How to Determine Equipment Immunity to ESD

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INTRODUCTION

Electrostatic discharge (ESD) is a natural phenomenon which was first recognized around 600 BC and was documented in *Tales from Millet*. Electrostatic charges occur when two materials of different dielectric strengths, such as wool and glass, are rubbed together. When one of the materials becomes sufficiently charged, it can arc to another object with a lower resistance to the ground. Electrostatic discharge (ESD) and its effects are one of the main sources of interference to electronic equipment. The high frequency and very high voltage of the static discharge impulse can damage or destroy electronic components.

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Basic ESD standards IEC 801-2 and IEC 1000-4-2 address the generators, test setups, environmental classes and test levels for ESD immunity testing. This article explains how some of the parameters were developed by the technical committee responsible for the standard, how the ESD phenomenon is simulated, and different test methods. Some issues not fully covered in the IEC standard are also explained.

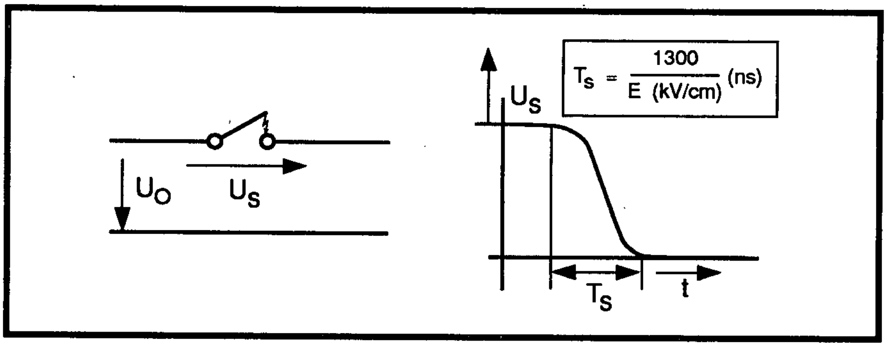

FIGURE 1. *Closing a Switch by an Air Discharge.*

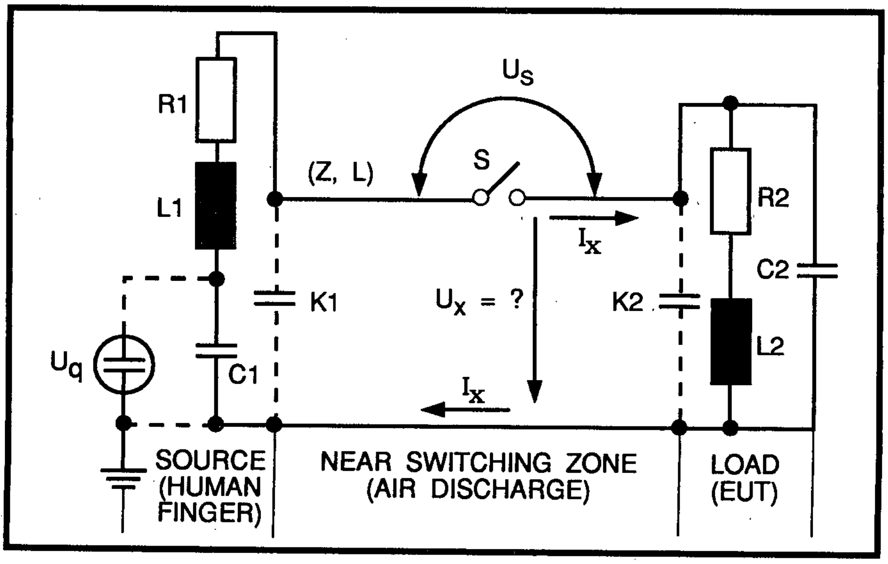

FIGURE 2. *The Propagation of an ESD Interference Impulse.*

THE ESD INTERFERENCE SOURCE

Experience has shown that particularly harmful interference is caused by quick changes of voltage and current, such as when a switch makes a rapid transition from the insulated to the conductive state. This type of event can also happen when a charged human finger approaches a computer keyboard. Before the finger touches the keyboard, an air discharge occurs.

The formula in Figure 1, which is derived from Toepler's law, states that the field intensity prevailing at the time of the switching process largely determines the effective switching time. The higher the field strength, the shorter the switching time, T_s. The field strengths which occur before the air discharge can be very high. As in our example, this is the case when a finger moves rapidly toward an object. Measurements of human ESD show switching times

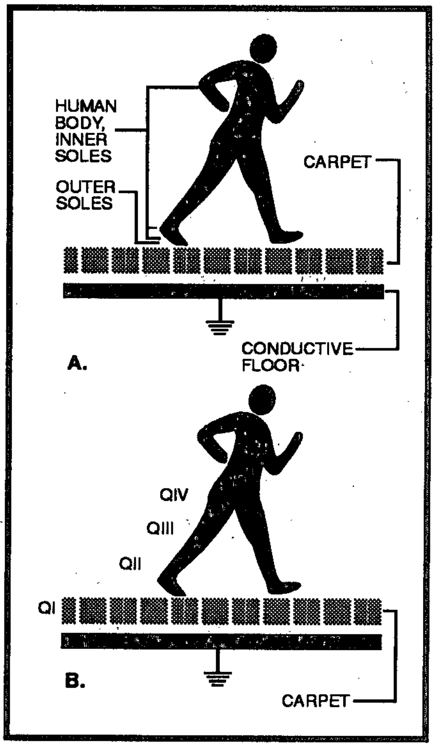

FIGURE 3. *The Electrostatic Charging of a Human Body.*

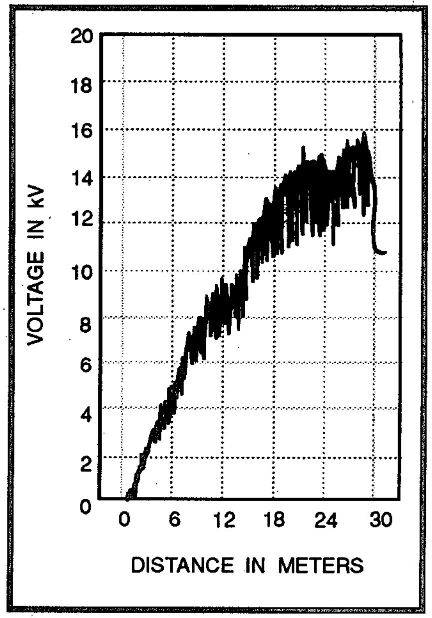

FIGURE 4. *Charging Process of a Person (kV vs. Distance in Meters).*

in the range of 100 ps to 30 ns. Figure 2 represents the three sections of an ESD circuit: 1) the source, which is the human body; 2) the switch zone, which is the discharge area between the finger and the EUT; and 3) the load, which is the EUT. The maximum frequency of the transients U_x and I_x is determined by T_s. Therefore, the EUT is affected by the highest frequency defined by T_s.

THE HUMAN ELECTROSTATIC CHARGE

A common example of an ESD event involves a person walking on a synthetic carpet. The person becomes charged under certain conditions. How does this happen? The question can be answered when we study how people walk on a carpet. This activity can be described as an electronic system which consists of four components:

- The human body, including the inner soles of the shoes. This component can be considered an electrical conductor. Normally, the resistance between two randomly chosen points in a person's body is below 100 Mohm.

Humans only feel an electrostatic discharge when the voltage level is at approximately 3 kV or above.

- The outer sole, which is a good insulator. The resistance for leather is about 0.1 to 100 Gohm and for rubber is about 1000 Gohm.
- The carpet, which is also a fairly good insulator. Depending on the material, a carpet can have various impedance values.
- A conductive and grounded floor, which potentials can be measured against.

As a person walks across the carpet, two different materials rub against each other and the lower sole surface becomes charged. This is represented by QII in Figure 3. This charge is transferred onto the rest of the body (Figure 3: QIII and QIV). When a part of the body touches a grounded conductor, that part of the charge will discharge; e.g. the charge QIV will flow off immediately. After several steps, a charge of up to 10^{-6}C or more can be accumulated depending on the resistance of the shoes and the carpet. With an average capacitance of a "system" (person/carpet/ground) of about 10 pF, a voltage of up to 15 kV can be generated.

Figure 4 shows an example of voltages generated by a human walking on a carpet.

Humans only feel a discharge when the voltage level is at approximately 3 kV or above. Detailed investigations of human electrostatic discharges have shown that in reality the discharge process is made up of a number of individual charges. This is illustrated in Figure 4.

Figure 5 shows the relationship between generated voltages and air humidity for different materials.

From a study of electrostatic discharges produced by different people, it is clear that many different current impulse discharges are generated. The rise time of such currents is between 100 ps and 30 ns. Figure 6 shows how the measurements were made.

An analysis of results obtained from measurements gives the following:

- Skin resistance, R, is approximately 150 ohms.
- Human capacitance, C, is approximately 150 pF.

- Voltages up to 15 kV are calculated from the current amplitude and the human capacitance.

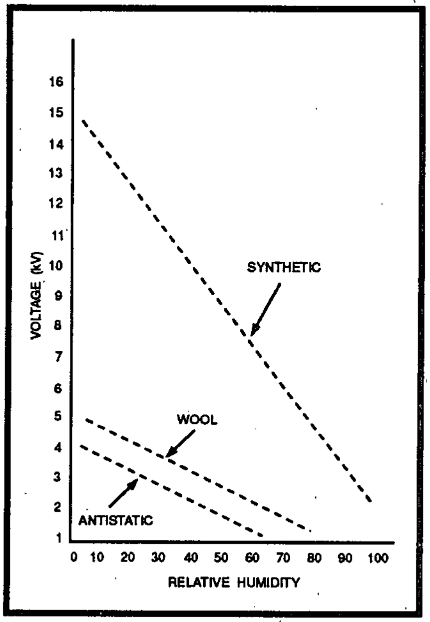

FIGURE 5. *Possible Voltages for Different Materials.*

The discharge wave shape was found to be very different from person to person and also from measurement to measurement. Two extreme examples are shown in Figure 7.

As recently as five to eight years ago, equipment was not capable of measuring rise times smaller

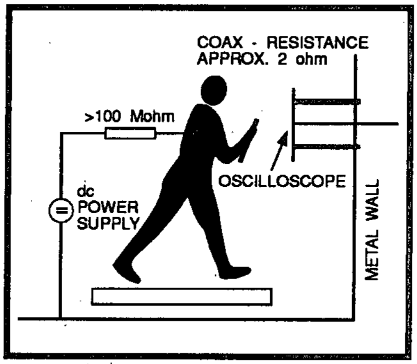

FIGURE 6. *Setup for Human Discharge Current Measurements.*

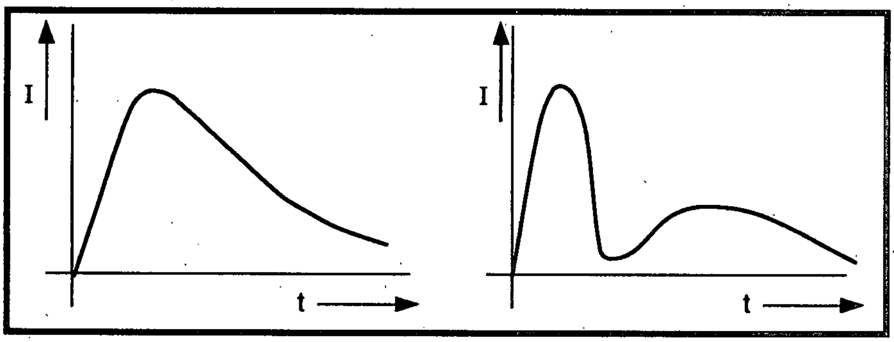

FIGURE 7. *Different Discharge Current Wave Shapes (ns).*

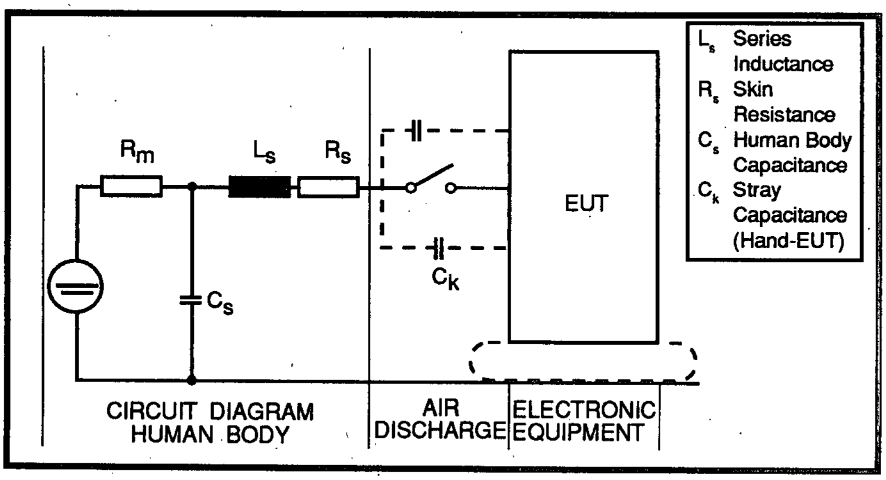

FIGURE 8. *Diagram of a Human Discharge Circuit.*

than 1 ns in a single shot operation. Today measuring systems capable of recording rise times of 100 ps in a single impulse are commercially available.

The earlier measurement limitation resulted in a slow rise time of only 5 ns in the first edition of the IEC 801-2 standard. More recent measurements, using equipment with a bandwidth of greater than 1 GHz, have shown that the rise time for an ESD can be up to 100 ps.

Note that impulses caused by equipment discharge can differ from object to object, because the discharge circuits vary so greatly (Figure 8). Capacitances in the range of 100 pF up to several nF and relative voltages in the range of 1 kV to 300 kV are possible. The discharge resistance is, in many cases, around 1 ohm. The charge carrier and the electronics are often part of the same system. One single representative circuit diagram cannot adequately represent all types of equipment discharges.

COUPLING PATHS

Figure 9 illustrates how coupling paths of ESD transients can have many configurations. The coupling which is most dominant will be determined by the EUT and the test setup.

Experience has shown that when an ESD occurs, it is the E-field collapse and the discharge current that play the dominant role in damaging equipment. In the new revision of IEC 801-2 (1991), the E-field collapse and discharge current are described in the following two test methods:

- The direct discharge method (discharge current)
- The indirect discharge method (E-field collapse)

THE AFFECTED SYSTEM

As electrostatic charge carriers, humans represent the biggest danger to electronics or explosive material in a manufacturing site. Several examples emphasize this danger. Electronic engineers are aware of the electrostatic charging process taking place while working with semiconductor elements. When unpacking semiconductor components, a person touching an IC conductor and charged to a voltage level of 100 volts can cause irreparable damage through several layers of semiconductor material. Interference to computer programs, microprocessors, quartz clocks, etc. can also be caused by electrostatic discharges and the ensuing field changes triggered by air discharges. Additionally, explosives can be detonated by electrostatic discharges. Such incidents have occurred in the chemical and ordnance industries. An ESD event in these industries can cause material damage and human casualties.

SIMULATION OF HUMAN ELECTROSTATIC DISCHARGES

The application of the IEC 801-2 (issue 1984) standard reveals many inadequacies, including those discussed below.

- Non-reproducible test results. Measurements showed that the following parameters influence the discharge current wave shape:
  - approach speed of the test finger to the object
  - surface of the test object (shape of the electrode-field distributions)
  - atmospheric conditions, such as temperature, humidity and pressure
  - charging voltage
- Lack of frequency spectrum changes for different charging voltages. The rise time of the current impulse is very strongly dependent on the charging voltage, resulting in a change of the frequency spectrum. Typical values for the rise time (Ta) of a current discharge are from 100 ps to 5 ns for voltages to 8 kV. For voltages above 8 kV, rise times for Ta can equal 5 to 30 ns.

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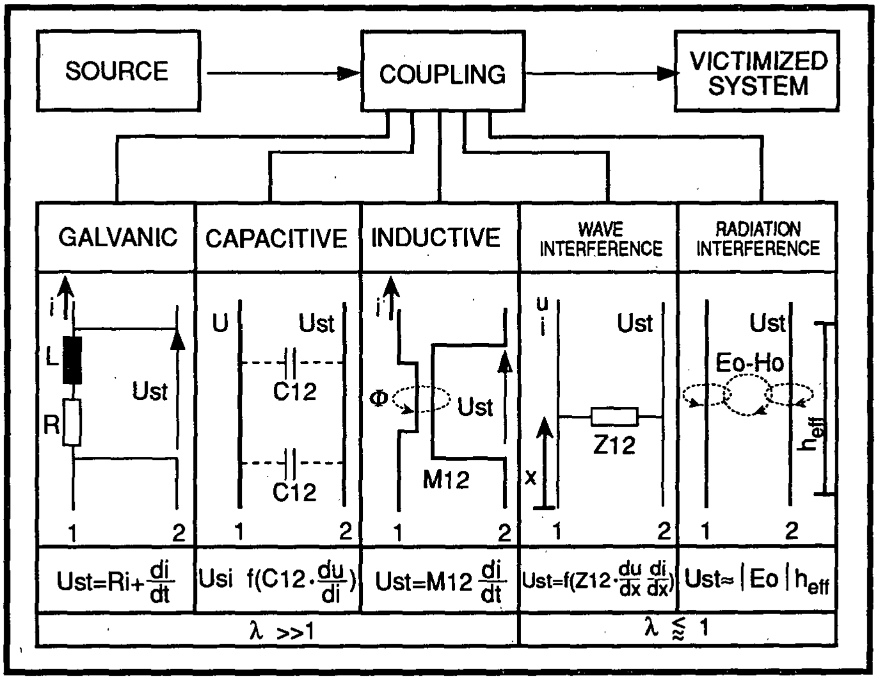

FIGURE 9. *Possible Types of Coupling Paths Between Two Circuits.*

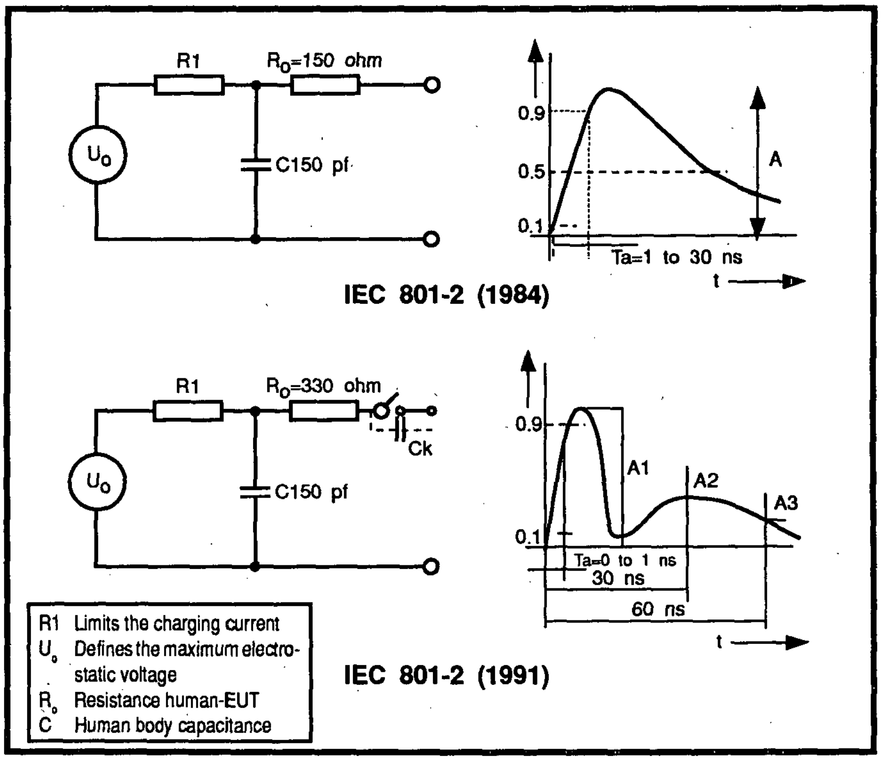

FIGURE 10. *The Differences Between IEC 801-2 (1984) and IEC 801-2 (1991).*

- Variations in EUTs not addressed. A variety of test objects were not considered. EUTs with protective casings and the effects of indirect electrostatic discharge were ignored.

- Variations in discharges not addressed. Human body and equipment discharge were not addressed in terms of EUT type and its end environment.

The new edition of IEC 801-2 (published 1991) addresses all these points. Figure 10 illustrates the difference between the two editions of IEC 801-2 for wave shapes and discharge networks.

TEST MODES

The direct discharge method is the preferred method of testing in the new IEC 801-2. However, it is not always an option when testing an EUT with a nonconductive surface, such as plastic and some types of paints. The type of test or coupling which should be used can be determined from the flow chart given in Figure 11.

When conducting ESD tests, the manufacturer and the customer must agree that in addition to laboratory tests, on-site tests under normal operating conditions should also be performed.

TEST SETUP REQUIREMENTS

In order to achieve comparable results when testing for immunity, the wave shapes from the

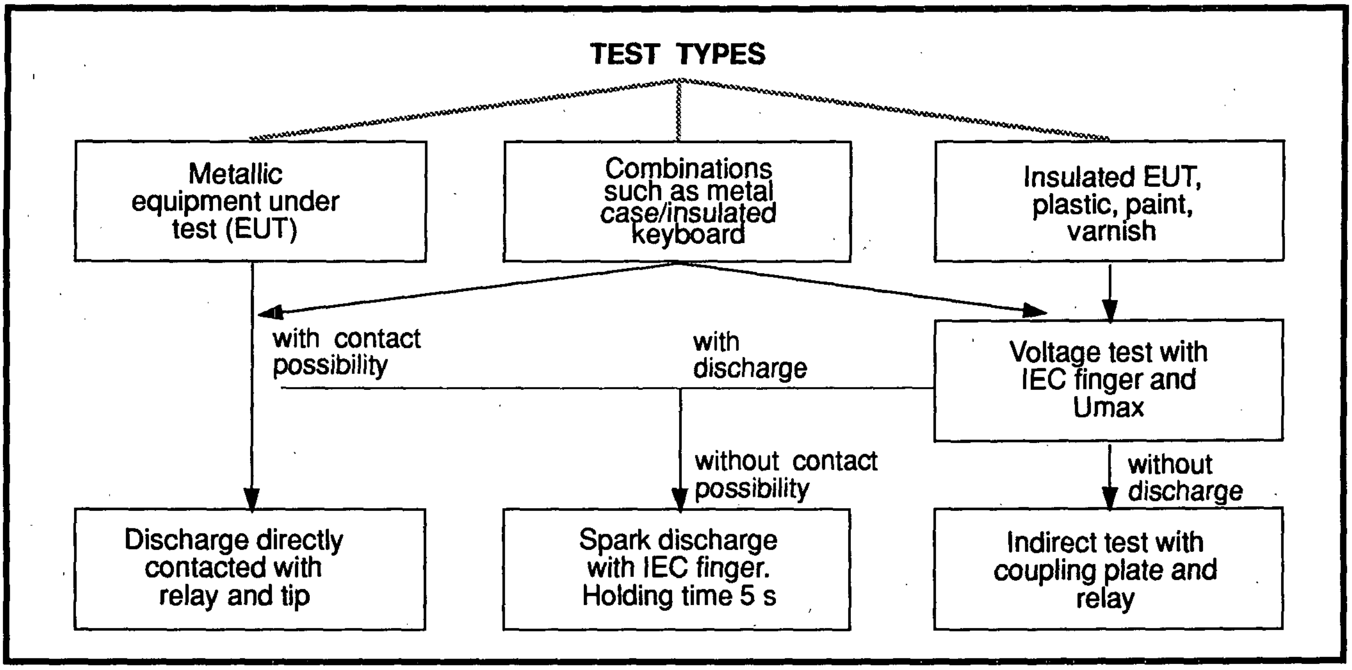

***FIGURE 11.** The Test Modes in Accordance with IEC 801-2 (1991).*

LEVEL	TEST VOLTAGE kV±30%	PEAK CURRENT A±30%	TAIL TIME 30 ns A±30%	TAIL TIME 60 ns A±30%
1	2	7,5	4	2
2	4	15	8	4
3	6	22,5	12	6
4	8	30	16	8

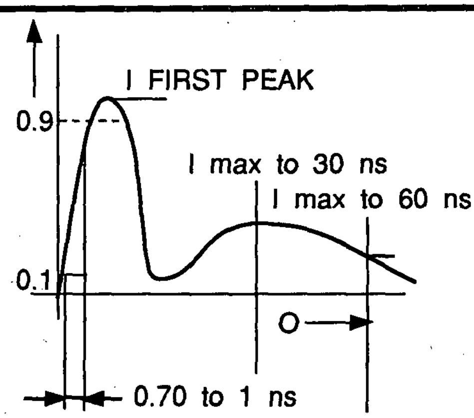

***FIGURE 12.** The Definition of the Impulse Wave Shape IEC 801-2 (1991).*

Basic Standard	IEC IEC VDE	801-2 1000-4-2 0843	(1991) (1992) part 2
Product Standards	FTZ CCITT NAMUR	12TR1 K.17 Pages 1-4	 Issue 1989 Edition 1988
Generic Standards	CENELEC	EN 50 082-1	Issue 1992
Summary Standards	IEC VDE	77 B CO4 0846 part 11	

TABLE 1. *ESD Standards.*

CLASS	RELATIVE HUMIDITY AS LOW AS %	ANTISTATIC MATERIAL	SYNTHETIC MATERIAL	MAXIMUM VOLTAGE
1	35	X		2
2	10	X		4
3	50		X	8
4	10		X	15

TABLE 2. *Environmental Classes.*

ESD generator should be kept within narrow tolerances. Most test equipment can be categorized according to use for QA, R&D or field tests.

For Quality Assurance Test Equipment:
- Reproducibility of the ESD phenomenon is very important.
- For frequencies in the range of up to 100 MHz, measurement of single impulses is very difficult. Calibration and standardization of the equipment should be conducted in a special standards laboratory.
- Both polarities of the transient impulses must be selectable.
- The conditions under which the EUT will be used must be as reproducible as possible.

For R&D Test Equipment:
- The repetition frequency of the interference impulses must be varied.
- The voltage test levels must be increased until the design engineer can determine the exact susceptibility threshold of the equipment.
- Extensive documentation describing the interference parameters, as well as the coupling and filtering elements, must be available. In other words, the amplitude density spectrum of the interference impulses, coupling attenuation and filter attenuation must be known and documented.

For Field Testing/Service Equipment:
- The equipment should be portable and easy to use.

IEC 801-2 (1991)
Figure 12 shows voltage test levels and current wave shapes in accordance with the IEC 801-2 (1991).

Lower currents and voltages are used in the new edition of IEC 801-2 for the following reasons:

- Many tests carried out with new ESD generators have shown that equipment under test failed with only 8 kV, but withstood voltages of up to 15 kV with the old generator.
- By comparing the current between 8 kV (old) and 4 kV (new), it was found that the first current amplitudes were quite similar. But because the rise time of the 4 kV (new) was considerably steeper and showed a higher frequency content, a more thorough test resulted with 8 kV.
- No measurement equipment could be found to measure discharge levels up to 30 kV. The IEC technical committee questioned this voltage level and concluded it was derived from faulty measurements.

SAFETY ASPECTS
Most EMC testers operate with high voltage and/or currents. Careless handling or the disregard of operating and safety instructions can be extremely dangerous and even fatal. EMC testers must be operated by competent and trained personnel only. The replacement of components and any adjustments or calibrations inside the tester must be performed by qualified service engineers. The energy stored in an ESD generator is very small, and a discharge through the body is not very dangerous. Nevertheless, receiving an unintentional discharge from an ESD generator is usually unpleasant. Operators should remember that after using an ESD pistol, the tip must be earthed to remove any residual charge.

LEVEL	TEST VOLTAGE CONTACT DISCHARGE kV	LEVEL	TEST VOLTAGE AIR DISCHARGE
1	2	1	2
2	4	2	4
3	6	3	8
4	8	4	15
X	SPECIAL	X	SPECIAL

TABLE 3. *Test Voltages. Note: "x" is not defined. This level is subject to negotiations and is determined for specific equipment.*

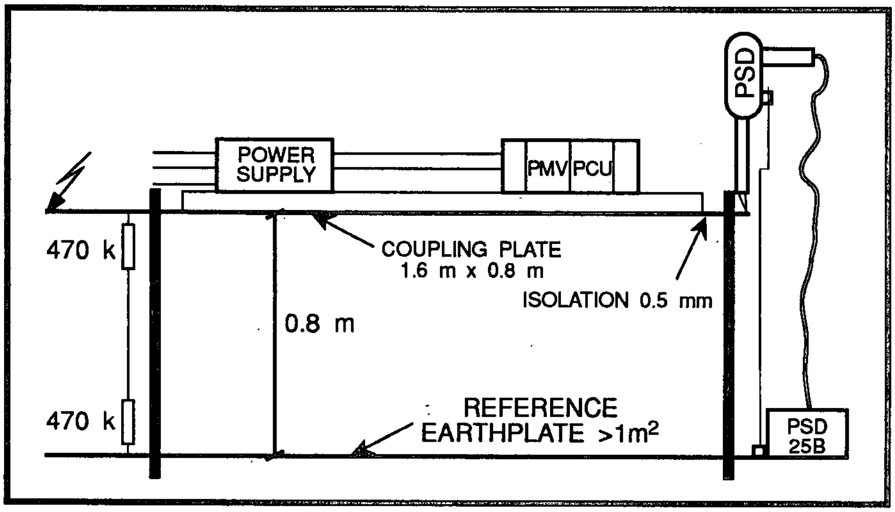

FIGURE 13. *Indirect Current Discharge.*

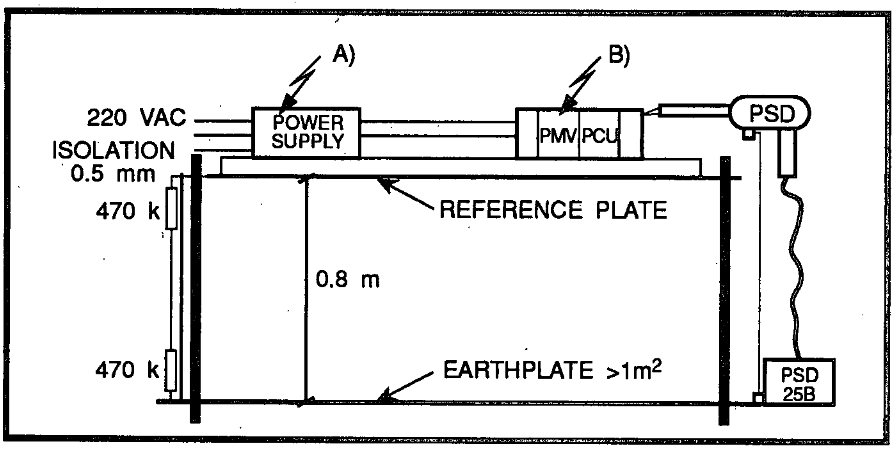

FIGURE 14. *Direct Current Discharge.*

When conducting tests with high voltage or when working with high voltages in general, the following cautionary and safety measures must be observed:

- The EUT must not be touched during the test. Also the EUT should be covered by a protective shield and conspicuously marked as a dangerous test object.
- If the EUT has to be operated or adjusted during the test, the generator must be switched off.
- If the test impulses are superimposed on the mains or supply voltage, the possible follow-on currents, which are caused by surge protection elements, must be considered. Therefore, the circuit must be equipped with the necessary safety fuses.
- In the case of extended breaks in the tests, it is recommended that the generator be switched off by deactivating the power switch.

ESD STANDARDS

Table 1 lists various standards that require ESD tests.

The installation and environmental classes recommended by different standards are related to the test levels outlined earlier in this article (Figure 12). For some material, e.g., wood, concrete and ceramic, a level 2 test is sufficient. The required ESD stress for the 15 kV synthetic material environment is more than adequately covered by the 8 kV/30 A Class 4 using the ESD generator contact discharge (Table 2).

As mentioned previously, the direct contact discharge is the preferred test method. The severity levels shown in Table 3 are recommended for ESD tests. Once a level is chosen all lower levels must also be met.

FAILURE CRITERIA

The variety of equipment and systems which need to be tested complicates the task of establishing general evaluation criteria for static discharge effects. The test results may be classified on the basis of the operating conditions and the functional specifications of the EUT according to the following performance criteria:

- Normal performance within the specification limits.

- Temporary degradation or loss of function or performance which is self-recoverable.
- Temporary degradation or loss of function or performance which requires operator intervention or system reset.
- Degradation or loss of function which is not recoverable, due to damage of equipment (components), software, or loss of data.

TEST CONFIGURATIONS

For most electronic equipment, both direct and indirect test methods must be used. The most efficient way to achieve this is by arranging the equipment for the indirect method (Figure 13). For the direct method, the connection to the 470 kohm resistors must be short circuited (Figure 14).

TEST PLAN

As early as possible in the project stage, a test plan must be established by the manufacturer and the sales engineer (or by the project manager). Such a test plan should contain the following details:

Description of the System

- Description of the system integration
- Description of functional aspects
- Internal environmental conditions
- Environmental classes
- Interference levels of interference measurements

Failure Criteria

As described

Test Procedures

- Description of the test setup, including all accessory equipment with drawings and pictures
- Determination of test levels and wave shapes
- Determination of the conductors/points into which the interference has to be coupled
- Test time and repetition frequency
- Polarity of the impulses

CONCLUSION

ESD testing places increased demands on users and manufacturers of test equipment. The user is confronted with an increasing number of systems to be tested, the test standards are more detailed and the test equipment is more complicated. The systems to be tested will have to be operated at nominal values. Process impedances must be simulated and all peripheral equipment must be set up and decoupled.

In turn, manufacturers are confronted with an increasing demand for test equipment that can be varied with the complexity of transients with regard to voltages, currents and frequencies.

In order to carry out these tests, information must be available on test levels and the characteristics of the EUT, including site setup, grounding, process programs, and admissible interference levels. The deviation of an analog signal within the tolerance band is more admissible than a single bit error in a memory or data communication system.

All these points taken together suggest that EMC must be considered at an early stage, before new electronic products are designed or marketed. This will reduce the amount of testing and ensure that the required tests are realistic. The end result will be a high quality product that will function well during its intended use.

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