the next several centuries, experimental work by Gauss, Coulomb, Faraday and Franklin established a solid basis in the knowledge and understanding of electrostatics.

In the latter part of the 19th century the interest in electricity shifted from electrostatics to electrodynamics (batteries and generators). Except for the invention of systems like the electrostatic precipitator for cleaning industrial smoke, electrostatic air filters for cleaning the air in enclosed environments and ionizer bars to control the build up of static electricity during the manufacture of textiles and paper, electrostatics was generally relegated to the classroom and to spectacular demonstrations in science museums.

More Recent History

This situation began to change after WWII with the appearance and increasingly widespread use of polymeric, highly insulating materials such as polyethylene, polypropylene, polyvinyl chloride (PVC), etc. The manufacture and handling of these products became a problem, especially in dry locations. Large static charge accumulations resulted in machinery shut downs, explosions and fires.

It was not until static electricity began to impair the reliability and operation of electronic equipment that electrostatic phenomenon began to be taken seriously. With the development of Metal Oxide Semiconductor (MOS) technology in the 1960s, the effects of an invisible static discharge (levels below 2000V) were finally realized. Initially, static control procedures consisted of shorting the device leads together during shipment, using carbon loaded packaging or shorting bars, and grounding workers who were handling the devices. By the late 1960s, the military began to define the electrostatic characteristics of materials and to specify their use in specific applications. In 1969, Method 4046 "Electrostatic Properties of Materials" was incorporated into Federal Test Method Standard 101. Shortly thereafter, MIL-B-81705 "Barrier Materials, Flexible, Electrostatic-Free, Heat Sealable" was issued. For the first time a specification and a test procedure defined the electrostatic performance of materials under specified test conditions for specific applications. Over the next decade, the military generated MIL-HDBK-263 "Electrostatic Discharge Control Handbook for Protection of Electrical and Electronic Parts, Assemblies and Equipment" and MIL-STD-883 "Electrostatic Discharge Sensitivity Classification".

Resistivity had always been considered a key parameter in specifying a material's "*antistatic" p*roperties. ASTM-D -257 "DC Resistance or Conductance of Insulating Materials" and ASTM-D-991 "Rubber Property-Volume Resistivity of Electrically Conductive and Antistatic Products", were issued in 1925 and 1948 respectively by the American Society for Testing and Materials. These test methods were widely used to define and measure "*antistatic*" material. Today, "*Antistatic*", as defined in the EOS/ESD Glossary of Terms, refers to the ability of a material to resist tribocharging and is *NOT* a function of Resistivity.

Carbon loaded conductive material can generate a higher triboelectric charge on some materials, such as epoxy IC packages, than a chemically treated plastic that has a much higher surface resistivity (10^3 versus 10^{11} ohms per square). The resistive property of material defines its ability to dissipate charge. A materials *antistatic property* defines the ability to resist being charged triboelectrically.

By the late 1970^s, military and industry began working together to address the far reaching effects of static electricity. Over the past two decades, the war against ESD has come a long way. From its origin as a disorganized array of static control methods and products there has emerged a sophisticated approach to static control involving government, academia, suppliers and users. One of the most important contributions to static awareness was the establishment of the ESD Association along with the formation of special task groups within the military and established industry associations such as the EIA (Electronics Industries Association), ASTM (American Society for Testing and Materials) and the IEEE (Institute of Electrical and Electronics Engineers).

Through the ESD Association, symposia have been held every year since 1979 where static awareness, failure mechanisms, test methods, static control techniques are discussed and new technologies to control ESD are presented. The Association has recently become an ANSI (American National Standards Institute) recognized organization for developing ESD test methods and standards. Other organizations can now incorporate these accredited ESD Association Test Methods directly into their own standards. **Table 1** lists the principal ESD standards and test methods.

Since the early days of static control, many new products have been developed, but the available methods to test these products were limited. It became obvious that new standards and test methods were needed and existing ones had to be modified to better define what could and could not be tested. This is illustrated by specification EIA-541 "Packaging Material Standards for ESD Sensitive Items". This standard was eight years in the making when it was finally issued in 1988. Even as the final revisions were being added plans were underway to upgrade many of its test procedures. At the present time, this work is being carried on by ESD Association standards committees.

STANDARDS	ISSUES ADDRESSED
EOS/ESD S1.0	Personnel Grounding Wrist Straps
ESD DS1.1	Evaluation, Acceptance & Functional Testing of Wrist Straps (Revised)
ESD STM2.1	Resistance Test Method for ESD Protective Garments
ANSI/EOS/ESD S3.1	Ionization
EOS/ESD S4.1	Worksurfaces - Resistive Characterization
ESD DS4.1	Worksurfaces - Resistive Characterization (Revised)
ESD STM4.2	Worksurfaces - Charge Dissipation Characteristics
ANSI EOS/ESD S5.1	ESD Sensitivity Testing Human Body Model Component Level
ANSI ESD S5.2ESD	Sensitivity Testing Machine Model Component Level
ESD DS5.2	ESD Sensitivity Testing Machine Model (Revised)
ESD DS5.3	ESD Sensitivity Testing Charged Device Model
ANSI EOS/ESD S6.1	Grounding - Recommended Practice
ANSI ESD S7.1	Floor Materials - Resistive Characterization of Materials
ANSI ESD S8.1	ESD Awareness Symbols
ESD S9.1	Resistive Characterization of Footwear
ANSI EOS/ESD DS11.11	Surface Resistance Measurement of Static Dissipative Planar Materials
ESD DS11.12	Volume Resistance Measurement of Static Dissipative Planar Materials
ANSI ESD S11.31	Evaluating the Performance of ESD Shielding Bags
ESD STM12.1	Seating – Resistive Characterization
ESD ADV 1.0	Glossary of Terms
ESD ADV 2.0	ESD Handbook
ESD ADV 3.2	Selection of Acceptance of Air Ionizers
ESD ADV 11.2	Triboelectric Charge Accumulation Testing
ESD ADV 53.1	ESD Protective Workstations
WIP 2.2	Garments. Field Attenuation
WIP 3.3	Ionization, Periodic Verification of Charge Generation Characteristics
WIP 5.3.1	Device Testing, Charged Device Model, Socketed
WIP 5.4	Device Testing, Transient Latch-Up
WIP 10.1	Automated Handlers, Resistive Measurement
WIP 10.2	Automated Handlers, Charge Generation
WIP 11.13	Packaging – 2 Point Resistance Test
WIP 11.14	Packaging – Bulk Loose Fill
WIP 11.32	Electrostatic Shielding – Corrugated Materials
WIP 13.1	Hand Tools – Soldering Irons
WIP 14.1	ESD Simulators
WIP 53.2	Workstations, Related Storage Equipment
WIP 54.1	Flooring/Footwear Systems, Resistance in Combination with a Person
WIP 54.2	Flooring/Footwear Systems, Voltage Accumulation on a Person
WIP 55.1	Clean Room Operations
WIP 2020	Conversion of Mil-Std-1686 to a commercial document.
ASTM D-257	Resistance or Conductance of Insulating Materials
ASTM D-991	Volume Resistivity of Electrically Conductive & Antistatic Products
ASTM D-2679	Standard Test Method for Electrostatic Charge
ASTM F-150	Electrical Resistance of Conductive Resilient Flooring
AATCC-134	Electrostatic Propensity of Carpets
CECC00015	Protection of Electrostatic Sensitive Devices (Europe)
EIA-541	Packaging Material Standards for ESD Sensitive Items
IEC 801-2	Electromagnetic Compatibility for Industrial Process Measurement
MIL HDBK-263A	Handbook for Protection of Electronic Parts, Assemblies & Equipment
MIL-STD 883D	Electrostatic Discharge Sensitivity Classification
MIL-STD-1686A	Program for Protection of Electronic Parts, Assemblies & Equipment
MIL-B-81705C	Barrier Materials, Flexible, Electrostatic Protective, Heat Sealable
FTS Method 4046	Electrostatic Properties of Materials

Table 1

Measuring Resistivity

One of the most misused test methods for measuring static control material is Surface Resistivity Per ASTM-D-257". This method was originally developed for measuring the resistivity of insulating materials. The surface resistivity of an ideal material is constant across the surface, however, many static control materials such as laminates and composites are neither insulating nor homogeneous and have bulk resistance properties. A laminate may consist of a very thin surface layer having high surface and volume resistivities laminated to a much lower resistance layer, however, the actual resistance measured through a thin layer may be low even though its volume resistivity is high. When the surface resistivity of this laminate is measured in accordance with method ASTM-D-257, a parallel resistance path through the material occurs resulting in a perceived low surface resistivity. What is actually being measured is the resistance through the material to the low resistance layer, across this layer, then back through the material. When this measured resistance is converted to surface resistivity by multiplying the measured resistance by the electrode geometry, a significant error is introduced.

This well-known problem was addressed when the test standard for static control worksurfaces was developed and issued in 1990 as EOS/ESD Standard S4.1 "Worksurfaces-Resistive Characterization". Many static control work-surfaces are constructed as described in the laminate example above. In S4.1, resistance at defined locations between two points and between a point and ground are specified using a defined electrode configuration and a defined test voltage. *Surface resistivity* is no longer used to specify static control worksurfaces.

EOS/ESD Standard S11.11 "Surface Resistance Measurement of Static Dissipative Planer Materials" was developed to address the problem with ESD protective packaging. A defined concentric ring electrode configuration that meets the criteria specified in ASTM-D-257 was selected to measure the surface resistance of planar (flat) material. The resistance measured may be the result of surface only or surface and bulk resistance of the material. By defining the size, weight and configuration of the probe, the test voltage, and performing the measurement under tightly controlled environmental conditions, inter-laboratory measurements accuracy was reduced from two orders of magnitude to better than one-quarter of an order of magnitude. Measurement accuracy is also greatly enhanced by specifying an electrode alignment fixture and test procedure. **Figure 1** shows a typical surface resistivity and surface resistance probe along with calibration check fixtures that meets both ASTM-D-257 and EOS/ESD S11.11 requirements.

Figure 1

If the material being tested meets the criteria for ESD S11.11, the measured value obtained can be converted to an ohms per square (Ω/sq.) value by multiplying the resistance by 10. This is due to the probe's concentric ring electrode geometry which results in a surface resistivity equal to ten times the measured resistance.

ESD Association Standard S 11.12 "Volume Resistance of Planar Materials" addresses a similar problem found in specifying volume resistivity. Again, the resistance through the material using defined electrode geometry and specified test procedure is used to characterize the volume resistance of ESD protective material.

Other areas where resistance measurement uses a defined electrode configuration include ESD S7.1 and DS7.2 for flooring, S2.1 for garments, S12.1 for seating, and S4.1 for worksurfaces. These standards all use a five-pound probe with a two and a one half-inch diameter conductive rubber electrode. **Figure 2** shows a typical probe.

Figure 2

EIA-541

The static shielding bag was introduced in 1977, but no test method existed at that time to easily measure its static shielding characteristics. A surface resistivity of less than 1×10^4 ohms per square was specified but when the shielding layer is buried in the laminate there was no accurate way to measure it. In addition, the fact that the basic material is static shielding does not mean that the final product provided effective shielding. The capacitive probe test was adopted into EIA-541 for verifying the relative effectiveness of static shielding bags. The main difficulty with this test method, however, was the latitude allowed in conducting it.

A new test method, EOS/ESD S11.31-1992 "For Evaluating the Relative Performance of Electrostatic Shielding Bags" was developed to address the shortcomings in the EIA-541 test method. This standard measures the energy detected by a capacitive sensor placed inside the bag when the outside of the bag is exposed to a human body model discharge of 1000 volts. Areas addressed by this method are defining the discharge waveform and capacitive sensor, the use of a current probe to measure current through a specified resistance of 500 ohms, (in lieu of the dual voltage probes used in EIA-541) and defining bag size (8" x 10"). With this test method, the energy resulting from the current pulse, instead of the difference in peak voltage across the sensor, is calculated. Testing has indicated that energy can be correlated to device failure inside the bag.

The oldest and most difficult test to perform is the measurement of the charge developed on material as a result of triboelectric charge generation. Specifications still exist today using cat fur (MIL-P-19644C "Cat Fur") and the attraction or repulsion of ashes or smoke. Two test methods are described in EIA-541: The first, evaluates the antistatic properties of device (IC) shipping tubes while the second references bags and pouches. In the first method, devices are slid through the shipping tube under test and into a Faraday Cup. The charge, not the voltage, developed on the device is measured in nanocoulombs.

When carefully performed the test can give reliable results. The second test uses quartz and Teflon disks that are bounced around inside a test bed during a defined shaking cycle and then dumped into a Faraday cup. This test is very cumbersome and has been virtually abandoned.

The test method that is currently used by most organizations is the modified incline plane test. This method was first introduced at the 1984 EOS/ESD Symposium and was subsequently modified several times. This method uses a twelve-inch plane inclined at an angle of 15°. Quartz and Teflon cylinders are rolled down a sample of material mounted to the plane. The cylinder drops into a Faraday cup and the resulting charge is measured. Quartz and Teflon are used to represent material at both ends of the triboelectric series as seen in **Table 2**.

TRIBOELECTRIC SERIES

POSITIVE (+)

Human Hands
Rabbit Fur
Glass (Quartz)
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
KEL F
Silicon
Teflon

NEGATIVE (-)

Table 2

This test method can also result in inconsistent measurements, however, if each test parameter is well defined and the release of the cylinders down the plane is tightly controlled, repeatability and accuracy are greatly increased. This test and several other methods are described in ESD Adv. 11.2.

MIL-B-81705

Mil-B-81705-B was upgraded in 1988 to Mil-B-81705-C. This specification incorporates transparent metallized polyethylene material and is designated as Type III. In addition, resistivity and capacitive probe shielding tests of the appropriate materials are specified along with static-decay. Since the capacitive probe test in this specification references EIA-541, any future changes made to EIA-541 will affect Mil-B-81705-C (including resistivity requirements). Although numerous commercial organizations reference this specification, compliance testing is only performed for military applications.

ESD Susceptibility of Devices

Work is being carried out to develop and/or improve standards for determining the ESD susceptibility of electronic devices and equipment. The Military, the ESD Association, the IEEE and the IEC are performing this work.

Mil-Std-883D defines the ESD sensitivity classification of devices used in military hardware. This standard has also been generally adopted for commercial use. The waveform used simulates a discharge from a human body. It defines a model (HBM) of 100 pf discharged through 1500 ohms. Since its inception in 1980, the discharge waveform characteristics have undergone numerous upgrades along with the way the waveform is applied to device pin combinations. The latest version, Method 3015.7, requires the current waveform to be measured with a 350 MHz scope by discharging the HBM network directly to ground. The measurement is performed at 4,000 V. The rise time is specified at 2 to 10 ns and the pulse decay time at 150 ns. Ringing is limited to 15 percent of peak.

ESD Association Standard S5.1 “Human Body Model (HBM) Electrostatic Discharge Sensitivity Testing” provides a more comprehensive procedure for performing ESD susceptibility tests. Waveform verification is required for all voltage steps used up to 8kV instead of only at 4kV as specified in MIL-STD-883D. A second calibration circuit is used where the current is measured through a 500 ohm resistor. This waveform must have a rise time of 5 to 20 ns with a pulse decay time of 200 ns.

Two additional ESD models are the Machine Model (MM) and the Charged Device Model (CDM). The Machine Model, first introduced in Japan, simulates a discharge from a metal object. This model consists of a 200pf capacitor discharged through a zero ohm resistor. The Charged Device Model simulates a device that has become charged and then is discharged to ground through one of the leads. Standards covering these models are ESD S5.2 and ESD S5.3 respectively.

ESD Susceptibility of Equipment

Determining the ESD susceptibility of equipment is governed by a completely different set of standards. For human body discharge the military references MIL-STD-883D. For a discharge from a metal object held by a person the IEC 801-2 standard is most commonly used. The IEC (International Electrotechnical Commission) is an organization made up of members from 40 different countries. IEC 801 “Electromagnetic compatibility for industrial process measurement and control equipment” is a five part standard (with a sixth under development) that covers EMI, ESD, and Surge Voltage Immunity requirements for electronic equipment. Part 2: “Electrostatic Discharge Requirements” covers electrostatic discharge directly to and in proximity of electronic equipment. The original IEC 801-2 (1984) specified an air discharge up to 15 kV whereby the ESD simulator was brought rapidly towards the Equipment Under Test (EUT) until a discharge occurred. The model used for this was a 150 pf capacitor discharged through a 150 ohm resistor. The current waveform specified is a pulse with a 5 ns rise time and a pulse decay time to 50 percent of 30 ns. Typical waveforms are shown in **figure 3**.

The latest version of IEC 801-2 (1991) specifies both an air discharge and a contact discharge. In the contact discharge mode a 330 pf capacitor charged up to 8 kV is discharged through a 150 ohm resistor. The waveform for this pulse is much faster than that of a discharge from a human finger. The specified waveform, shown in Figure 5, consists of a fast (0.7-1 ns) rise time current pulse followed by a lower, more slowly decaying pulse. The Power Engineering Society of the IEEE has developed the “ Guide on Electrostatic Discharge from Personnel and Small Mobile Furnishings Part II-ESD Withstand Capability Evaluation Methods for Electronic Equipment subassemblies. This Guide includes information about test conditions, equipment, and procedures for ESD testing of printed circuit boards and other subassemblies.

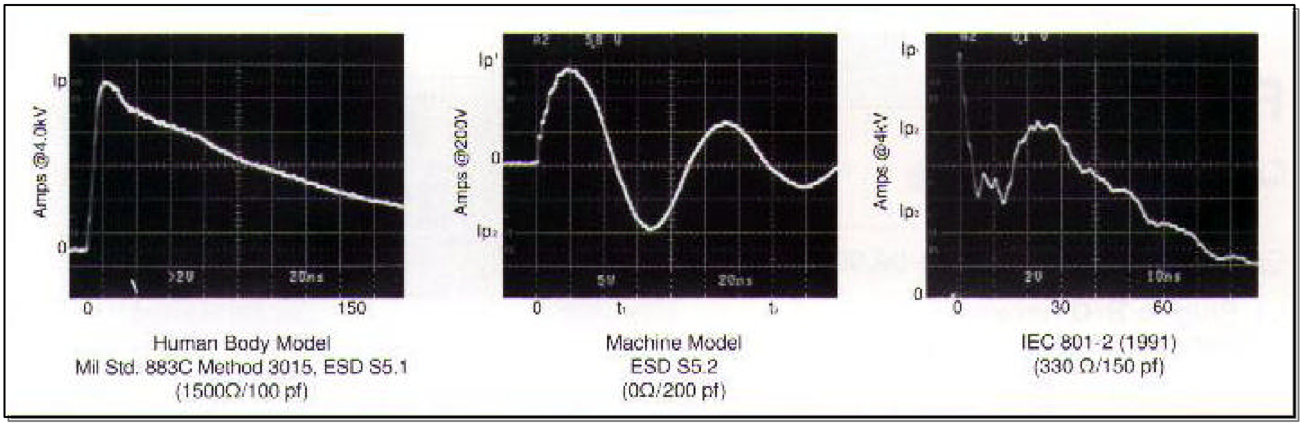
Ip
Amps @4.0kV
0
>2V
20ns
0
150
Human Body Model
Mil Std. 883C Method 3015, ESD S5.1
(1500Ω/100 pf)
Ip'
Amps @200V
0
Ip₂
5V
20ns
0
Machine Model
ESD S5.2
(0Ω/200 pf)
Amps @4kV
2V
10ns
0
30
60
IEC 801-2 (1991)
(330 Ω/150 pf)

Figure 3