ESD2000i Charge Reservoir™
ESD Simulator

Operator's Manual

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06/20/94

CAUTION

In its operation, this equipment unavoidably produces hazardous voltages and currents at its outputs. Hazardous voltages are conventionally defined as any voltages greater than 42.5 volts at 5 milliamps. Hazardous currents are conventionally defined as those associated with outputs greater than 200 VA or 20 joules at more than two volts. This equipment is capable of sourcing up to 26 kVolts, with currents potentially as high as 100 Amps.

Because of these hazards, certain cautions should be observed. Among these are those listed below.

1. This device uses a grounded three wire plug. It must be attached to a grounded three wire electrical outlet. Furthermore, use only extension cords which are rated 15 amps or greater, three wire, and are UL Listed or CSA certified.

2. Do not expose this equipment to excessively moist environments or to sources of dripping water.

3. Should erratic operation or fumes be observed in association with the equipment, the equipment should be disconnected from the AC power source and Compliance Design should be notified.

4. There are no user serviceable parts in this equipment. Refer all servicing to Compliance Design Incorporated.

5. This equipment should never be used by other than trained personnel. It should not be used if the personnel are subject to heart or neurological conditions.

6. ESD testing should be done only in areas dedicated solely to that purpose. Proper grounding techniques must be observed to ensure the safety of personnel conducting the tests.

7. Use of rubber floor mats provides additional protection and is recommended.

8. In organizing the test area, one should consider the possibility of fire or explosion of the EUT under surge. Take precautions such as having fire extinguishers ready and removing combustible material from the site. Personnel should never remain in line of sight of open circuit boards under test as these components may fail explosively, scattering fragments throughout the test area. Use of goggles is mandatory.

Table of Contents

INTRODUCTION 2

DEVELOPING A TEST PLAN 3

USING THE ESD2000i 4

CALIBRATION OF THE ESD2000i 5

ACCESSORIES 6

WARRANTY 7

INTRODUCTION

No longer a curiosity, the hazards of electrostatic events and the prevention of such have prompted the need for test methods which yield repeatable results. Compliance Design's ESD2000i electrostatic discharge simulator has been developed to meet the needs of those responsible for regulatory compliance with ESD standards. Utilization of the latest ESD technology and Compliance Design's Charge Reservoir™ has yielded sub-nanosecond risetimes for contact discharge events in strict accordance with IEC801-2, Issue 2. The base unit will supply up to 25 kilovolts to its air discharge probes and up to 9 kilovolts to each of the contact discharge probes. Compliance Design offers custom probes to model the requirements of many industry standards, all of which will operate in conjunction with a single compact base unit.

To aid the user in testing for system level ESD immunity we have included a copy of an article entitled, "System Level ESD Immmunity Testing", from the Compliance Engineering 1992 Reference Guide. This article addresses such topics of interest as the evolution of the human ESD model, setting up an ESD test site, and evaluating test results. Furthermore, we suggest that a comprehensive review of the standard, IEC801-2, Issue 2 is in order to facilitate all phases of ESD testing.

DEVELOPING A TEST PLAN

Developing a test plan prior to the application of potentially destructive ESD events will help in producing repeatable results as well as aid in yielding worthwhile data. Having a test plan may also reduce significantly the number of test samples required to yield a compliant product. IEC801-2, Issue 2, suggests that the following questions be considered in conjunction with some investigatory testing when constructing a plan:

1. What are the representative operating conditions of the EUT?

2. Should the unit be tested as table top or floor standing equipment?

3. Will indirect application of the discharge to the horizontal or vertical coupling planes be required, and in which positions should the vertical plane be placed?

4. Where should the discharges be applied?

5. Will air or contact discharges be required at these test points?

6. What severity levels will be necessary?

7. How many discharges should be applied at each point in order to determine compliance?

Taking the time to answer these questions before initiating ESD testing will take the user a long way toward gathering repeatable, reliable test results.

USING THE ESD2000i

Compliance Design's newest ESD Charge Reservoir has been designed for ease of use as well as for precise simulation of actual human ESD events. The ESD2000i consists of one base unit, one contact discharge probe, one air discharge probe, one return strap, a power cord, and the associated documentation.

The base unit contains the high voltage power supply and all safety interlock circuitry. An IEC style ac power socket is located adjacent to the ON/OFF switch on the rear panel. The LED meter located on the front panel prominently displays the actual probe tip voltage in dc kilovolts, which may be controlled by adjusting the knob labelled VOLTAGE ADJUST on the lower left hand side of the front panel. Control information between the probes and the base unit is transmitted through the 6 pin low voltage connector located below the meter. The high voltage jacks, labelled + and -, may be found to the right of the control socket.

Begin by selecting either a contact or air discharge probe, and then choose the polarity of the event to be simulated. Plug the 6 pin connector into the jack and then insert the high voltage connector into the appropriate jack, + or -. Connect the return strap between the stud located below the tip of the chosen probe and the reference ground plane in the lab in order to ensure that the worst case waveform as defined in the standard may be achieved. The return cable should not be closer to the EUT than .2m during discharge, and any excess cable should be wound noninductively. **WARNING! The use of the ground strap provided is necessary to ensure the safety of the user in all configurations.** Turn the VOLTAGE ADJUST knob fully counterclockwise, and apply power. The probe tip voltage will now be variable with movement of the VOLTAGE ADJUST knob from less than 1kV to the upper limit of the probe selected, 9kV for contact and 25kV for air probes.

> **Note:** To ensure the safety of the user, the tip of the air probe will not be energized until the user engages the switch on the probe. Consequently, the meter will not register a voltage until the switch has been activated. After the switch on the air probe has been released, the charge at the tip will be drained away in a few seconds to protect the user from accidental discharge.The contact probe has its tip isolated from the high voltage by a relay which has its coil energized through the action of the switch on that probe, thus a voltage will be present at the relay while the unit is on and this voltage will be displayed on the meter. The tips of the probes should be avoided at all times despite these precautions.

The ESD2000i may now be used to simulate the desired events according to the test plan which has been developed. Contact discharges may be achieved simply by placing the tip of the contact probe against test points on the EUT and engaging the switch for each preset severity level. The air discharge method may be effected by energizing the probe tip to the desired voltage and approaching the EUT test points as fast as possible without causing mechanical damage to the unit. Indirect application of a discharge may also be accomplished with the contact probe. Place the probe tip against either the horizontal or the vertical coupling plane as necessary according to the standard, and discharge the probe.

WARNING!
Do not discharge the probes directly into the front panel meter as this may result in permanent failure of the meter.

CALIBRATION OF THE ESD2000i

The calibration of the ESD2000i Charge Reservoir™ ESD Simulator consists of verification of performance of the 150pF/330 Ohm contact probe in accordance with the procedure detailed in IEC801-2, Issue 2, section 6.2. This calibration requires the use of a 1GHz analog bandwidth oscilloscope, a current sensing transducer as specified in the standard, and a faraday cage of sufficient size to house the measuring instrument while allowing 1m of separation between the probe grounding terminal and the target. The ESD2000i has been designed and had its performance tested for compliance with the parameters outlined in Table 2 of the standard. Particular attention should be paid to the placement of the return strap during this calibration, keeping the return loop as large as possible. The procedural details of performance verification may be found in the standard, which is available by calling *Compliance Engineering* at (508) 264-4208. In addition an article describing the calibration process is included as part of this manual.

ACCESSORIES

Compliance Design has a number of accessories for use with the ESD2000i Charge Reservoir™ ESD Simulator. These include a vertical coupling plane for indirect application of discharge, an IEC801-2, Issue 2 current sensing transducer for performance verification, and both magnetic and electric field generating probe tips for evaluating the vulnerability of an EUT to these specific components of the ESD event. Furthermore, we are able to offer a wide array of custom probes upon request. Contact Compliance Design to expand your ESD testing capabilities with any of these options.

LIMITED WARRANTY

Compliance Design Incorporated warrants that its products, at the time of delivery, are free from defects of workmanship and material under normal use and service. CDI reserves a right, at its exclusive option, to replace or repair, in its own factory, any articles which are disclosed to CDI's satisfaction to be defective within one year of delivery. Transportation charges to CDI's factory shall be prepaid by the buyer.

> THIS WARRANTY IS EXPRESSED IN LIEU OF ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, INCLUDING THE WARRANTY OF FITNESS FOR A PARTICULAR PURPOSE, MERCHANTABILITY AND/OR ANY AND ALL OBLIGATIONS OR LIABILITIES. CDI NEITHER ASSUMES NOR AUTHORIZES ANY OTHER PERSON TO ACT AS AGENT FOR CDI OR TO ASSUME ANY OTHER LIABILITIES IN CONNECTION WITH DELIVERY OF THIS PRODUCT.

This warranty is limited to 90 days on out-of-warranty repairs and shall not apply to any products which have been repaired or altered by the buyer, or which have been misused or subjected to neglect or accident.

System Level ESD Immunity Testing

By Glen Dash & Isidor Straus, Managing Editors, Compliance Engineering, (508) 264-4208

System level ESD is primarily concerned with immunity to electrostatic discharge in the field. In the words of the EC's EMC directive, the equipment must "operate as intended" in the face of typical environmental disturbance. With the implementation of that directive (See *Static Control in the European Community*), ESD performance levels are effectively mandatory for any equipment destined for the EC. Even when not required by law, an adequate level of ESD immunity is also good design practice, as it enhances equipment reliability, longevity and marketability. In this article, we review the basic techniques and performance standards of product ESD testing. As we shall show, there are two competing standards with which manufacturers should be familiar.

Development of the Human ESD Model

In order to establish body capacitance and other electrical characteristics of the human ESD event, numerous studies have taken to the field, measuring actual discharges from human beings in a variety of environments. Typically, these field studies measure the potential built up on the person prior to discharge (i.e. the open circuit voltage) and the discharge current waveform. From this information, an approximate circuit model for the human ESD event can be inferred.

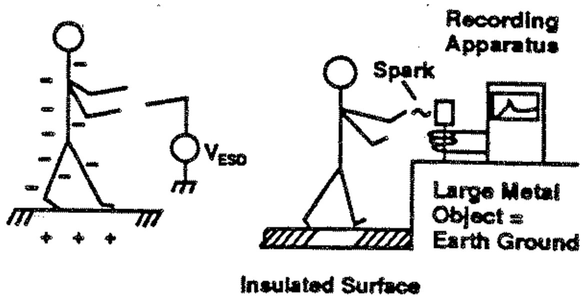

FIGURE 1: How human ESD models are derived: First, the open circuit voltage on the fingertip is measured. Then the short circuit current is monitored during discharge to ground.

Although scientific controversy persists on the finer points, there is agreement on the basics:

- The charge carrying capacity of a conductive object is related to its size. For a human being, a value of 150 picofarads is appropriate.
- The dynamics of the discharge current are more complex. The current amplitude during discharge, and thus the impedance of the discharge path, varies with experimental conditions. Higher currents (a lower impedance discharge path) occur when the spark is drawn through a handheld metallic tool, such as a screwdriver, key, or ring. A limiting case of this phenomenon is "furniture discharge," where a charged metal object, such as a cart or file cabinet is the ESD source, and there is no intervening arm/hand discharge impedance.
- A simple resistor (R-C circuit) is inadequate for modelling the discharge path. The discharge current waveform contains a very rapid leading "spike" due to the intrinsic capacitance of the human hand.
- The brief but intense initial spike is of crucial importance. Some equipment is extremely sensitive to this spike; its presence is essential to accurate and repeatable ESD sensitivity characterization.
- The speed of approach at the time of discharge is a critical parameter for ESD performance. Rapid approach is associated with a repeatable ESD waveform. This can be achieved with contact (sometimes called direct injection) tests, where the simulator electrode is brought into direct contact with the equipment under test and the discharge path is made by the rapid closure of a relay internal to the simulator. If air discharge is employed, the simulator should be moved rapidly toward the equipment tests.

These findings have been incorporated into the IEC's revised standard, IEC 801-2, Issue 2, "Electromagnetic Compatibility for

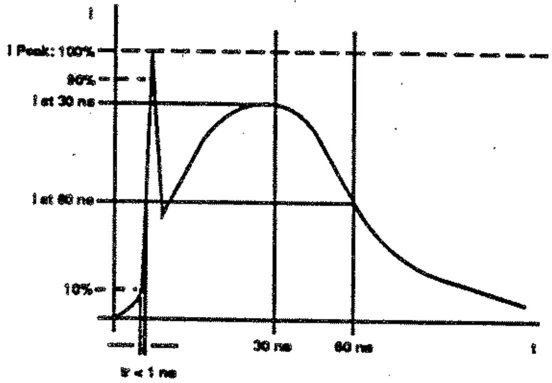

FIGURE 2: Shown above is the current waveform required by IEC 801-2 (Issue 2). Note that the important generic immunity standard EN 50-082-1 uses a less complex waveform without the leading spike.

Peak Current Requirements IEC 801-2, Issue 2)		Additional Requirements	
Direct Injection Simulator Voltage	First Peak Current of Discharge (±10%)	Current (±30%) 30 ns	Current (±30%) 60 ns
2 kV	7.5 A	4 A	2 A
4 kV	15 A	8 A	4 A
6 kV	22.5 A	12 A	6 A
8 kV	30 A	16 A	8 A

TABLE 1: Waveform parameters of IEC 801-2 (Issue 2).

Industrial Process Measurement and Control Equipment - Part 2: Electrostatic Discharge Requirements." This standard is very influential. The EC's EMC Directive will use the EN 55 101 series of compatibility requirements, whose ESD immunity requirements are derived from IEC 801-2.

In incorporating recent advances in the understanding of ESD physics, IEC 801-2, Issue 2, departs from earlier ESD standards in several important respects:

Many of these facts were elucidated in the late 1980's. Earlier in the decade, the common approach was to simulate the ESD discharge as single impulse, modeled by a simple R-C network without the inclusion of the "hand" capacitance. This practice was codified in IEC standard 801-2 (1984). As understanding of ESD phenomena deepened, many experts concluded that the IEC standard needed updating, which resulted in IEC 801-2, Issue 2 (1991), "EMC for Industrial Process Measurement and Control Equipment, Part 2: Electrostatic Discharge Requirements." This standard incorporates recent advances in understanding of ESD, and will form the basis for the ESD recommendations of upcoming harmonized EN standards, particularly the planned EN 50 024, which will cover immunity of information technology equipment.

Which Standard to Use?

The 1984 version of IEC 801-2 is still important, however. It is called out in EN 50-082-1 as the method to use for ESD immunity evaluation. EN 50-082-1 is a generic immunity standard that provides baseline performance requirements for demonstrating compliance with the EMC Directive. Where product-specific standards exist, they supersede the generic requirements. Since the EMC Directive is still young, many products will have to be qualified according to the generic standard. Therefore, a knowledge of IEC 801-2 (1984) is important. In the near future, an increasing number of product specific standards will require tests based on Issue 2 of that standard. It is useful to review the main features and highlight the differences between these two standards.

- *Circuit Model:* IEC 801-2 (1984) uses a simple 150 pf/150 ohm RC model. Issue 2 changes the simulator parameters to 150 pf/330 ohms. Perhaps more importantly, the importance of "hand capacitance" is explicitly recognized in the new standard.

- *Air vs. Direct Injection Testing:* IEC 801-2 (1984) is based on air discharge testing. Issue 2 emphasizes direct injection testing. It relegates air discharge testing to a secondary status, recommending it be used to test insulation barriers where the contact necessary for injection testing is unachievable.

- *Test Levels:* It is the current profile of the discharge which causes ESD upset; but ESD simulators are calibrated in terms of the voltage potential present on the simulator circuit capacitor. At higher voltages, the two test methods deliver different current profiles because of air corona effects. Figure 5 shows the relation between the two methods for a given peak current.

- The generic immunity standard, EN 50-082-1 requires a modest immunity level of 8 kV to air discharge, using the 150 pf/150 ohm circuit of the IEC 801-2 (1984). Proposals under consideration for the ITE product specific standard recommend immunity levels of 3 kV for direct injection and 8 kV for air discharge, using the more recent 150 pf/330 ohm simulator.

- *Waveshape:* The 1984 standard specifies the current waveform as a single pulse with a 5 ns risetime and a 30 ns width (at the 50% level). IEC 801-2 Issue 2 provides detailed waveform

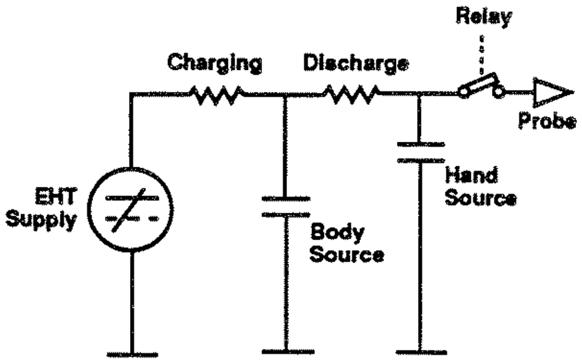

FIGURE 3 *ESD simulator circuit. Earlier simulators do not include the additional "hand" capacitance. The total capacitance is generally 150 pf, and the discharge resistance is 150 or 330 ohms, depending on the applicable standard.*

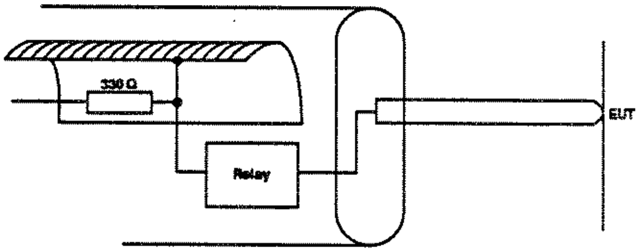

FIGURE 4: *A hand capacitance, also known as a free space or distributed capacitance, can be simulated by building a metal plate into the probe. For direct injection simulation, the probe tip is pressed against the EUT and the discharge made by activating the relay. For air discharge tests, the relay is left closed and the probe is brought towards the EUT until a spark occurs.*

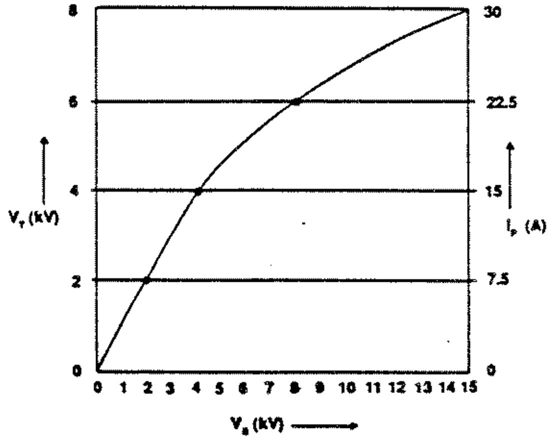

FIGURE 5: *The peak current (IP) produced by through-air ESD simulators differs from the peak current produced by current injection techniques for the same applied voltage. The peak current produced by current injection techniques is proportional to the voltage of the simulator's capacitance (VT). However, the voltage for ESD simulator employing through-air discharge techniques is nonlinearly related to current. Corona effects which start to exhibit themselves above 4 kilovolts are one possible cause. VT is the voltage on the probe tip prior to discharge for a direct injection probe. VE is the voltage on the probe tip prior to discharge for a through-air type probe.*

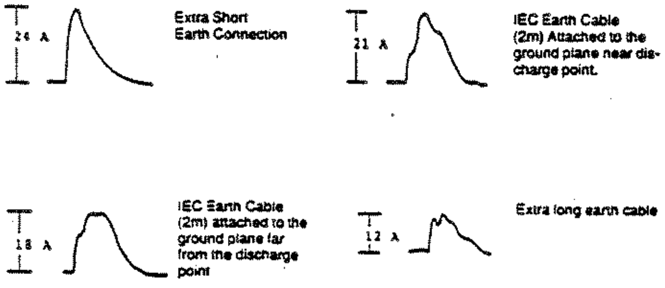

FIGURE 6: The ESD simulator's ground return is an important factor in its overall performance. Changing its length, and therefore its inductance, can have a great effect on the actual current discharge waveform.

parameters, with emphasis on the direct injection current profile. An intense, leading spike with a 1 ns rise time is required, and the current is specified at 30 and 60 ns. The more detailed waveform is reported to resemble real world discharges more closely, and to provide more repeatable test results, than that of the earlier standard.

Setting Up A Test Site

In setting up a test site, we need not rigorously control temperature or humidity. While low humidity is required for human beings to build up high voltages, the high voltage supply built into a properly designed ESD simulator supplies the proper potential regardless of humidity. However, a test site must have one parameter controlled. It should have a reference earth ground available (Figure 7). Since the effect of an electrostatic discharge is due to a potential difference between the probe tip and earth ground, we should ensure that we have an earth ground available in our test site which will not vary in voltage when a discharge occurs. If it did, then the instantaneous amount of current flowing from our probe tip and through the device under test would be reduced and the worst case discharge waveform would not be achieved.

Creating a reference ground eliminates the difficulties described above. The third wire return alone cannot be used because it is inductive and we have no way of knowing how long an inductive path there is between our test site and earth ground via the laboratory's AC wiring. Therefore, we have to create a local "earth" ground. We can do this by using a large ground plane.

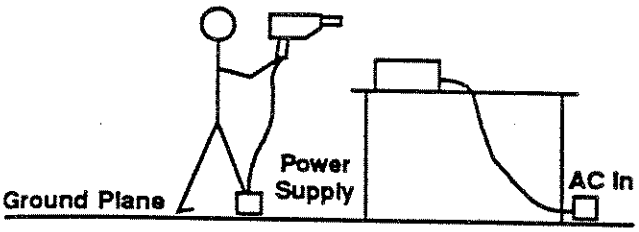

FIGURE 7: A ground plane is needed on the floor of the test site in order to supply a local earth ground.

We would like to create on the floor of our test laboratory a ground plane whose potential will not change very much during discharge. This ground plane is a metallic plane which has a free space capacitance. Empirical studies have placed this capacitance at about 30 pf per square foot. Therefore, a 10 foot x 10 foot ground plane "looks" like a very high quality 3000 pf capacitor. (Note that proximity to another plane is not needed to derive this capacitance. Energy is stored in the field proximate to the plane itself, not in the dielectric between one plane and an opposing plane.)

Our discharge capacitor is about 150 picofarads, so the intrinsic capacitance of our ground plane system must be many times that amount. Even if the ESD generator was discharged directly to a ground plane of this size, the voltage of the plane would only rise slightly. By attaching the ground plane to the third wire return, this voltage can be bled off into the earth ground. For safety considerations, it's important that the ground plane be attached to the third wire ground of the laboratory's electrical system.

The IEC specifies the arrangements of the equipment under test (EUT) as well. Table top equipment is tested over a ground plane which extends 100 mm beyond the edge of the EUT (Figure 8). Floor-standing equipment is also tested while standing on a metal floor extending 500 mm beyond the EUT. I/O cables are suspended 100 mm above this ground plane (Figure 9).

Another feature of our site is simply a metal plane which we can move around the device under test. This allows us to simulate discharge to a nearby object as opposed to the device we are testing. In cases of severe ESD susceptibility, even discharges to a nearby metal object will affect the equipment being tested. Discharging to this "radiating plane" first may help us to observe an ESD problem without directly discharging to the unit. Units which are extremely susceptible may be destroyed by a direct discharge.

The simulator ground return is connected to the site ground plane. Note that this is so even when discharge is to a radiating plane which is, in turn, resistively grounded. The length of this lead affects the current waveform delivered during discharge. Longer leads are associated with increased inductance (see Figure 6) and a slower discharge. IEC 801-2 says that the ground return lead length will ordinarily be 2 meters, although it can be extended to 3 meters if necessary. Regardless of lead length, the current waveform specification into a low impedance target must be met.

Two other features of our test setup have to be considered before testing proceeds. First, the equipment under test should be fully exercised. Software, for example, should query all devices, I/O addresses, and memory locations during the course of the ESD test. In this way, ESD problems which may be associated with a particular port or memory location will show up during testing. Second, because many of the disruptive effects of electrostatic discharge are caused by radiated emissions, cables should be attached to at least one port of each kind on the EUT. These cables can act as antennas, picking up the radiated emissions and passing them down the cable, where they may be interpreted as data. Ideally, these cables should be terminated with a peripheral which has been previously checked for ESD problems. If the peripheral is not available, the cables can be left unterminated.

With these arrangements in place, we can proceed to the testing itself, setting the ESD simulator to a low starting voltage. In all tests, the approach should be as rapid as possible. A "flick of the wrist" technique should be used for consistent results during air discharge tests. The first discharge should be made to a nearby object, such as the "radiating plane." By moving the plane around the equipment under test, problems can be found with poorly designed units. The voltage should be increased gradually to 20 kilovolts (8 kV for current injection testing). Approximately 20 discharges at each voltage level are sufficient for this phase of the test.

If discharges to the radiating plane do not reveal ESD problems, we can begin a preliminary phase of testing by discharging to the device itself to determine at what points the equipment under test is most susceptible. Every point likely to be touched by the end user should be probed, starting with a low voltage such as 2 - 3 kilovolts. Special attention should be paid to the face of a CRT, the keyboard and backshell connectors since these are frequently touched. The operator should note what points on the equipment under test are most susceptible.

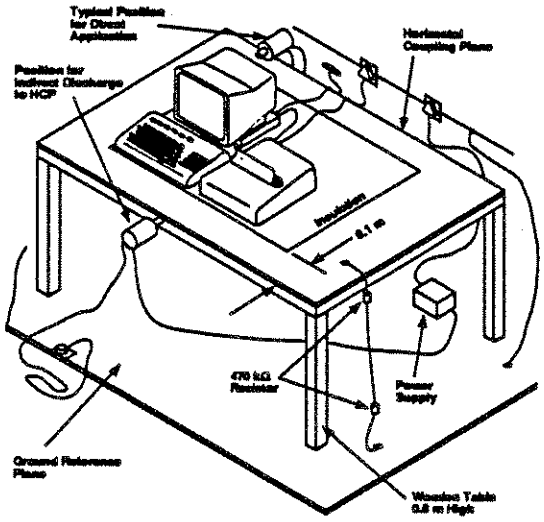

FIGURE 8: Table top units are tested atop a horizontal coupling plane (HCP). The HCP is resistively grounded to the ground reference plane.

Once the preliminary scan has determined the location of the greatest sensitivity and worst case cable and peripheral placement, a more detailed examination can be made. Begin by discharging to each of these sensitive locations at least 300 times for each voltage. Gradually work up from the lowest test voltage to the highest and observe how many system errors occur. If an acceptable number of system errors is produced during the discharge test, the operator should move on to other points on the equipment under test and repeat the examination. All in all, a good electrostatic discharge test takes two to four hours to complete.

Criteria for Passing And Failing

System upset can occur in three basic forms. First there are *transient* system upsets which do not permanently alter the system operation. These include snow or roll of a video screen or a momentary slowdown of printer operation. A second kind of error is more serious. *Soft errors* come in two forms. Some are *correctable* and the operator can correct the problem with a keyboard entry. Others are *noncorrectable* and the operator cannot undo the damage without reinitialization. Finally, there are *hard errors* which are defined as equipment destruction. For all systems hard errors are intolerable.

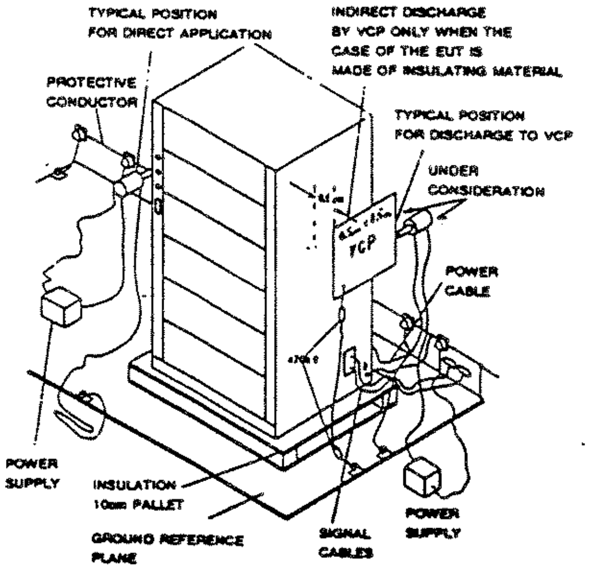

FIGURE 9: Floor-mounted units are mounted 10cm above the ground reference plane. This plane must extend at least 0.5m beyond the EUT in all directions.

As noted above, the EMC Directive's generic immunity requirement is 8 kV for air discharge. Generally speaking, transient errors can be tolerated, while loss of data or actual damage is unacceptable. Manufacturers should realize, however, that what constitutes an adequate level of ESD performance is somewhat subjective, depending on the equipment's operating environment, failure characteristics, and reliability requirements. Table 2 shows a representative set of criteria. This table is based on a standard statistical formula. Different requirements for statistical confidence, or the presence of hardware windows of vulnerability which vary with the equipment's operating state, can lead to the requirements for a different number of trials.

Voltages		# Of Discharges	Error Type # Of Errors (% Error to 95% Confidence)			
Thru Air	Current Inj.		Transient	Soft Correctable	Soft Non-Correctable	Hard
5 kV	4 kV	300	0 (1%)	0 (1%)	0 (1%)	0 (1%)
10 kV	6 kV	300	135 (50%)	8 (5%)	0 (1%)	0 (1%)
15 kV	8 kV	300	— (100%)	34 (15%)	8 (5%)	0 (1%)
20 kV	10 kV	300	— (100%)	— (100%)	— (100%)	0 (1%)

TABLE 2: A Table of Tolerable Errors. The table indicates tolerable errors at different applied voltages. The number in parentheses indicates the desired percent failure rate to a 95% confidence level. The number above it is the number of errors tolerable which allows classification of the device as meeting such failure rate. For example, if through-air discharge are used, the table indicates that in the field, no more than 15% of events should result in "soft correctable" errors for 95% of the machines at an applied voltage of 15kV. Using a standard statistical formula, this means no more than 34 soft errors should be observed out of 300 discharges applied during testing.

A word of caution. Normally, the amount of energy stored by the capacitor in the ESD simulator is not high enough to hurt anyone seriously. It can, however, cause a discomforting shock and serve as a surprise to the unwary. Because of this, care should be taken when using any ESD generator. The EUT and any metal objects to which discharge could occur must have a third wire safety ground. Care should be taken at all times to observe the placement of the discharge probe's tip to make sure that unintentional discharge does not occur. Needless to say, those with medical problems, especially cardiac problems, should not be involved with ESD testing.

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ESD Simulator Calibration

By Jon Curtis and Jon M. Christiano, Compliance Design Inc., (508) 264-4668

Trend-setting standards identify calibration of the ESD waveshape as the prime factor effecting repeatibility among test sites.

Accurate calibration of the Electrostatic Discharge (ESD) simulator is required to achieve repeatable test results. Trend-setting standards such as IEC 801-2:1991 consistently identify calibration of the ESD waveshape as the prime factor effecting repeatiblity among test sites and even between tests at the same site. Modern techniques and more detailed waveshape specifications promise to eliminate the old anecdote about the product which passed ESD testing in the morning only to fail under identical conditions after lunch. To understand how such a conundrum is possible, we need to examine calibration in detail and briefly consider test technique.

The ultimate goal of the ESD test is to predict accurately the performance of the Equipment Under Test (EUT) when it is subject to ESD in the end-use environment. Most natural ESD events take place when a charged person touches a product or a significant mass of metal in the near vicinity of the product. The rapid charge migration from the person to the touched object, typically through an short ionized air path, is referred to as an electrostatic discharge. Early simulators attempted to mimic this physical event exactly, but are now understood to have fallen far short of that objective. Such simulators consisted of a probe containing a charged capacitor connected by a resistor to a metal tip with the approximate dimensions of the human finger tip. When the probe tip was brought close enough to the EUT, a discharge occurred. This technique of applying ESD came to be known as the *air discharge* method. Early calibration attempts for these first generation simulators focused on specifications for the capacitive and resistive values, the charge voltage, and the physical dimensions of the probe tip.

Repeatable Test Technique

As people gained familiarity with early ESD standards contempt was bred. Results were often unrepeatable and real problems experienced in the field were not detected at the testing stage. A backlash resulted in some manufacturers reverting to test methods pioneered during the Spanish inquisition, charging up a real engineer, we'll call the victim "Sparky", and forcing him to discharge to the EUT. But even the discharges produced by Sparky proved unreliable (the "flinch" factor), and the search was on for the root of the variation. It turned out that two major factors were at fault. Approach speed and non-uniformity of ESD generation between simulators.

If you use a slow approach speed, and bring the probe in gently to the EUT, the result is usually an ESD event with a slow rise time (see Figure 1: Region III). Vigorous, quick wrist snaps bring the probe in fast and tend to result in ESD pulse shapes with quick rising edges (see Figure 1: Region I). First attempts to control this parameter used a fixed gap between the simulator tip and the EUT which would ionize when the voltage across the gap reached a specific level. On first examination this appears to be a repeatable method. Unfortunately, it produces repeatable waveshapes with uniformly *slow* rising edges. Unfortunate because fast waveshapes do exist in the real world and the exclusive use of slow waveshapes in testing nearly guarantees field failures. With plastic EUTs where there is no exposed metal the solution is to approach *fast*. Modern standards specify that the EUT "...should be approached as fast as possible (without causing mechanical damage)". This guidance might have been enough for all situations except for a natural

Severity Level	Voltage (±5%) kV	First peak current of discharge ±10% A	Rise time nS	Current (±30%) at 30 nS A	Current (±30%) at 60 nS A
1	2	7.5	0.7 to 1	4	2
2	4	15	0.7 to 1	8	4
3	6	22.5	0.7 to 1	12	6
4	8	30	0.7 to 1	16	8

TABLE 1: *IEC 801-2:1991 waveshape parameters.*

phenomenon. As probe voltage increases, air ionizes faster and the ionization process appears to distort the rising edge of the ESD event. Making quick enough approach speeds to stay in Region I is almost impossible at voltages above 4kV. As a result of this anomaly, the waveshapes formed have a tendency to slip into Region II or even Region III at higher voltages despite the use of fast-approach techniques.

For EUTs with exposed metal surfaces a better approach exists. The best way to get fast, fairly repeatable waveshapes is to form the arc with a mechanical relay. After all, the closure rates of such relays are extremely fast and so virtually eliminate the variable approach speed problems. Consistent Region I waveshapes with sub-nanosecond rising edges may be achieved at these mechanical approach speeds. Modern ESD simulators incorporate such relays and wherever possible the *contact discharge* method of application is employed. In this method of ESD application, the charged RC Human Body Model is separated from the probe tip by a high voltage mechanical relay. The tip is placed against the EUT and the relay is then closed. The arc takes place within the relay and the charge is injected into the EUT through the tip (hence the method's other name, *current injection*).

The other factor impacting repeatiblity is uniform waveshape generation between simulators. This is where calibration is imperative. The mechanical constraints on ESD simulator construction of the early standards were not effective in producing simulators with identical test characteristics. As a result, IEC 801-2:1991 essentially abandons generator mechanical specifications in favor of electrical specifications. In this document the current waveshape's rise time and amplitude at peak, 30 nS and 60 nS, are specified (see Table 1). The voltage on the capacitive element is also specified. Values for the RC model are given but their distribution within the probe is left up to the manufacturer. Great care must be exercised to produce the desired waveshape from the physical components of the model.

The modern waveshape is really a composite of two events. An examination of Figure 2 reveals an initial sharp current peak followed by a much longer duration current swell. To see why such a waveshape is necessary we need to examine the natural ESD event in detail. Consider the instant just before discharge occurs. The charged hand has moved in close to the uncharged victim object. The voltage potential between the two points has caused a charge migration over the human body which has resulted in a local build up of charge at the hand. Fast forward a picosecond in time. Discharge occurs and the local reservoir of charge on the hand migrates to the victim in an instant, causing the first sharp current

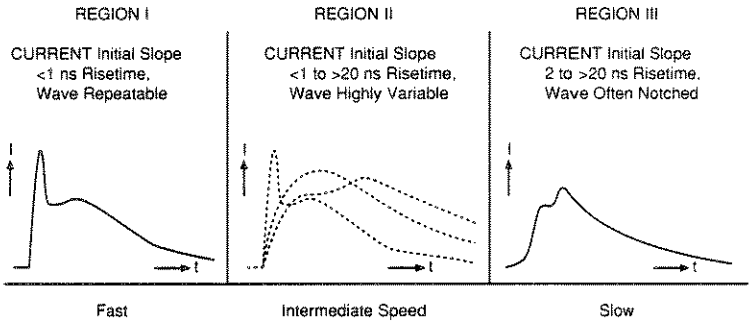


FIGURE 1: *Waveform variation as a function of approach speed.*

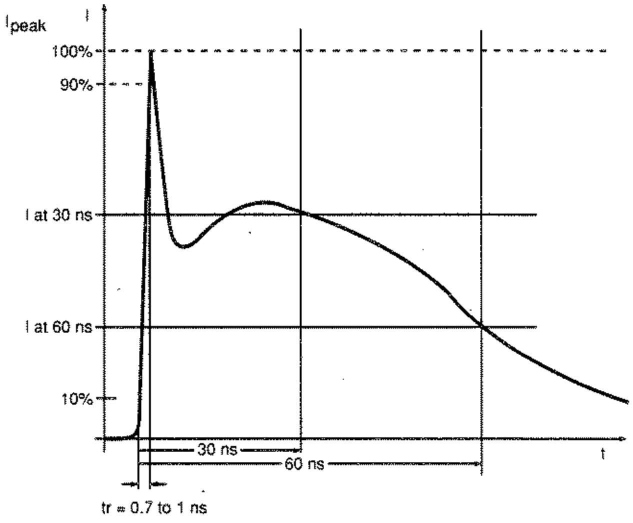


FIGURE 2: *IEC 801-2: 1991 waveshape.*

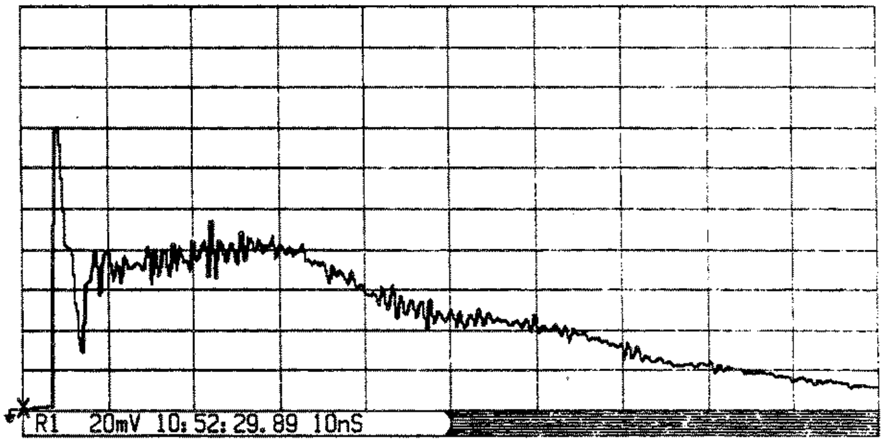
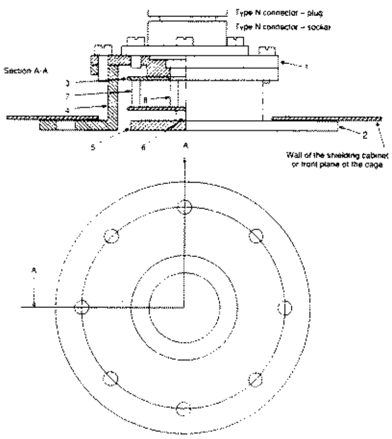


FIGURE 3: *Typical simulator calibration waveshape.*



Item	Qty	Screws	Qty
1	1	M3 PAN HD SC × 6.5 mm LG	12
2	1		
3	1		
4	1		
5	1	M2.5 PAN HD SC × 5.0 mm LG	3
6	1		
7	25	Resistor 51 Ω	
8	5	Resistor 240 Ω	

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FIGURE 4: *Target construction details.*

peak. In the next 100 nS, the distributed charge on the rest of the body migrates from the far regions of the body to the victim resulting in the longer current swell. Proper calibration of the ESD simulator insures that the magnitudes and durations of both events are carefully controlled to align with the requirements of the current standard.

The Right Stuff: A *Fast* 'Scope

Early ESD standards specified the event rise time at 5 nS. Why so slow? State-of-the-art oscilloscopes used to characterize human ESD events were incapable of observing faster events. Effectively the researchers measured the impulse response of the measuring instruments rather than the rise time of the event they were attempting to observe. The particular oscilloscope needed to get a picture of the modern ESD event is a rare beast. It must be able to record a single shot event with a resolution in the 250 pS range and a bandwidth of 1 GHz. Analog and digital instruments are available that fit the bill, but digital storage oscilloscopes (DSOs) must have sample rates for single capture of at least 4 Gigasamples/second in order to resolve the rise time of the front edge. Watch out for DSOs that claim a high sample rate for repetitive events and indicate a much lower single shot sample rate in the fine print. The authors have found that the best instrument to use is one which incorporates a hybrid oscilloscope design which contains at its core an analog oscilloscope mated to a highly adaptable digital capture and display module. Unfortunately such instruments are not cheap, typically costing in excess of $30,000. At present no less expensive alternatives are known to exist.

ESD Measurement: the Target

Before measuring the ESD waveshape produced by a simulator, one must first define the load across which the waveshape will be measured. IEC 801-2:1991 specifies a coaxial resistive assembly which has been found to be relatively well behaved out to more than 2.5 GHz (see Figures 4 and 5). This assembly is a current dividing transducer which has a transconductance of 1A/1V into 50 Ω. The symmetrical cylindrical construction gives the target its impressive high frequency performance. Most targets are machined out of brass, but copper is also an acceptable material. To insure the target's low surface resistance, the base metal is plated with a 1mm thickness of silver.

Basic Calibration Setup

The ESD probe tip is placed against a target mounted in a 1.5m x 1.5m metal plane and the ground return strap is attached to the plane 1m from the target. The discharge relay is then closed and the subsequent output from the target is observed on a 1 GHz oscilloscope (see Photo 1). The ground return cable must be the one normally used in testing and it should be arranged to form as large a loop as possible away from the metal reference plane. Usually a high bandwidth 50 Ω attenuation pad is required between the target and the oscilloscope to protect the oscilloscope (see Figure 6 for a functional block diagram).

The metal plane may be part of a faraday enclosure around the oscilloscope to shield it from the near field effects of the discharge, but the standard makes the use of a faraday enclosure optional. The authors have found that many scopes available on the market incorporate chassis level shielding which makes an additional faraday box around the instrument redundant.

Static Voltage Measurements

Another important item to be calibrated is the voltage on the capacitive element in the ESD simulator. This parameter should be accurate to within 5% of the nominal simulator meter readout. The measurement should be made at a number of points across the voltage range of the instrument to verify the linearity of the metering circuitry. The

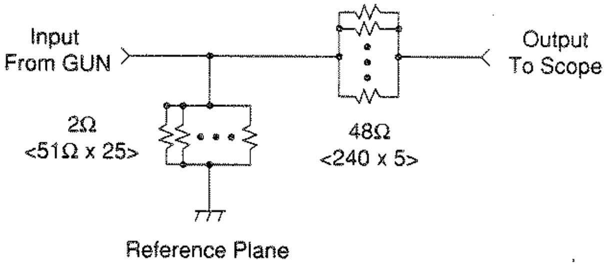

FIGURE 5: *Target schematic.*

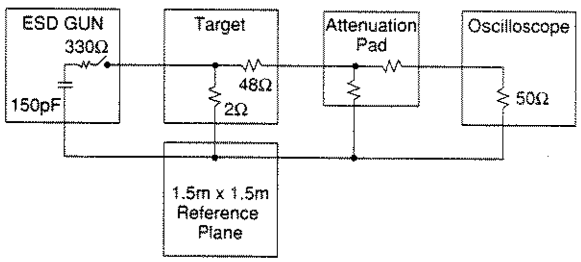

FIGURE 6: *Functional block diagram of the calibration setup.*

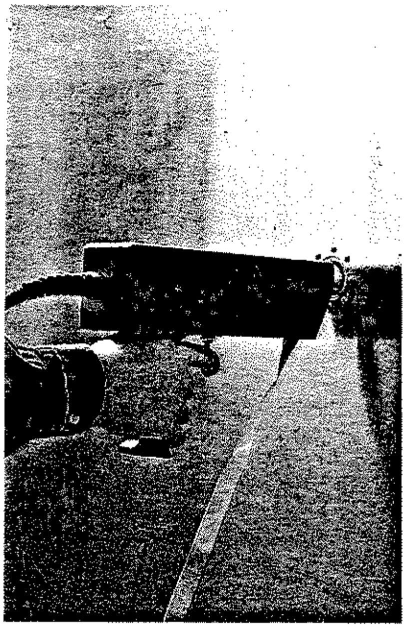

PHOTO 1: Typical ESD calibration setup.

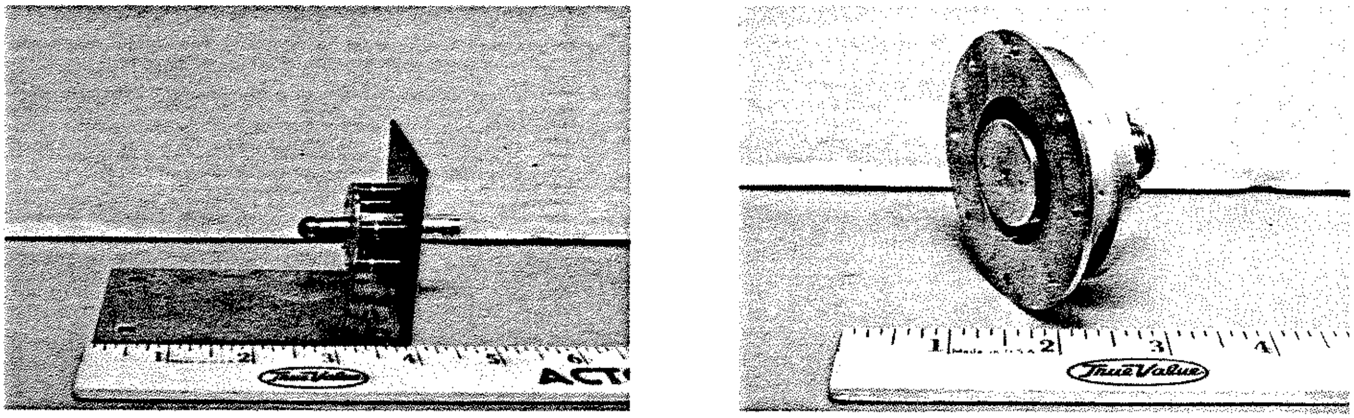

PHOTO 2: Target evolution: The target on the left is the 1984 target, while the one of the right is the higher bandwidth 1991 version.

preferred measuring instrument is an electrostatic voltmeter with a very high impedance, in excess of 30 GΩ. Beware of using a lower impedance instrument and correcting algebraically for the voltage divider created with the power supply impedance. At the high voltages used in ESD simulators, leakage due to corona (current flowing through ionized air) readily contributes to inaccurate measurements. The use of a high impedance instrument is essential to insure that loading of the power supply is kept to a minimum and the corona formed is indicative of the real case when the measuring instrument is *not* attached.

Note also that the measurement is specified to be made at the capacitor. Because of the high impedance (50- 100 MΩ) of the power supply, the reading can be significantly effected by corona leakage into the air off the sharp tip of the contact discharge probe if the measurements are made at the tip with the relay closed. Since the point of this calibration is to insure that the capacitor has the correct charge stored in it at the instant before the relay is closed, the tip should not be connected to the capacitor during this calibration measurement.

Mechanical Specifications

Several physical parameters relating to the simulator should be investigated during the calibration process. The probe tips for air and contact discharge should conform to their respective geometries called out in the standard (see Photo 3). Furthermore the ground return cable should be a nominal 2 meters in length.

Confidence that a product will perform well in the field is partly the result of accurate and repeatable ESD testing. Calibration plays a vital role in the testing process. Pay close attention to the calibration details and keep Sparky away from the test area.

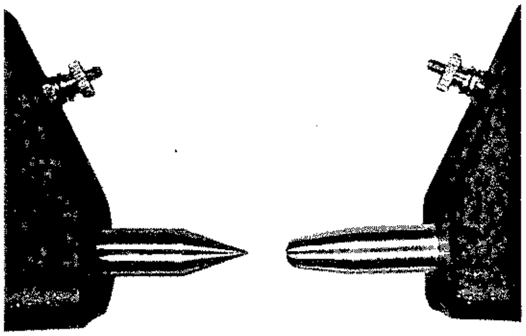

PHOTO 3: ESD simulator tips. Left: Contact discharge. Right: Air discharge.

References

[1] IEC 801-2:1991, *Electromagnetic compatibility for industrial process measurement and control equipment Part 2: Electrostatic discharge requirements.*

[2] Hyatt, Hugh M., *High Voltage Calibration For ESD Diagnostics*, **1993 EOS/ESD Symposium Proceedings**, pp. 17-25.

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