CONTENTS

4 General

This standard relates to equipment, systems, subsystems and peripherals which may be involved in static electricity discharges owing to environmental and installation conditions, such as low relative humidity, use of low-conductivity (artificial-fiber) carpets, vinyl garments, etc., which may exist in all locations classified in standards relevant to electrical and electronic equipment (for more detailed information, see Clause A.1).

NOTE From the technical point of view, the precise term for the phenomenon would be static electricity discharge. However, the term electrostatic discharge (ESD) is widely used in the technical world and in technical literature. Therefore, it has been decided to retain the term electrostatic discharge in the title of this standard.

5 Test levels

The preferred range of test levels for the ESD test is given in Table 1.

Contact discharge is the preferred test method. Air discharges shall be used where contact discharge cannot be applied. Voltages for each test method are given in Table 1. The voltages shown are different for each method due to the differing methods of test. This does not imply that the test severity is equivalent between test methods.

Details concerning the various parameters which may influence the voltage to which the human body may be charged are given in Clause A.2. Clause A.4 also contains examples of the application of the test levels related to environmental (installation) classes.

For air discharge testing, the test shall be applied at all test levels in Table 1 up to and including the specified test level. For contact discharge testing, the test shall be applied at the specified test level only unless otherwise specified by product committees.

Further information is given in Clauses A.3, A.4 and A.5.

Table 1 – Test levels

Contact discharge		Air discharge	
Level	Test voltage kV	Level	Test voltage kV
1	2	1	2
2	4	2	4
3	6	3	8
4	8	4	15
x [a]	Special	x [a]	Special

[a] "x" can be any level, above, below or in between the others. The level shall be specified in the dedicated equipment specification. If higher voltages than those shown are specified, special test equipment may be needed.

6 Test generator

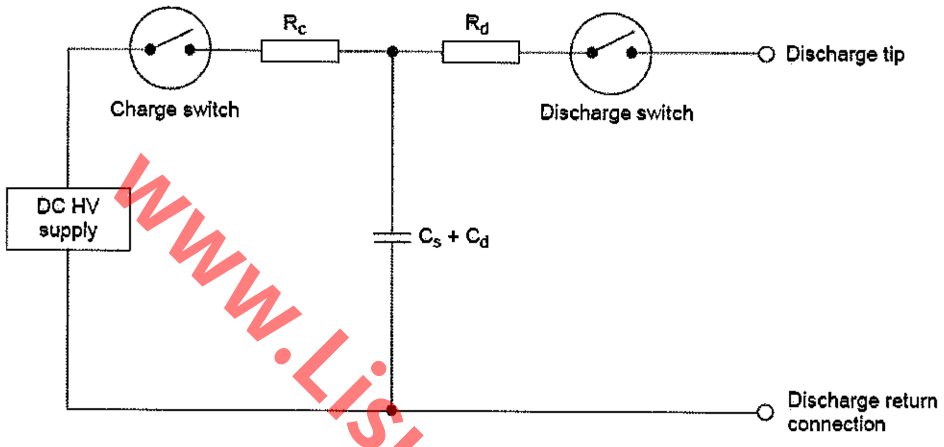
6.1 General

The test generator consists, in its main parts, of

- charging resistor R_c;
- energy-storage capacitor C_s;
- distributed capacitance C_d;
- discharge resistor R_d;
- voltage indicator;

- discharge switch;
- charge switch;
- interchangeable tips of the discharge electrode (see Figure 3);
- discharge return cable;
- power supply unit.

A simplified diagram of the ESD generator is given in Figure 1. Constructional details are not given.



NOTE 1 C_d is a distributed capacitance which exists between the generator and its surroundings.

NOTE 2 $C_d + C_s$ has a typical value of 150 pF.

NOTE 3 R_d has a typical value of 330 Ω.

Figure 1 – Simplified diagram of the ESD generator

The generator shall meet the requirements given in 6.2 when evaluated according to the procedures in Annex B. Therefore, neither the diagram in Figure 1, nor the element values are specified in detail.

6.2 Characteristics and performance of the ESD generator

The test generator shall meet the specifications given in Tables 2 and 3. Figure 2 shows an ideal current waveform and the measurement points referred to in Tables 2 and 3. Conformance with these specifications shall be demonstrated according to the methods described in Annex B.

Table 2 – General specifications

Parameters	Values
Output voltage, contact discharge mode (see NOTE 1)	At least 1 kV to 8 kV, nominal
Output voltage, air discharge mode (see NOTE 1)	At least 2 kV to 15 kV, nominal (see NOTE 3)
Tolerance of output voltage	±5 %
Polarity of output voltage	Positive and negative
Holding time	≥5 s
Discharge mode of operation	Single discharges (see NOTE 2)

NOTE 1 Open circuit voltage measured at the discharge electrode of the ESD generator.

NOTE 2 The generator should be able to generate at a repetition rate of at least 20 discharges per second for exploratory purposes.

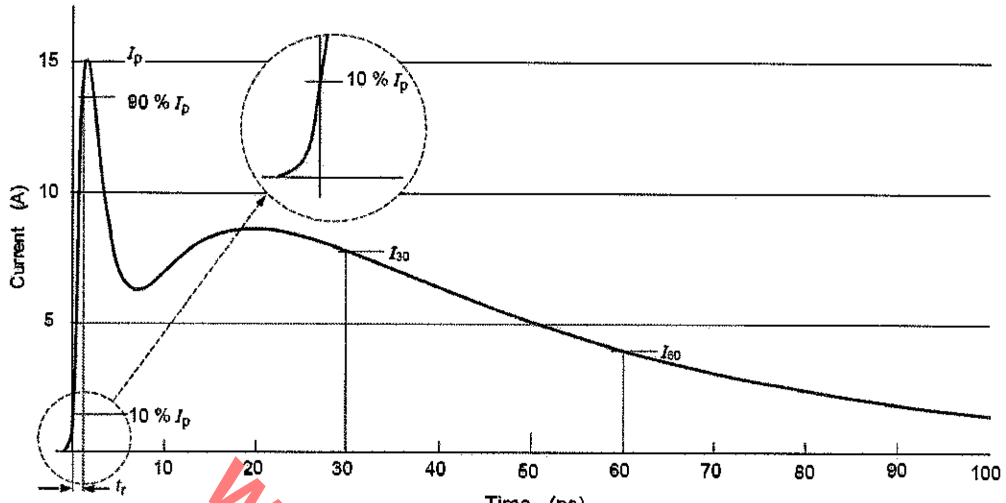
NOTE 3 It is not necessary to use a generator with 15 kV air discharge capability if the maximum test voltage to be used is lower.

Table 3 – Contact discharge current waveform parameters

Level	Indicated voltage kV	First peak current of discharge ±15 % A	Rise time t_r (±25 %) ns	Current (±30 %) at 30 ns A	Current (±30 %) at 60 ns A
1	2	7,5	0,8	4	2
2	4	15	0,8	8	4
3	6	22,5	0,8	12	6
4	8	30	0,8	16	8

The reference point for measuring the time for the current at 30 ns and 60 ns is the instant when the current first reaches 10 % of the 1st peak of the discharge current.

NOTE The rise time, t_r, is the time interval between 10 % and 90 % value of 1st peak current.



IEC 2206/08

Figure 2 – Ideal contact discharge current waveform at 4 kV

The equation for the idealized waveform of Figure 2, $I(t)$, is as follows:

$$I(t) = \frac{I_1}{k_1} \times \frac{\left(\frac{t}{\tau_1}\right)^n}{1+\left(\frac{t}{\tau_1}\right)^n} \times \exp\left(\frac{-t}{\tau_2}\right) + \frac{I_2}{k_2} \times \frac{\left(\frac{t}{\tau_3}\right)^n}{1+\left(\frac{t}{\tau_3}\right)^n} \times \exp\left(\frac{-t}{\tau_4}\right)$$

where

$$k_1 = \exp\left(-\frac{\tau_1}{\tau_2}\left(\frac{n\tau_2}{\tau_1}\right)^{1/n}\right)$$

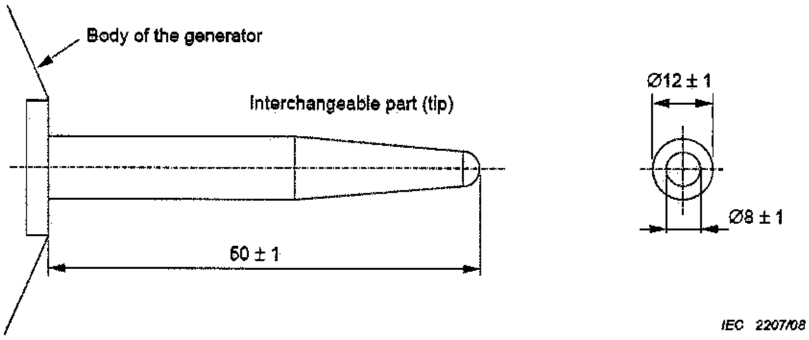
$$k_2 = \exp\left(-\frac{\tau_3}{\tau_4}\left(\frac{n\tau_4}{\tau_3}\right)^{1/n}\right)$$

and

τ_1 = 1,1 ns; τ_2 = 2 ns; τ_3 = 12 ns; τ_4 = 37 ns;
I_1 = 16,6 A (at 4 kV); I_2 = 9,3 A (at 4 kV);
n = 1,8.

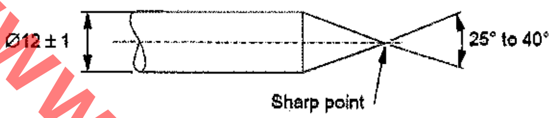
The generator should be provided with means of preventing unintended radiated or conducted emissions, either of pulse or continuous type, so as not to disturb the EUT or auxiliary test equipment by parasitic effects (see Annex D).

The discharge electrodes shall conform to the shapes and dimensions shown in Figure 3. The electrodes may be covered with insulated coatings, provided the discharge current waveform specifications are met.



IEC 2207/08

3a) – Discharge electrode for air discharges



IEC 2208/08

3b) – Discharge electrode for contact discharges

Figure 3 – Discharge electrodes of the ESD generator

For the air discharge test method the same generator is used and the discharge switch has to be closed. The generator shall be fitted with the round tip shown in Figure 3a). Because the same ESD generator is used no further specifications for the air discharge method exist.

The discharge return cable of the test generator shall be (2 ± 0,05) m long, and constructed to allow the generator to meet the waveform specification. The length of the discharge return cable is measured from the ESD generator body to the end of the connecting point. It shall be sufficiently insulated to prevent the flow of the discharge current to personnel or conducting surfaces other than via its termination, during the ESD test.

The discharge return cable used for testing shall be the same or identical with the cable used during calibration.

In cases where a 2 m length of the discharge return cable is insufficient, (e.g. for tall EUTs), a length up to 3 m may be used. The waveform specification shall be met with the cable(s) used during testing.

6.3 Verification of the ESD setup

The purpose of verification is to ensure that the ESD test setup is operating. The ESD test setup includes:

- the ESD generator;
- the discharge return cable;
- the 470 kΩ bleeder resistors;
- the ground reference plane, and,
- all of the connections that form the discharge path.

Examples for the ESD test setup are given in Figure 4 for table-top equipment and in Figure 5 for floor-mounted equipment.

To verify the proper ESD test setup, one verification method may be to observe that at low voltage settings, a small spark is created during air discharge to the coupling plane and a larger spark is created at higher settings. It is essential to verify the ground strip connection and location prior to this verification.

Rationale: Since waveforms from ESD generators do not typically change in subtle ways (for example, the rise time and duration of the waveform do not drift), the most likely ESD generator failures would be that no voltage was delivered to the discharge electrode or that no voltage control was present. Any of the cables, resistors or connections along the discharge path may be damaged, loose or missing, resulting in no discharge.

It is recommended that the ESD test setup is verified prior to testing.

7 Test setup

7.1 Test equipment

The test setup consists of the test generator, EUT and auxiliary instrumentation necessary to perform direct and indirect application of discharges to the EUT in the following manner:

a) contact discharge to the conductive surfaces and to coupling planes;
b) air discharge at insulating surfaces.

Two different types of tests can be distinguished:

- type (conformance) tests performed in laboratories;
- post installation tests performed on equipment in its final installed conditions.

The preferred test method is that of type tests performed in laboratories.

The EUT shall be arranged in accordance with the manufacturer's instructions for installation (if any).

7.2 Test setup for tests performed in laboratories

7.2.1 Test requirements

The following requirements apply to tests performed in laboratories under environmental reference conditions outlined in 8.1.

A ground reference plane (GRP) shall be provided on the floor of the laboratory. It shall be a metallic sheet (copper or aluminum) of 0,25 mm minimum thickness; other metallic materials may be used but they shall have at least 0,65 mm minimum thickness.

The ground reference plane (GRP) shall project beyond the EUT or the horizontal coupling plane (when applicable) by at least 0,5 m on all sides, and shall be connected to the protective grounding system.

Local safety regulations shall always be met.

The EUT shall be arranged and connected according to its functional requirements.

A distance of 0,8 m minimum shall be provided between the EUT and the walls of the laboratory and any other metallic structure.

The EUT and ESD generator (including any external power supply) shall be grounded in accordance with their installation specifications. No additional grounding connections are allowed.

The positioning of the power and signal cables shall be representative of installation practice.

The discharge return cable of the ESD generator shall be connected to the ground reference plane. Only in cases where the length of the cable exceeds the length necessary to apply the discharges to the selected points, the excess length shall, where possible, be placed non-inductively off the ground reference plane. The discharge return cable shall not come closer than 0,2 m to other conductive parts in the test setup except the ground reference plane.

NOTE 1 It is allowed to connect the discharge return cable to the metallic wall of the test laboratory provided that wall is electrically bonded to the GRP.

The connection of the earth cables to the ground reference plane and all bondings shall be of low impedance, for example by using mechanical clamping devices for high frequency applications.

Where coupling planes are specified, for example to allow indirect application of the discharge, they shall be constructed from a metallic sheet (copper or aluminum) of 0,25 mm minimum in thickness (other metallic materials may be used but they shall have at least 0,65 mm minimum in thickness) and shall be connected to the GRP via a cable with a 470 kΩ resistor located at each end. These resistors shall be capable of withstanding the discharge voltage. The resistors and cables shall be insulated to avoid short circuits to the GRP when the cable lies on the GRP.

NOTE 2 The 470 kΩ bleeder resistors which are contained in the grounding cables of the HCP and VCP (see Figures 4 to 8) are used to prevent the charge applied to the planes disappearing instantly after the discharge of the ESD generator to the plane. This increases the impact of the ESD event to the EUT. The resistors should be capable of withstanding the maximum discharge voltage applied to the EUT plane during the test. They should be positioned close to each end of the grounding cable in order to create a distributed resistance.

Additional specifications for the different types of equipment are given below.

7.2.2 Table-top equipment

The test setup shall consist of a non-conductive table, (0,8 ± 0,08) m high, standing on the ground reference plane.

A horizontal coupling plane (HCP), (1,6 ± 0,02) m × (0,8 ± 0,02) m, shall be placed on the table. The EUT and its cables shall be isolated from the coupling plane by an insulating support (0,5 ± 0,05) mm in thickness.

NOTE It is recommended that the insulating properties are maintained.

If the EUT is too large to be located 0,1 m minimum from all sides of the HCP, an additional, identical HCP shall be used, placed (0,3 ± 0,02) m from the first HCP. The table has to be enlarged or two tables may be used. The HCPs shall not be bonded together, other than via resistive cables to the GRP.

Any mounting feet associated with the EUT shall remain in place.

An example of the test setup for table-top equipment is given in Figure 4.

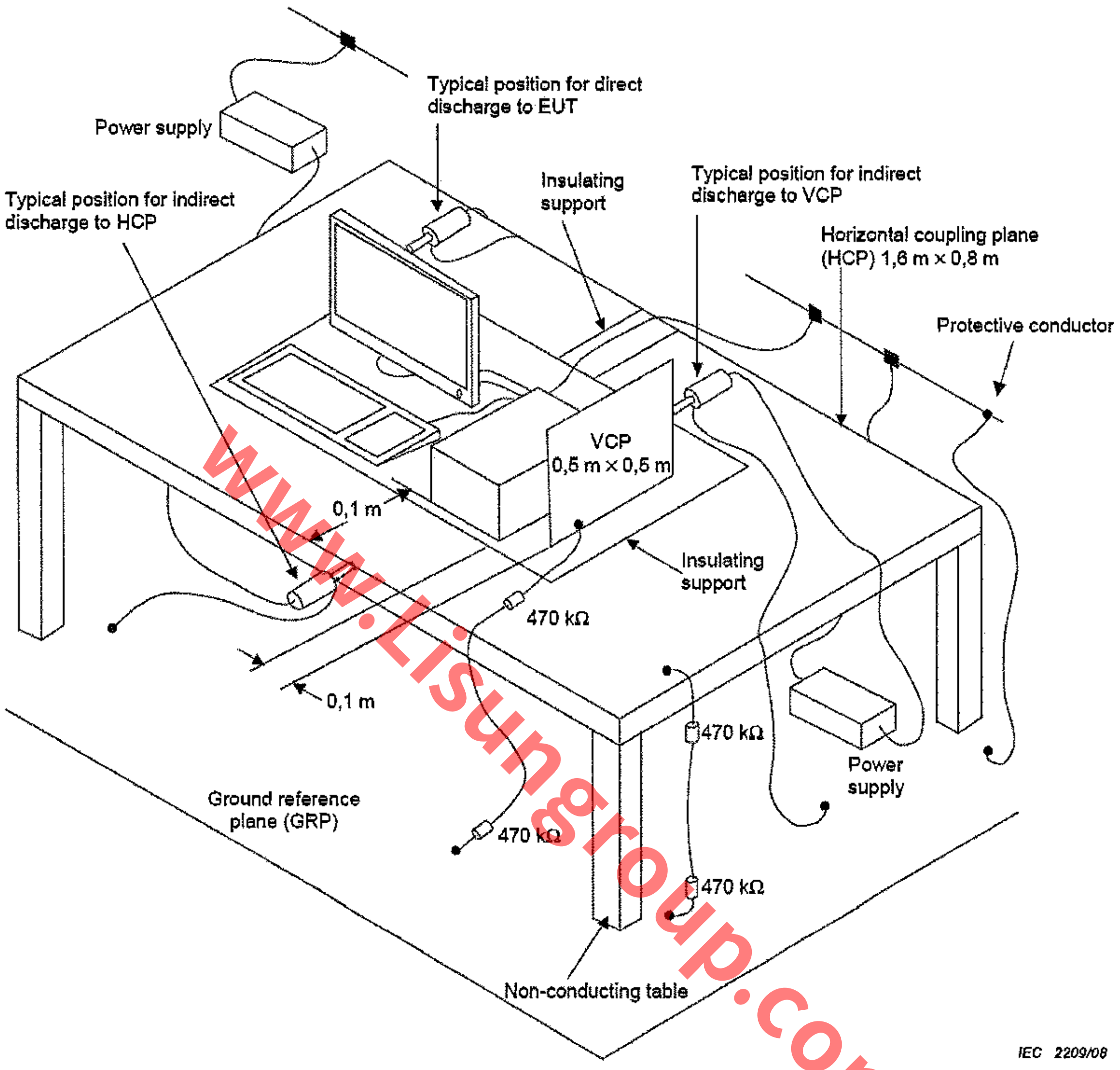


Figure 4 – Example of test set-up for table-top equipment, laboratory tests

7.2.3 Floor-standing equipment

The EUT shall be isolated from the ground reference plane by an insulating support of 0,05 m to 0,15 m thick. The EUT cables shall be isolated from the ground reference plane by an insulating support of (0,5 ± 0,05) mm. This cable isolation shall extend beyond the edge of the EUT isolation.

An example of the test setup for floor-standing equipment is given in Figure 5.

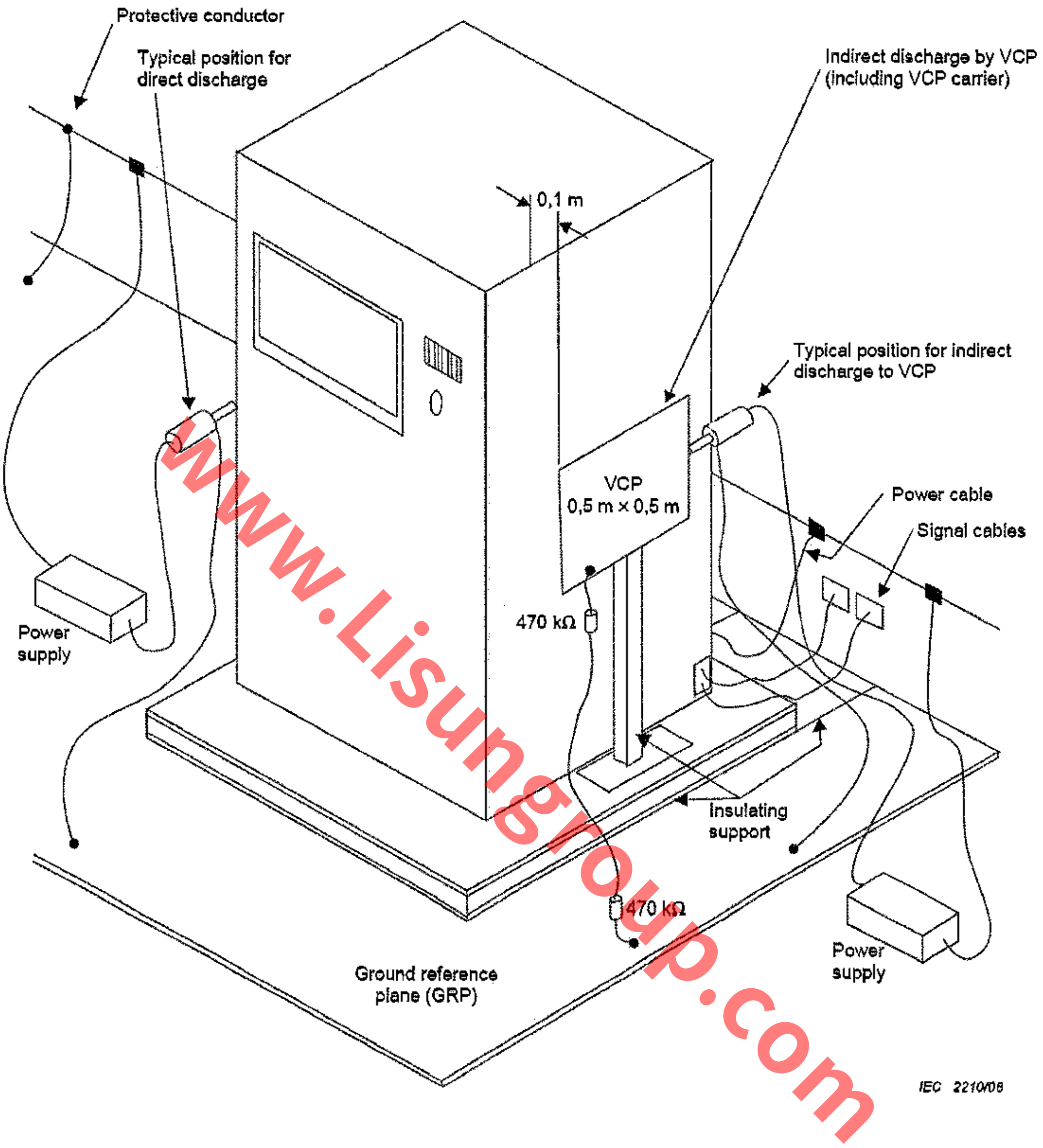


Figure 5 – Example of test setup for floor-standing equipment, laboratory tests

Any mounting feet associated with the EUT shall remain in place.

7.2.4 Ungrounded equipment

7.2.4.1 General

The test setup described in this subclause is applicable to equipment or part(s) of equipment whose installation specifications or design precludes connection to any grounding system. This includes portable, battery-operated (internal and external) with or without charger (ungrounded power cable) and double-insulated equipment (class II equipment).

Rationale: Ungrounded equipment, or ungrounded part(s) of equipment, cannot discharge itself similarly to class I mains-supplied equipment. If the charge is not removed before the next ESD pulse is applied, it is possible that the EUT or part(s) of the EUT be stressed up to twice the intended test voltage. Therefore, this type of equipment or equipment parts could be charged at an unrealistically high charge, by accumulating several ESD discharges on the capacitance of the class II insulation, and then discharge at the breakdown voltage of the insulation with a much higher energy.

The general test setup shall be identical to the ones described in 7.2.2 and 7.2.3 respectively.

To simulate a single ESD event (either by air or by contact discharge), the charge on the EUT shall be removed prior to each applied ESD pulse.

The charge on the metallic point or part to which the ESD pulse is to be applied, for example, connector shells, battery charge pins, metallic antennas, shall be removed prior to each applied ESD test pulse.

When one or several metallic accessible parts are subjected to the ESD test, the charge shall be removed from the point where the ESD pulse is to be applied, as no guarantee can be given about the resistance between this and other accessible points on the product.

A cable with 470 kΩ bleeder resistors, similar to the one used with the HCP and VCP is the preferred device to remove charges; see 7.2.

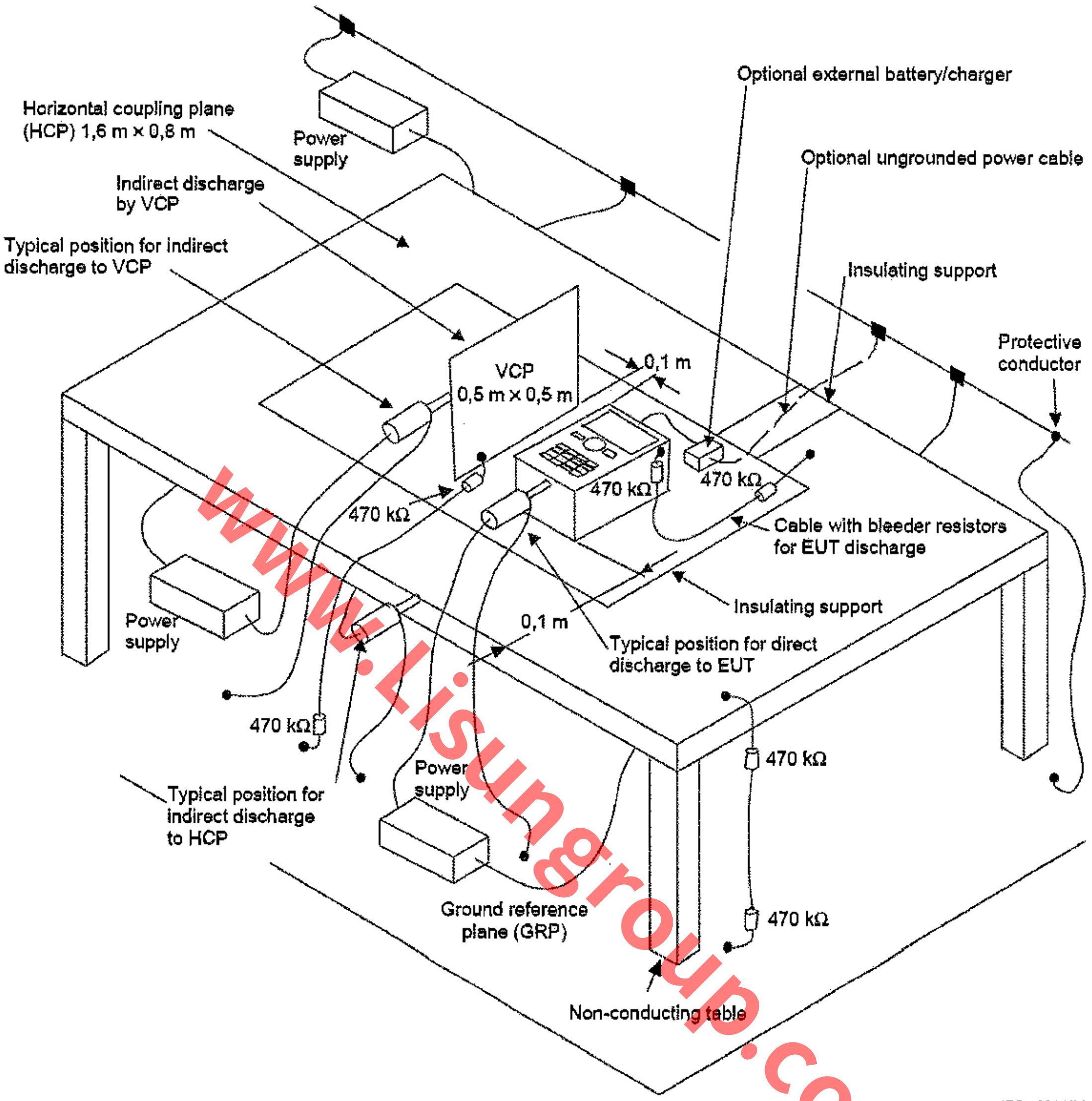
As the capacitance between EUT and HCP (table-top) and between EUT and GRP (floor-standing) is determined by the size of the EUT, the cable with bleeder resistors may remain installed during the ESD test when functionally allowed. In the cable with bleeder resistors, one resistor shall be connected as close as possible, preferably less than 20 mm from the EUT test point. The second resistor shall be connected near the end of the cable attached to the HCP for table-top equipment (see Figure 6), or GRP for floor-standing equipment (see Figure 7).

The presence of the cable with the bleeder resistors can influence the test results of some equipment. A test with the cable disconnected during the ESD pulse takes precedence over the test with the cable installed during the test, provided that the charge has sufficiently decayed between the successive discharges.

Therefore as an alternative, the following options may be used:

- the time interval between successive discharges shall be extended to the time necessary to allow natural decay of the charge from the EUT;
- sweeping of the EUT with a grounded carbon fibre brush with bleeder resistors (for example, 2 × 470 kΩ) in the grounding cable.

NOTE In case of dispute concerning the charge decay, the charge on the EUT can be monitored by a non-contacting electric field meter. When the charge has decayed below 10 % of the initial value, the EUT is considered to be discharged.



IEC 2211/08

Figure 6 – Example of a test setup for ungrounded table-top equipment

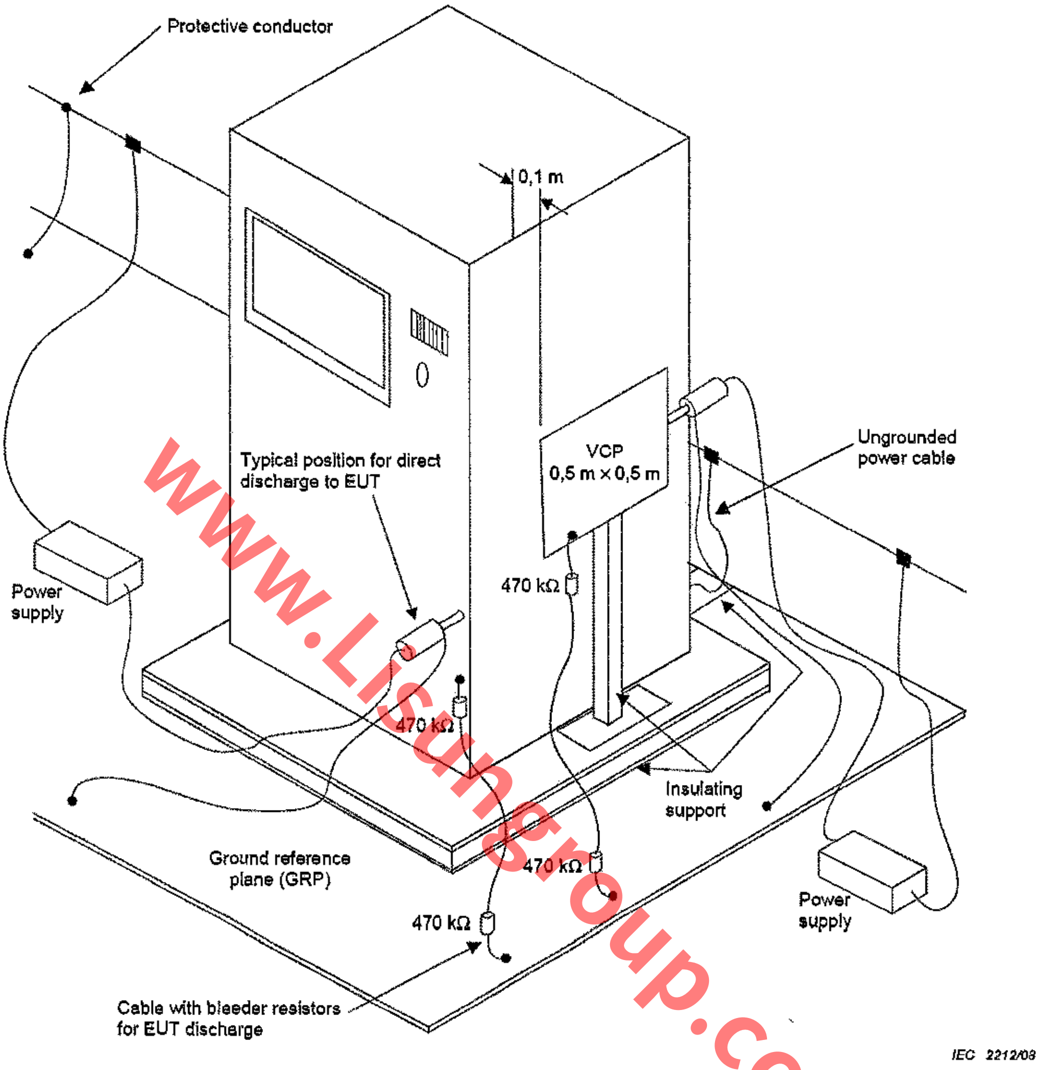


Figure 7 – Example of a test setup for ungrounded floor-standing equipment

7.2.4.2 Table-top equipment

Table-top equipment without any metallic connection to the ground reference plane shall be installed similarly to 7.2.2 and Figure 4.

When a metallic accessible part, to which the ESD pulse is to be applied, is available on the EUT, this part shall be connected to the HCP via the cable with bleeder resistors; see Figure 6.

7.2.4.3 Floor-standing equipment

Floor-standing equipment without any metallic connection to the ground reference plane shall be installed similarly to 7.2.3 and Figure 5.

A cable with bleeder resistors shall be used between the metallic accessible part, to which the ESD pulse is to be applied, and the ground reference plane (GRP); see Figure 7.

7.3 Test setup for post-installation tests

These post installation tests, which are performed in situ, may be applied when agreed between manufacturer and customer. It has to be considered that other co-located equipment may be unacceptably affected.

NOTE In addition, the EUT itself may suffer significant ageing from in situ ESD testing. The mean time to failure (MTTF) of many modern electronic circuits decreases significantly if these circuits had once to withstand the discharge of static electricity. The malfunction does not need to occur immediately during the ESD test but the device will often fail much faster than a device which never had to withstand ESD tests. Taking this into consideration it may be wise to decide to perform no in situ ESD testing at all.

If it is decided to perform post installation ESD tests the EUT shall be tested in its final installation conditions.

In order to facilitate a connection for the discharge return cable, a ground reference plane shall be placed on the floor of the installation, close to the EUT at about 0,1 m distance. This plane should be of copper or aluminium not less than 0,25 mm thick. Other metallic materials may be used, providing the minimum thickness is 0,65 mm. The plane should be approximately 0,3 m wide, and 2 m in length where the installation allows.

This ground reference plane should be connected to the protective earthing system. Where this is not possible, it should be connected to the earthing terminal of the EUT, if available.

The discharge return cable of the ESD generator shall be connected to the reference plane. Where the EUT is installed on a metal table, the table shall be connected to the reference plane via a cable with a 470 kΩ resistor located at each end, to prevent a build-up of charge.

The ungrounded metallic parts shall be tested following 7.2.4 The cable with the bleeder resistors shall be connected to the GRP close to the EUT.

An example of the setup for post-installation tests is given in Figure 8.

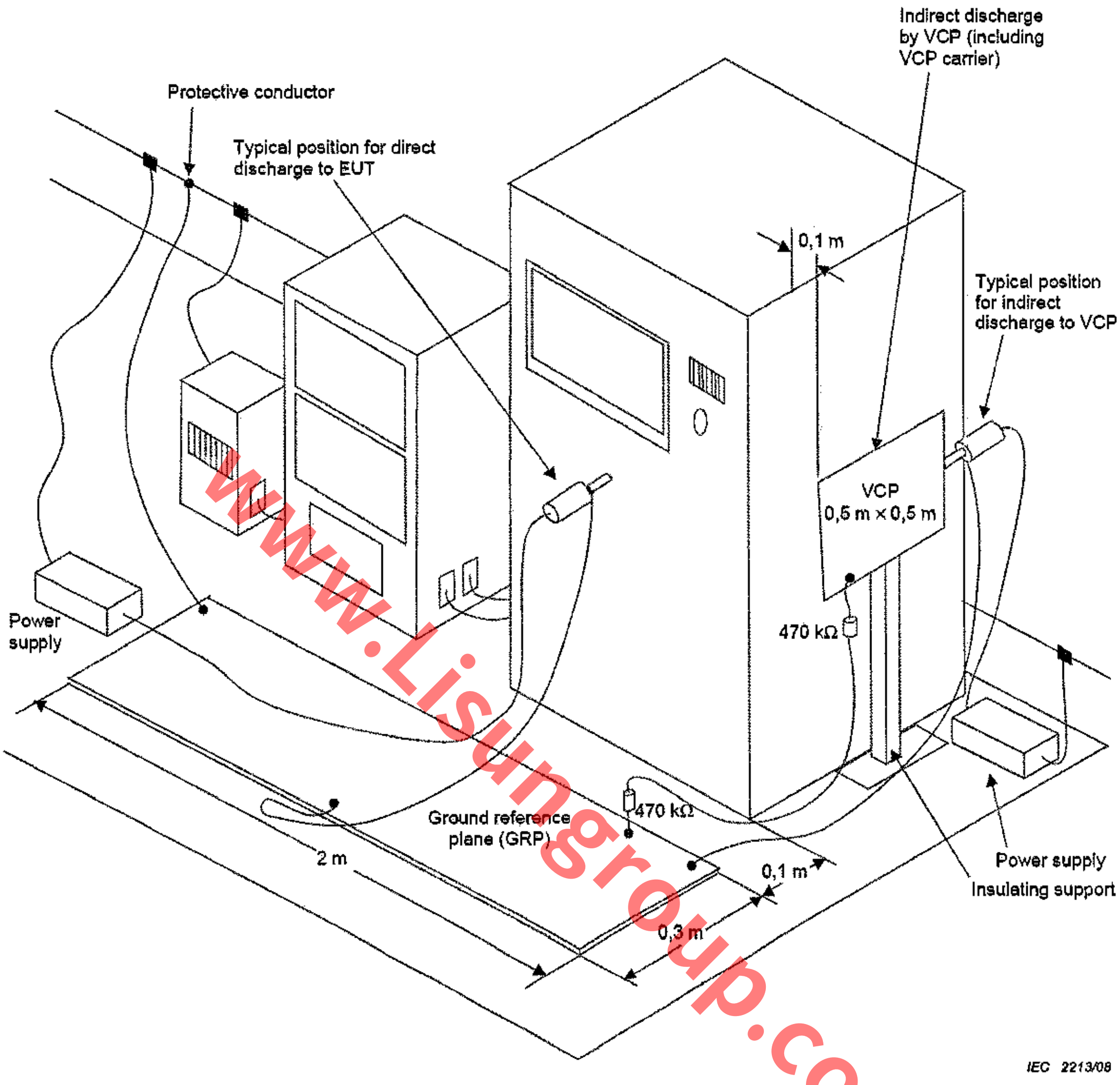


Figure 8 – Example of test setup for floor-standing equipment, post-installation tests

8 Test procedure

8.1 Laboratory reference conditions

8.1.1 Environmental parameters

In order to minimize the impact of environmental parameters on test results, the tests and calibration shall be carried out in climatic and electromagnetic reference conditions as specified in 8.1.2 and 8.1.3.

8.1.2 Climatic conditions

The EUT shall be operated within its intended climatic conditions.

In the case of air discharge testing, the climatic conditions shall be within the following ranges:

- ambient temperature: 15 °C to 35 °C;
- relative humidity: 30 % to 60 %;
- atmospheric pressure: 86 kPa (860 mbar) to 106 kPa (1 060 mbar).

NOTE Other values may be applicable for equipment used only in particular climatic environments.

8.1.3 Electromagnetic conditions

The electromagnetic conditions of the laboratory shall be such as to guarantee the correct operation of the EUT in order not to influence the test results.

8.2 EUT exercising

The test programs and software shall be chosen so as to exercise all normal modes of operation of the EUT. The use of special exercising software is encouraged, but permitted only where it can be shown that the EUT is being comprehensively exercised.

For conformance testing, the EUT shall be continually operated in its most sensitive mode (program cycle) which shall be determined by preliminary testing.

If monitoring equipment is required, it should be decoupled from the EUT in order to reduce the possibility of false indications.

8.3 Execution of the test

8.3.1 Discharges to the EUT

The testing shall be performed by direct and/or indirect application of discharges to the EUT according to a test plan. This should include:

- representative operating conditions of the EUT;
- whether the EUT should be tested as table-top or floor-standing;
- the points at which discharges are to be applied;
- at each point, whether contact or air discharges are to be applied;
- the test level to be applied;
- the number of discharges to be applied at each point for conformance testing;
- whether post-installation tests are also to be applied.

It may be necessary to carry out some investigatory testing to establish some aspects of the test plan.

NOTE 1 Refer to Annex E for examples of uncertainty budgets in case of necessity to provide measurement uncertainty.

NOTE 2 In case of variations in test results, Annex F proposes an escalation strategy of ESD to determine the sources of differences.

8.3.2 Direct application of discharges to the EUT

Unless stated otherwise in the generic, product-related or product-family standards, the electrostatic discharges shall be applied only to those points and surfaces of the EUT which are accessible to persons during normal use. The following exclusions apply (i.e. discharges are not applied to those items):

a) those points and surfaces which are only accessible under maintenance. In this case, special ESD mitigation procedures shall be given in the accompanying documentation;

b) those points and surfaces which are only accessible under service by the (end-)user. Examples of these rarely accessed points are as follows: battery contacts while changing batteries, a cassette in a telephone answering machine, etc.;

c) those points and surfaces of equipment which are no longer accessible after fixed installation or after following the instructions for use, for example, the bottom and/or wall-side of equipment or areas behind fitted connectors;

d) the contacts of coaxial and multi-pin connectors which are provided with a metallic connector shell. In this case, contact discharges shall only be applied to the metallic shell of these connectors.

   Contacts within a non-conductive (for example, plastic) connector and which are accessible shall be tested by the air-discharge test only. This test shall be carried out by using the rounded tip finger on the ESD generator.

   In general, six cases shall be considered:

Table 4 – Cases for application of ESD on connectors

Case	Connector shell	Cover material	Air discharge to:	Contact discharge to:
1	Metallic	None	–	Shell
2	Metallic	Insulated	Cover	Shell when accessible
3	Metallic	Metallic	–	Shell and cover
4	Insulated	None	[a]	–
5	Insulated	Insulated	Cover	–
6	Insulated	Metallic	–	Cover

NOTE In case a cover is applied to provide (ESD) shielding to the connector pins, the cover or the equipment near to the connector to which the cover is applied should be labelled with an ESD warning.

[a] If the product (family) standard requires testing to individual pins of an insulated connector, air discharges shall apply.

e) those contacts of connectors or other accessible parts that are ESD sensitive because of functional reasons and are provided with an ESD warning label, for example, r.f. inputs from measurement, receiving or other communication functions.

   Rationale: Many connector ports are designed to handle high-frequency information, either analogue or digital, and therefore cannot be provided with sufficient overvoltage protection devices. In the case of analogue signals, bandpass filters may be a solution. Overvoltage protecting diodes have too much stray capacitance to be useful at the frequencies at which the EUT is designed to operate.

In all the previous cases, the accompanying documentation should give special ESD mitigation procedures.

The final test level should not exceed the product specification value in order to avoid damage to the equipment.

The test shall be performed with single discharges. On each pre-selected point at least 10 single discharges (in the most sensitive polarity) shall be applied.

NOTE 1 The minimum number of discharges applied is depending on the EUT; for products with synchronized circuits the number of discharges should be larger.

For the time interval between successive single discharges an initial value of 1 s is recommended. Longer intervals may be necessary to determine whether a system failure has occurred.

NOTE 2 The points to which the discharges should be applied may be selected by means of an exploration carried out at a repetition rate of 20 discharges per second, or more.

The ESD generator shall be held perpendicular, whenever possible, to the surface to which the discharge is applied. This improves repeatability of the test results. If the ESD generator cannot be held perpendicular to the surface, the test condition used to perform the discharges shall be recorded in the test report.

The discharge return cable of the generator shall be kept at a distance of at least 0,2 m from the EUT whilst the discharge is being applied and should not be held by the operator.

In the case of contact discharges, the tip of the discharge electrode shall touch the EUT, before the discharge switch is operated.

In the case of painted surfaces covering a conducting substrate, the following procedure shall be adopted:

If the coating is not declared to be an insulating coating by the equipment manufacturer, then the pointed tip of the generator shall penetrate the coating so as to make contact with the conducting substrate. Coating declared as insulating by the manufacturer shall only be submitted to the air discharge. The contact discharge test shall not be applied to such surfaces.

In the case of air discharges, the ESD generator shall approach the EUT as fast as possible until contact between the electrode and the EUT is made (without causing mechanical damage). After each discharge, the ESD generator (discharge electrode) shall be removed from the EUT. The generator is then retriggered for a new single discharge. This procedure shall be repeated until the discharges are completed. In the case of an air discharge test, the discharge switch, which is used for contact discharge, shall be closed.

8.3.3 Indirect application of the discharge

8.3.3.1 Discharges to objects near the EUT

Discharges to objects placed or installed near the EUT shall be simulated by applying the discharges of the ESD generator to a coupling plane, in the contact discharge mode.

In addition to the test procedure described in 8.3.2, the requirements given in 8.3.3.2 and 8.3.3.3 shall be met.

8.3.3.2 Horizontal coupling plane (HCP) under the EUT

Discharge to the HCP shall be made horizontally to the edge of the HCP.

At least 10 single discharges (in the most sensitive polarity) shall be applied at the front edge of each HCP opposite the centre point of each unit (if applicable) of the EUT and 0,1 m from the front of the EUT. The long axis of the discharge electrode shall be in the plane of the HCP and perpendicular to its front edge during the discharge.

The discharge electrode shall be in contact with the edge of the HCP before the discharge switch is operated (see Figure 4).

Product standards may require that all sides of the EUT are exposed to this test.

8.3.3.3 Vertical coupling plane (VCP)

At least 10 single discharges (in the most sensitive polarity) shall be applied to the centre of one vertical edge of the coupling plane (Figures 4 and 5). The coupling plane, of dimensions 0,5 m × 0,5 m, is placed parallel to, and positioned at a distance of 0,1 m from, the EUT.

Discharges shall be applied to the coupling plane, with sufficient different positions such that the four faces of the EUT are completely illuminated. One VCP position is considered to illuminate 0,5 m × 0,5 m area of the EUT surface.

9 Evaluation of test results

The test results shall be classified in terms of the loss of function or degradation of performance of the equipment under test, relative to a performance level defined by its manufacturer or the requestor of the test, or agreed between the manufacturer and the purchaser of the product. The recommended classification is as follows:

a) normal performance within limits specified by the manufacturer, requestor or purchaser;

b) temporary loss of function or degradation of performance which ceases after the disturbance ceases, and from which the equipment under test recovers its normal performance, without operator intervention;

c) temporary loss of function or degradation of performance, the correction of which requires operator intervention;

d) loss of function or degradation of performance which is not recoverable, owing to damage to hardware or software, or loss of data.

The manufacturer's specification may define effects on the EUT which may be considered insignificant, and therefore acceptable.

This classification may be used as a guide in formulating performance criteria, by committees responsible for generic, product and product-family standards, or as a framework for the agreement on performance criteria between the manufacturer and the purchaser, for example where no suitable generic, product or product-family standard exists.

10 Test report

The test report shall contain all the information necessary to reproduce the test. In particular, the following shall be recorded:

- the items specified in the test plan required by Clause 8 of this standard;
- identification of the EUT and any associated equipment, for example, brand name, product type, serial number;
- identification of the test equipment, for example, brand name, product type, serial number;
- any special environmental conditions in which the test was performed, for example, shielded enclosure;
- any specific conditions necessary to enable the test to be performed;
- performance level defined by the manufacturer, requestor or purchaser;
- performance criterion specified in the generic, product or product-family standard;
- any effects on the EUT observed during or after the application of the test disturbance, and the duration for which these effects persist;
- the rationale for the pass/fail decision (based on the performance criterion specified in the generic, product or product-family standard, or agreed between the manufacturer and the purchaser);
- any specific conditions of use, for example cable length or type, shielding or grounding, or EUT operating conditions, which are required to achieve compliance;
- climatic conditions;
- drawing and/or pictures of the test setup and EUT arrangement.

A.4 Selection of test levels

The test levels should be selected in accordance with the most realistic installation and environmental conditions; a guideline is given in Table A.1.

Table A.1 – Guideline for the selection of the test levels

Class	Relative humidity as low as %	Antistatic material	Synthetic material	Maximum voltage kV
1	35	x		2
2	10	x		4
3	50		x	8
4	10		x	15

The installation and environmental classes recommended are related to the test levels outlined in Clause 5 of this standard.

For some materials, for example wood, concrete and ceramic, the probable level is not greater than level 2.

It is important, when considering the selection of an appropriate test level for a particular environment, to understand the critical parameters of the ESD effect.

The most critical parameter is perhaps the rate of change of discharge current which may be obtained through a variety of combinations of charging voltage, peak discharge current and rise time.

For example, the required ESD stress for the 15 kV synthetic material environment is more than adequately covered by the 8 kV/30 A Class 4 test using the ESD generator contact discharge defined in this standard.

However, in a very dry environment with synthetic materials, higher voltages than 15 kV occur.

In the case of testing equipment with insulating surfaces, the air discharge method with voltages up to 15 kV may be used.

A.5 Selection of test points

The test points to be considered may, for example, include the following locations as applicable:

- points on metallic sections of a cabinet which are electrically isolated from ground;
- any point in the control or keyboard area and any other point of man-machine communication, such as switches, knobs, buttons, indicators, LEDs, slots, grilles, connector hoods and other operator-accessible areas.

A.6 Technical rationale for the use of the contact discharge method

In general the reproducibility of the air discharge method is influenced by, for example, the speed of approach of the discharge tip, humidity, and construction of the ESD generator, leading to variations in pulse rise time and magnitude of the discharge current.

In air discharge ESD testers, the ESD event is simulated by discharging a charged capacitor through a discharge tip onto the EUT, the discharge tip forming a spark gap at the surface of the EUT.

The spark is a very complicated physical phenomenon. It has been shown that with a moving spark gap the resulting rise time (or rising slope) of the discharge current can vary from less than 1 ns and more than 20 ns, as the approach speed is varied.

Keeping the approach speed constant does not result in constant rise time. For some voltage/speed combinations, the rise time still fluctuates by a factor of up to 30.

NOTE At high voltages, the air discharge can occur in multiple successive discharges.

A triggering device which is commonly known to produce repeatable and fast rising discharge currents is the relay. The relay should have sufficient voltage capability and a single contact (to avoid double discharges in the rising part). For higher voltages, vacuum relays prove to be useful. Experience shows that by using a relay as the triggering device, not only the measured discharge pulse shape is much more repeatable in its rising part, but also the test results with real EUTs are more reproducible.

Consequently, the relay-driven ESD generator is a device that produces a specified current pulse (amplitude and rise time).

This current is related to the real ESD voltage, as described in Clause A.3.

A.7 Selection of elements for the ESD generator

A storage capacitance shall be used which is representative of the capacitance of the human body. A typical value of 150 pF has been determined suitable for this purpose.

A resistance of 330 Ω has been chosen to represent the source resistance of a human body holding a metallic object such as a key or tool. It has been shown that this metal discharge situation is sufficiently severe to represent all human discharges in the field.

A.8 Rationale related to the generator specification

A number of reasons have been postulated as being the cause of the reproducibility differences when applying the ESD test to actual EUTs. The test set up, calibration issues, etc. have been considered and proposals included in this publication.

Changes to the ESD generator specification have also been considered but no changes are proposed in this publication. The following is a summary of the rationale for this decision.

The two potential technical reasons, with respect to the generator specification, that have been raised as being the cause of reproducibility concerns are:

- the discharge current waveform of the generator after the first peak, i.e. between 2 ns and 60 ns;

- the E-field radiated by the generator when the electrostatic discharge is applied to the EUT.

The first reason was dealt with by the maintenance team and a tolerance of ± 35 % of the idealized form shown in Figure 2 was specified between 2 ns and 60 ns. During the development of this standard, this potential change to the discharge current specification was further modified to control the fall time of the first peak to (2,5 ± 1) ns at 60 % of the initial peak.

Round robin tests were conducted on different EUTs in three different laboratories with two types of generators, one type of generator being compliant with IEC 61000-4-2 Edition 1, the other type with the added specification as indicated above. Five different generators of each type were provided by five different manufacturers in this respect.

The results of the round robin tests of the modified ESD generator were in summary:

- there was a variation in the test level, at which the considered EUTs were affected, between different ESD generators;
- the modification of the discharge wave shape did appear to clean up the discharge current shapes in both the time and frequency domains;
- however, the new waveform did not lead to any significant improvement in the reproducibility of the test results on actual EUTs.

The second reason was considered, however, the resources required to undertake a further round robin series of tests would be significant with no guarantee that this parameter was the cause of reproducibility issues. Substantial technical study is needed to quantify the impacts from radiated fields on actual EUTs and to understand how to control the associated parameters that impact reproducibility of test results.

It was considered that the changes included in this publication would improve the reproducibility of the tests. Further investigation could be proposed for future editions of this standard in estimating the impact of E-field radiation on reproducibility.

Annex B
(normative)

Calibration of the current measurement system and measurement of discharge current

B.1 Current target specification – Input impedance

The coaxial current target used to measure the discharge current of ESD generators shall have an input impedance, measured between the inner electrode and ground, of no more than 2,1 Ω at d.c.

NOTE 1 The target is supposed to measure the ESD current into a perfect ground plane. To minimise error caused by the difference between a perfectly conducting plane and the input impedance of the target, a 2,1 Ω limit was set for the input impedance. But if the target's input impedance is too low, the output signal will be very small which may cause errors due to coupling into the cables and the oscilloscope. Furthermore, when a much lower resistance value is used, parasitic inductance becomes more severe.

NOTE 2 The input impedance and transfer impedance (Z_{sys}, Clause B.3) may be measured with high accuracy at d.c. or at low frequency.

B.2 Current target specification – Insertion loss

B.2.1 Measurement chain

Instead of specifying the insertion loss of the coaxial current target, the insertion loss of the measurement chain consisting of the target, attenuator and cable is specified. This simplifies the measurement system characterisation, as only this chain and the oscilloscope need to be characterised, instead of each element individually.

The variation of the insertion loss of the target-attenuator-cable chain may not exceed:

±0,5 dB, up to 1 GHz

±1,2 dB, 1 to 4 GHz.

With respect to the nominal value S_{21} of the insertion loss:

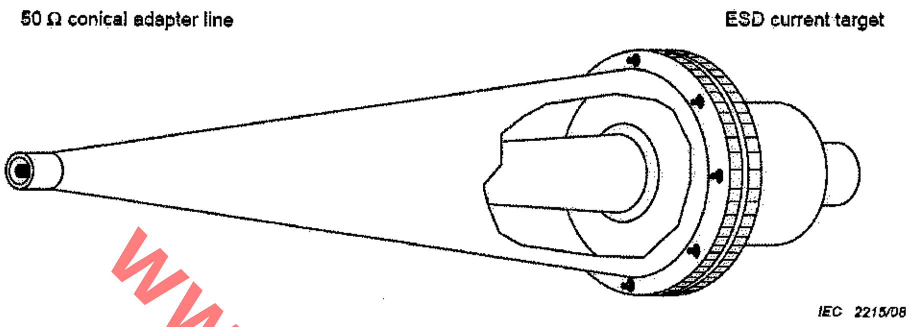
S_{21} = 20log [$2Z_{sys}/(R_{in} + 50\ \Omega)$] dB, where R_{in} is the d.c. input impedance of the target-attenuator-cable chain, when loaded with 50 Ω.

NOTE 1 Different calibration time intervals can be used for the d.c. transfer impedance and the more involved insertion loss measurements. If a repeated d.c. transfer impedance measurement shows a result which differs from the original measurement by less than 1 %, the user may assume the insertion loss of the target-attenuator-cable chain has not changed, providing the same cable and attenuator are used and no other indications (e.g., loose or damaged connectors) indicate otherwise.

NOTE 2 The target-attenuator-cable chain should always be considered as one entity. As soon as one element gets exchanged, or even when it gets disassembled and re-assembled, the whole chain needs re-calibration in order to insure compliance with the specification.

B.2.2 Target adapter line

The target adapter line shown in Figure B.1 connects a 50 Ω coaxial cable to the input of the ESD current target. Geometrically, it smoothly expands from the diameter of the coaxial cable to the target diameter. If the target is made such that the impedance calculated from the diameter ratio "*d*" to "*D*" (see Figure B.2) is not equal to 50 Ω, the target adapter line shall be made such that the outer diameter of its inner conductor equals the diameter of the inner electrode of the current target. The impedance shall be calculated using the dielectric constant of the material that fills the conical adapter line (typically air). The target adapter line shall maintain (50 ± 1) Ω within a 4 GHz bandwidth. The return loss of two target adapter lines placed face-to-face shall be better than 30 dB up to 1 GHz and better than 20 dB up to 4 GHz with a total insertion loss of less than 0,3 dB up to 4 GHz.



NOTE Other shapes than conical are acceptable.

Figure B.1 – Example of a target adapter line attached to current target

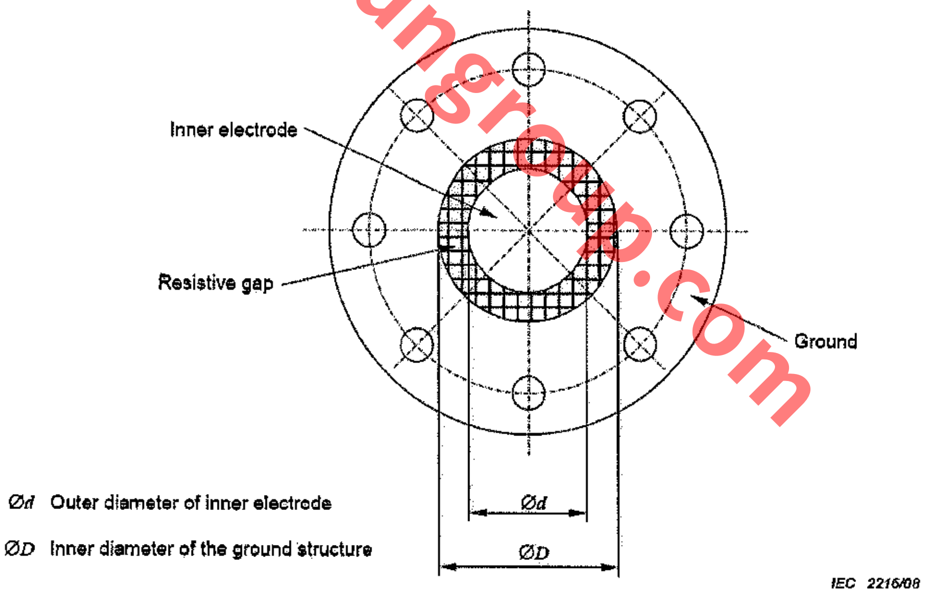


Figure B.2 – Example of a front side of a current target

B.2.3 Determining the insertion loss of a current target-attenuator-cable chain

The insertion loss of the chain is determined with a VECTOR network analyzer (VNA). Other systems to measure magnitude insertion loss may also be used provided that sufficient accuracy can be achieved.

The measurement procedure for the insertion loss is the following:

- Calibrate the network analyser at the calibration points shown in Figure B.3 (between attenuator and target and between attenuator and target adapter line).

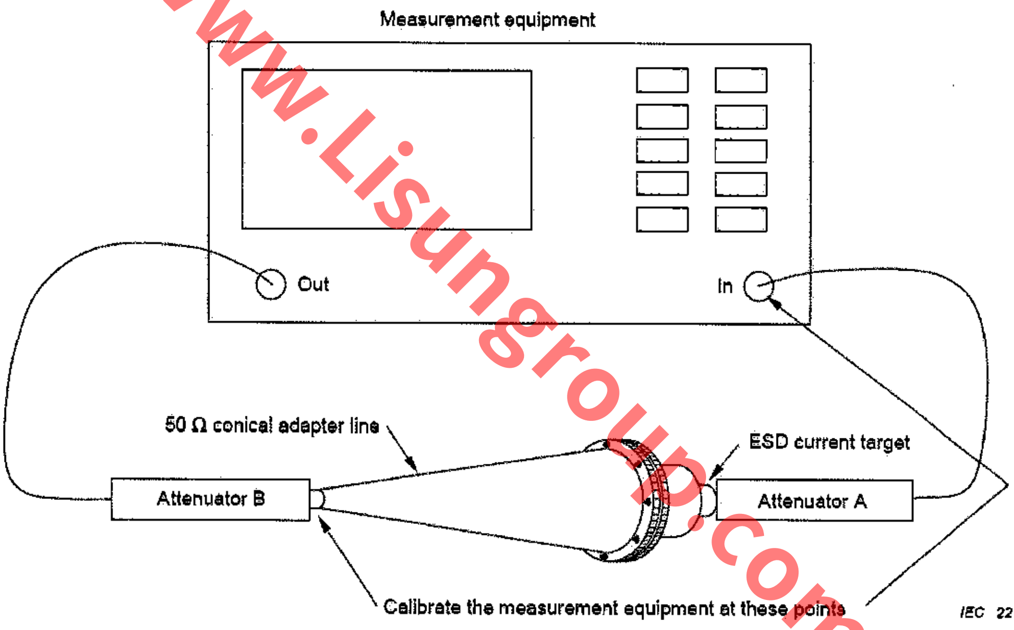
NOTE 1 If no network analyser is used, the procedure needs to be modified accordingly.

NOTE 2 Instead of d.c. the lowest frequency available with the network analyser should be used. The d.c. characteristics are measured separately.

NOTE 3 The stability of the centre contact of two adapter lines or of adapter line and target should be verified through repeated measurements, disconnecting and reconnecting the devices using different centre line angles.

- Connect a target adapter line to the target-attenuator (≥ 20 dB)-cable chain and insert it as shown in Figure B.3.
- Measure the insertion loss.

The insertion loss variation shall meet the requirements given in Clause B.2.



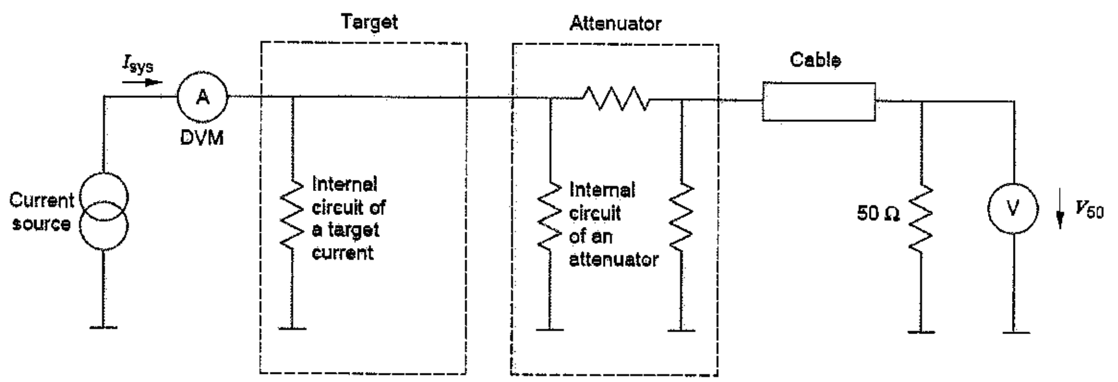
IEC 2217/08

Figure B.3 – Example of measurement of the insertion loss of a current target-attenuator-cable chain

B.3 Determining the low-frequency transfer impedance of a target-attenuator-cable chain

The low-frequency transfer impedance of a target-attenuator-cable chain is defined as the ratio between the current injected to the input of the target and the voltage across a precision 50 Ω load at the output of the cable (i.e., which is placed at the end of the cable instead of the oscilloscope).

In an ESD measurement, an oscilloscope displays a voltage V_{osc} if a current I_{sys} is injected into the target. To calculate the unknown current from the displayed voltage, the voltage is divided by a low-frequency system transfer impedance Z_{sys}.



IEC 2218/08

Figure B.4 – Circuit diagram to determine the low-frequency system transfer impedance

NOTE 1 The internal circuit of the target shown is just an example. Other internal circuits are possible.

The low-frequency system transfer impedance of the target-attenuator-cable chain can be determined by:

- Injecting a current I_{sys} of approximately 1 A into the front side of the current target. The front side is the side to which discharges are made.
- Z_{sys} is the key quantity for the generator calibration. The 50 Ω load shall have a tolerance of maximum of ±1 %.
- Measuring the voltage V_{50} across the precision 50 Ω load.
- Calculating the transfer impedance by:

$$Z_{sys} = \frac{V_{50}}{I_{sys}}$$

NOTE 2 To verify that thermal voltages do not influence the result, the measurement can be done with positive and negative current. Both results should be within less than 0,5 % of each other.

Other methods to determine the transfer characteristics of the whole target-attenuator-cable chain may be used.

B.4 Calibration of ESD generator

B.4.1 Calibration result

Comparable calibration result of an ESD evaluation is extremely important. This is particularly the case when tests are to be conducted using ESD generators from different manufacturers, or when testing is expected to extend over a long period of time. It is essential that repeatability be a driving factor in the evaluation. The ESD generator shall be calibrated in certain defined time intervals with respect to a recognized quality assurance system.

NOTE The process in this annex is given for calibration purposes. A different procedure for verification of the generator before testing is mentioned in 6.3.

The calibration of the ESD generator shall be performed within the range of the climatic conditions as specified in 8.1.2.

B.4.2 Test equipment required for ESD generator calibration

The following equipment is required for calibrating ESD generators:

- oscilloscope with sufficient bandwidth (≥2 GHz analogue bandwidth);

- coaxial current target-attenuator-cable chain;
- high-voltage meter capable of measuring voltages of at least 15 kV. It may be necessary to use an electrostatic voltmeter to avoid loading the output voltage;
- vertical calibration plane with the coaxial current target mounted in such a way that there is at least 0,6 m from the target to any edge of the plane;
- attenuator(s) with sufficient power capability as needed.

NOTE An example of a suitable coaxial current target is given in Annex C.

B.4.3 Procedure for contact mode generator calibration

The current target shall be mounted at the centre of the vertical calibration plane meeting the requirements of B.4.2. The connection for the ESD generator return current cable (ground strap) shall be made at the bottom centre of the plane 0,5 m below the target. The ground strap shall be pulled backwards at the middle of the cable, forming an isosceles triangle. It is not allowed to let the ground strap lay on the floor during calibration.

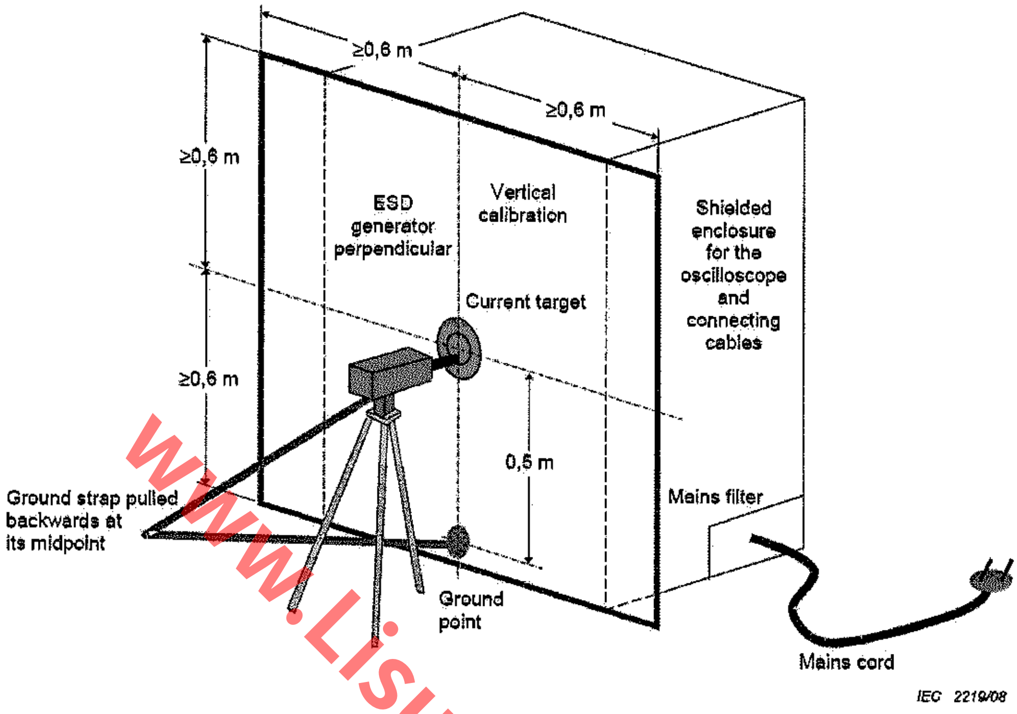
Follow the steps given below to verify if the current waveform of an ESD generator is within specifications. Record the wave-shape and measure the following parameters:

I_p peak value of the discharge current [A];
I_{30} value of the current 30 ns after the peak current has reached 0,1 times I_p [A];
I_{60} value of the current 60 ns after the peak current has reached 0,1 times I_p [A];
t_r rise time of the current [ns].

Table B.1 – Contact discharge calibration procedure

Step	Explanation
Discharge the ESD generator at each test level as defined in Table 1 five times for both polarities, store each result.	The specifications shall be met for all 5 discharges.
Measure I_p, I_{30}, I_{60}, t_r on each waveform.	The parameters shall be checked at each test level
Current at 30 ns Check if I_{30} is 2 A ± 30 %	The parameters shall be checked at each test level[a]
Current at 60 ns Check if I_{60} is 1 A ± 30 %	The parameters shall be checked at each test level[a]
Peak current Check if I_p is 3,75 A ± 15 %	The parameters shall be checked at each test level[a]
Rise time Check if t_r is 0,8 ns ± 25 %	The parameters shall be checked at each test level

[a] The value of the current given in this table corresponds to a voltage of 1 kV. This measured value changes proportionally to the generator voltage.



NOTE 1 The generator should be installed on a tripod or equivalent non metal low loss support.

NOTE 2 The generator should be powered in the same way as it will be used during test.

NOTE 3 A reversed setup compared to Figure B.5 can also be used.

Figure B.5 – Typical arrangement for calibration of ESD generator performance

Shielding of the oscilloscope is not necessary if it can be proven by measurement that indirect coupling paths onto the measurement system do not influence the calibration results.

The calibration system can be declared sufficiently immune (i.e. no Faraday cage necessary) if no triggering of the oscilloscope results when:

- the oscilloscope trigger level is set to ≤10 % of the lowest test level, and,
- the ESD generator is discharged with the highest test level to the outer ring of the target (instead of to the inner ring).

Annex D
(informative)

Radiated fields from human metal discharge and ESD generators

D.1 Overview on the processes causing intended and unintended fields

D.1.1 General

The electrostatic discharge from a human (via a small, hand-held metal piece) is the basis for the current waveform specified in this standard and its predecessors. This discharge from a human as well as the discharge from an ESD generator, are responsible for generating associated strong electromagnetic fields.

The following subclauses first review the process of a human discharge, and then review the process as it occurs with an ESD generator.

D.1.2 Human ESD

For an ESD event from a human to an EUT, the following sequence of events will occur.

a) As the hand-held metal piece approaches a metallic surface of an EUT and prior to the discharge of current, an electrostatic field exists. There is no (or only very little) current flowing and no relevant magnetic field is present.

b) Once the discharge is initiated between the hand-held metal part and the EUT, the electrostatic field collapses within the gap between the two. Starting from its initial value it collapses to a voltage across the gap of about 25 V to 40 V within 50 ps to 5 ns. The collapse time is depending on arc parameters, voltage, etc. The initial collapse of the electric field is the first step in a series of events that causes strong transient electromagnetic fields.

c) A current starts flowing on the metal part held by the human and on the EUT. The foremost current front expands with the velocity of light and within about 0,8 ns, it has reached the arm of the person. As the current continues to expand further on the EUT and the arm, it will experience reflections and losses due to radiation and resistance, leading to a complex pattern of current density on both the EUT and the person.

d) As the discharge process continues, the highest frequency components of the current will be attenuated quickly, mainly due to radiation. The current then becomes smoother (i.e. with less high-frequency content) as time increases and finally the body reaches a new electrostatic equilibrium with the EUT. The remaining charge on the body, however, may not be zero, as the arc might extinguish before the body has completely discharged. If the hand and metal object continues to approach the EUT, a second discharge might occur at a lower voltage leading to a sequence of ESDs, each one at a lower voltage, and each one having a faster rise time (partially attributed to the lower voltage).

e) During each discharge sequence, an observer located on some point of the hand, body or EUT will observe a charge density prior to the discharge, during the discharge phase a fast changing current and after the discharge a small remaining charge.

f) From antenna theory it is known that changing charge densities and changing currents will cause radiated fields. In close proximity the fields are dominated by the current and the charge directly, and in larger distances the current and charge time derivative will determine the fields. The transition region between the close proximity fields (near field) and fields seen at a larger distance (far field) is more complex. Measurements and simulations have shown that transient fields of ESD, at least for the most disturbing first nanoseconds, will reach far field conditions at a distance of 10 cm from the arc.

g) From the above it is clear that the current and charge time derivative are extremely important regarding upset (non destructive error) of electronic systems.

h) *It is important to note* that in a human discharge, the current and charge derivatives are determined by the collapse time of the voltage in the arc. Thus, the current rise time at the discharge determines the high-frequency components.

From the above, it is clear that the transient fields of a human-metal ESD are an important part of the ESD process. An ideal ESD generator would reproduce them in some quantified fashion. The field strengths of human-metal ESD, etc., are well known.

D.1.3 ESD generator

The next step is to analyze and compare process that occurs in present ESD generators. As most ESD testing is performed in contact mode, for reasons of reproducibility, the following is limited to contact mode ESD generators.

a) The discharge tip of the ESD generator is contacted to a grounded (in most cases) part of the EUT.

b) Prior to the discharge, a capacitor is charged within the ESD generator. In many designs most of the electrostatic field resulting from the charging process is confined within the ESD generator. As a result, the electrostatic field in the vicinity prior to the discharge is much less than the electrostatic field one would measure at the same point from a human charged with the same voltage.

c) The discharge is initiated by the closure of a relay internal to the ESD generator. The design of these special relays allows a very good reproducibility of the discharge current; however, because the relay is internal and not at the point at which the ESD generator touches the EUT, the initiation of discharge current flow is quite different from a human discharge.

d) The voltage collapse times within the relay are very fast, certainly less than 100 ps, which leads to a current wave travelling away from the relay in all directions and on all contacting metal parts and other metal parts in proximity. The current wave will propagate at the velocity of light (in dielectrics at reduced speed). The rise time of this current wave equals the voltage collapse time.

e) The voltage collapse time is less than 100 ps, but this standard requires a current rise time of (0,8 ± 0,2) ns measured at the point of contact to the target. To achieve this, measures are designed into the ESD generators that increase the rise time from the very low value within the relay to the standardized values at the discharge tip.

f) The transient fields are caused by *all* current time derivatives and charge density time derivatives. An important difference between the discharge from a generator and that from a human with metal must be noted: For a human discharge the current rise time at the arc is the fastest process and it determines the spectrum of the transient fields. However, with an ESD generator in contact mode the high-frequency spectrum is determined by the voltage collapse of the relay, not by the current rise time at the discharge tip.

g) Since all the changing currents in the generator cause transient fields, there is a contribution of the 100 ps rising currents in the relay to the transient fields from an ESD generator, as well as the contribution from the (0,8 ± 0,2) ns rising currents at the point of discharge. The transient fields caused by the faster events in the generator are in general unwanted transient fields since they increase the high-frequency content of these radiated fields beyond those developed from an equivalent human-metal discharge having the same current rise time and peak value at the point of discharge.

From the above it can be seen that the strength of the contribution of the fast rising currents to the transient fields is strongly dependent on the design of the ESD generator. This field contribution might be well suppressed, or it might dominate the transient fields in any given generator. Unfortunately, these contributions are not regulated in this standard resulting in the possibility that upset events during ESD testing can be highly dependant on the specific generator being used.

D.2 EUT reaction to ESD testing

During an ESD test the response of an EUT to a broad range of electrical disturbances is tested. The range includes: Voltage for dielectric breakdown, secondary breakdown at a gap away from the injection point, current for RI drop, magnetic field for *Ldi/dt* drop, magnetic fields for induced voltage, and electric fields for induced voltages (fields can be in both far fields and near fields). In this regard an ESD test differs from EMI testing by combining multiple tests into one.

Some examples of EUT failures due to different disturbances of the ESD test are:

- discharge into a connector PIN causing damage to an IC;

  In this example the *energy dissipated* in the IC, the maximum current or the charge transferred through the IC will most likely determine the damage threshold;
- discharge through a gap in a plastic enclosure allowing a spark to reach an IC;

  In this case the ESD test determines the *dielectric breakdown* strength of the gap through the plastic seam.
- discharge to a chassis causing the system contained in the chassis to become upset.

  In this example, it is most likely that the *transient fields* of the ESD event coupled into traces, wires or directly into ICs of the system, cause voltages or currents that will upset the logical function of the system.

The coupling mechanism from the current within the ESD generator to the fields is dominated by the current's time derivative, even at relatively moderate distances of e.g. 20 cm. Further, the coupling between the field and a wire, trace or IC in an EUT is a function of the rate of change of the electric and the magnetic field. In summary: The time derivatives involved both in the field creation and in the induction process contribute to the injected current, which leads to different pulse shapes for the current at the discharge tip and to different induced voltages in traces due to the fields. The induced voltages in traces typically have a width much more narrow than the initial ESD discharge current as defined in the standard, and they may exhibit ringing.

Due to the dependence of the transient fields on the design of the specific ESD generator (especially those field components with energy at frequencies above 300 MHz) one needs to expect that the induced currents on a trace, wire or within an IC are strongly affected by the specific design of the ESD generator. This could lead to large variation of test results (in most cases system upset, not destruction) if the same EUT is tested with different ESD generators and if the manufacturer of the ESD generator has not taken precautions to minimize the unwanted part of the electromagnetic fields that are caused by the fast voltage collapse within the relay. Note that these differences in test results only occur if the EUT is sensitive to high frequency fields, mainly >1 GHz.

D.3 Transient fields of ESD reference event

Transient fields of human metal ESD having rise times of about 850 ps at 5 kV charge voltage have been measured. An ideal ESD generator should reproduce these fields for 5 kV contact mode testing. To obtain the data, broadband (±1 dB between 1,5 MHz and 1,5 GHz) field sensors have been placed on the vertical reference plane at a distance of 0,1 m from the discharge point, i.e. target position.

Annex E
(informative)

Measurement uncertainty (MU) considerations

E.1 General

The repeatability of EMC testing relies on many factors or influences that affect the test result. These influences develop errors in order to generate disturbance quantity which may be categorized to random or systematic effects. The conformance of the realized disturbance quantity with the disturbance quantity defined in this standard is usually confirmed by a series of measurements (e.g. measurement of the rise time with an oscilloscope using attenuators). The result of each measurement is only an approximation to the value of the measurand and the measured quantity may differ from the true value by some amount due to MU. A critical element in determining MU is the uncertainty associated with calibration of test instrumentation.

In order to achieve a high reliability of calibration results, it is necessary to identify the sources of uncertainty involved in the measurement instrumentation and to make a statement of the uncertainty of the measurement.

E.2 Categories of uncertainty

Errors of measurement generally have two components; a random component (herein after referred to as type A) and a systematic component (herein after referred to as type B). Random uncertainty is associated with unpredictable effects. Systematic uncertainty is generally connected with the instrumentation used for the measurement. Systematic components can sometimes be corrected or reduced, but random components by definition cannot. Within a given measurement system there may be many effects which can influence either of these components.

It can happen that a random uncertainty of one test method can become a systematic uncertainty in another where the results of the first are applied. To avoid this possible confusion instead of systematic and random uncertainty the types of uncertainty contribution are grouped into two categories.

- Type A: those which are evaluated by statistical methods estimating their standard deviations for a series of tests. This generally follows a Normal or Gaussian type of distribution.

Distribution	**Combined uncertainty**	**Comments**
Normal or Gaussian	$U_c(y) = \sqrt{\frac{1}{(n-1)} \sum_{j=1}^{n} (u_j - \bar{u})^2}$	Typically sourced from verification records

- Type B: those which are evaluated by other means. They are usually associated with effects such as mismatch, cable losses, and non-linear characteristics in instrumentation. In an analysis the magnitude and distribution of type B uncertainties can be estimated based upon calibration data, instrument manufacturer's specifications or simply by knowledge and experience.

The classification into type A and type B does not mean that there is any difference in the nature of the components, it is a separation based on the evaluation of their nature. Both types can have probability distributions and the uncertainty components resulting from either type may be quantified by standard deviations.

E.3 Limitations

The following limitations and conditions apply to the considerations in this text.

- The uncertainty budget is limited to the uncertainty due to the measurement instrumentation (type B uncertainty). This does not, however, imply that a laboratory should ignore the influence of type A uncertainties, but that these should be separately assessed by individual test laboratories to obtain a more complete picture of their MU.
- All contributions are assumed to be uncorrelated.
- A level of confidence of 95 % is regarded as acceptable.

NOTE An example of a type B uncertainty budget is given in Table E.1, E.2 and E.3.

E.4 Calculation of type B uncertainty

The standard uncertainty is calculated from the determined value by applying the divisor assigned to its probability distribution.

The divisors for the individual probability distributions considered in this document are:

Distribution	Divisor	Comments
Normal	Coverage factor, k	$k = 2$ for 95 % confidence Typically sourced from calibration certificates
Rectangular	$\sqrt{3}$	Typically sourced from manufacturer's data for the instrument
U-shaped	$\sqrt{2}$	Mismatch uncertainty Uncertainty contribution most likely to be at the limits

In all cases where the distribution of the uncertainty is unknown, the rectangular distribution is taken as the default model.

Calculating the combined standard uncertainty for any test involves combining the individual standard uncertainties. This is valid provided that all quantities are in the same units, are uncorrelated and combine by addition in a logarithmic scale (usually in dB). However, the units for ESD calibrations as well as measurements should be given in %; calculating it as

$$10^{\frac{(\text{unit\_in\_dB})}{20}} \times 100$$

The result of this calculation is a combined standard uncertainty, $u_c(y)$, where

$$u_c(y) = \sqrt{\sum_{i=1}^{m} u_i^2(y)}$$

with $u_i(y)$ defined as the individual standard uncertainty.

The Student's t-distribution gives coverage factors (i.e. multipliers) for the uncertainty, assuming that the output variable, y, follows a Normal distribution.

By multiplying $u_c(y)$ by a coverage factor (k) an expanded uncertainty, U_c, giving a greater confidence level can be achieved. The coverage factor is obtained by the degrees of freedom; calculated from the relation between type A and type B uncertainties.

E.5 Compilation of an uncertainty budget

An uncertainty budget is a list of the probable sources of error in a measurement with an estimation of their probability distribution.

The calculation of an uncertainty budget requires the following steps:

a) specify the characteristic of the disturbance quantity (i.e. what is being generated by the instrumentation);

b) identify the contributions to uncertainty and their value;

c) define the probability distribution of each contribution;

d) calculate the standard uncertainty $u(x_i)$ for each contribution;

e) calculate the combined uncertainty $u_c(y)$, the coverage factor, k, and the expanded uncertainty, $U_c = u_c(y) \times k$;

f) apply the expanded uncertainty;

g) publication of the expanded uncertainty in quality documentation as necessary (it is not required for the test laboratory to publish these figures in test reports unless requested to do so).

Example of uncertainty budgets with identified contributors and associated values are given in Clause E.6. It should be noted that these are intended for guidance and a calibration- or test laboratory should identify the actual contributors and values for their particular test setup (i.e. the final budget may identify a minimum list of contributors that should be taken into account. A test lab will then need to identify additional contributors. This will provide better comparison of uncertainty between test labs).

E.6 Uncertainty contributors of ESD

Uncertainties for ESD calibration as well as for ESD tests cannot be handled in the same way as for emission- and other measurements since ESD tests do not have a numerical result, but will give a simple pass or fail as test result. During the ESD tests the disturbance quantity characterised by several parameters is applied to the EUT. One or more observable signals of the EUT are monitored or observed and compared against agreed criteria, from which the test result (pass/fail) is derived.

NOTE 1 For calibration, the word EUT is equal to: ESD generator under calibration.

NOTE 2 The phrase measurement instrumentation refers here to the instrumentation used for calibration.

A classical MU can, in principle, be applied to the measurement of the signals from the EUT. Since the process of measurement for the monitoring is EUT specific, a basic standard can not and should not deal with MU for the monitoring system (the observer), however, this may be performed.

Uncertainties can also be specified for the parameters of the disturbance quantity. As such, they describe the degree of agreement of the specified instrumentation with the specifications of this basic standard.

These uncertainties derived for particular measurement instrumentation do not describe the degree of agreement between the simulated electromagnetic phenomenon as defined in the basic standard and the real electromagnetic phenomena in the world outside the laboratory. Therefore, questions regarding the definitions of the disturbance quantity (e.g., ESD gun positioning to the target plane) are not relevant for the measurement instrumentation uncertainties.

Since the influence of the parameters of the disturbance quantity on the EUT is a priori unknown and in most cases the EUT shows non linear system behaviour, a single uncertainty number cannot be defined for the disturbance quantity as overall uncertainty. Each of the parameters of the disturbance quantity should be accompanied with a specific uncertainty, which may yield to more than one uncertainty budget for the test.

NOTE 3 This annex focuses on the uncertainties for calibration as an example.

The following list shows contributors used to assess both the measuring instrumentation and test setup influences:

- reading of peak value;
- reading of 10 % level;
- reading of 90 % level;
- reading of time at 30 ns and 60 ns;
- low-frequency transfer impedance Z_{sys};
- static voltage;
- mismatch chain - oscilloscope;
- target-attenuator-cable chain;
- oscilloscope horizontal measurement contribution;
- oscilloscope vertical measurement contribution;
- measurement system repeatability (type A);
- ESD generator orientation (type A);
- ESD generator location (type A);
- variation in test setup (type A);
- calibration of target, oscilloscope, attenuator.

It shall be recognized that the contributions which apply for calibration and for test may not be the same. This leads to (slightly) different uncertainty budgets for each process.

Aspects such as ESD gun orientation are considered to be type A uncertainties and such uncertainties are not generally treated in this basic standard. An exception to this rule has been made to account for the measurement system repeatability for measurements as well as for calibrations.

E.7 Uncertainty of calibration results

It is recommended to produce independent uncertainty budgets for each calibration item; that is I_p, I_{30}, I_{60}, t_r. For an ESD test, the disturbance quantity is the discharge current from the ESD generator that is applied to the EUT. The calibration items of this disturbance quantity are I_p, I_{30}, I_{60} and t_r. As described in Clause E.6, an independent uncertainty budget should be calculated for each of these parameters.

Tables E.1, E.2 and E.3 give examples of calculated uncertainty budgets for these parameters. The tables include the contributors to the uncertainty budget that are considered most significant for these examples, the details (numerical values, type of distribution, etc.) of each contributor and the results of the calculations required for determining each uncertainty budget.

Table E.1 – Example of uncertainty budget for ESD rise time calibration

Contributor	Distribution	Value ps	$u_i(y)$ ps	$u_i(y)^2$ ps^2	Comment
Reading of peak value	Normal $k = 2$	50	25	625	Uncertainty of peak value 6,3 % (Table E.2) times measured rise time 800 ps
Reading of time by 90 % peak current	Rectangular Divisor = $\sqrt{3}$	25	14	196	20 GS/s oscilloscope sampling rate
Reading of time by 10 % peak current	Rectangular Divisor = $\sqrt{3}$	25	14	196	20 GS/s oscilloscope sampling rate
Total oscilloscope horizontal measurement contribution (NOTE 1)	Normal $k = 2$	36	18	324	From the calibration laboratory of the oscilloscope
Target-attenuator-cable chain	Normal $k = 2$	30	15	225	From the calibration laboratory of the oscilloscope (NOTE 2)
Repeatability	Normal Divisor = 1	45	45	2 025	Obtained from type A evaluation (NOTE 3)
			Sum	3 591	
Combined standard uncertainty u_c on rise time			Root	60 ps	
Expanded uncertainty U on rise time	Normal $k = 2$	120 ps (15 %)			Confidence level 95 %

NOTE 1 The total oscilloscope horizontal measurement contribution contains the uncertainty contributions of the oscilloscope horizontal resolution, interpolation resolution, time base resolution, frequency measurement, rise time correction, etc.

NOTE 2 The calibration certificate of the chain often contains only the frequency response of attenuation. Here it has been assumed, that also the uncertainty contribution to rise time measurement has been supplied by the calibration lab, therefore $k = 2$.

NOTE 3 The repeatability is normally taken from at least 5 consecutive measurements. This is a type A evaluation and the formula for the standard deviation $s(\bar{q})$ for a set of n repeated measurements is given by

$$s(\bar{q}) = \sqrt{\frac{1}{n(n-1)}\sum_{j=1}^{n}(q_j - \bar{q})^2}$$

with q_j: result of the j^{th} measurement and $\bar{q}$ arithmetic mean of the results.

Table E.2 – Example of uncertainty budget for ESD peak current calibration

Contributor	Distribution	Value %	$u_i(y)$ %	$u_i(y)^2$ $\%^2$	Comment
Total oscilloscope vertical measurement contribution (NOTE 1)	Normal $k = 2$	3,2	1,6	2,56	From calibration laboratory
Target-attenuator-cable chain	Normal $k = 2$	3,6	1,8	3,24	From calibration laboratory
Mismatch: chain to oscilloscope	U-shaped Divisor = $\sqrt{2}$	2	1,4	2	From calibration or specifications (NOTE 2)
Low-frequency transfer impedance	Normal $k = 2$	6×10^{-6}	3×10^{-6}	9×10^{-12}	Internal calibration (NOTE 3)
Repeatability	Divisor = 1	1,5	1,5	2,25	Obtained from type A evaluation (NOTE 4)
			Sum	10,05	
Combined standard uncertainty u_c on peak current			Root	3,17	
Expanded uncertainty U of peak current	$k = 2$	6,3 %			Confidence level 95 %

NOTE 1 The total oscilloscope vertical measurement contribution contains the contributions of oscilloscope vertical resolution, LF linearity, HF linearity, offset resolution, etc. The calibration has to cover the whole frequency range, i.e. $f \leq 2$ GHz. However, the flatness has not to be better than that of a first order filter with f_c = 2 GHz cut off: i.e. $A(f) \sim \left|1 + (f/f_c)^2\right|^{-1/2}$.

NOTE 2 The mismatch contribution is due to the output reflection factor Γ_C of the target-attenuator-cable chain and the input reflection factor Γ_O of the oscilloscope. They should be obtained either from the calibration certificates or from specifications. Due to second order contributions of the errors in Γ, a reliable specification is sufficient. Note however, that also a specification has to cover the whole frequency range, and this is often not the case with oscilloscopes, so additional measurement might be required.

The mismatch contribution is:

$\Gamma_C \cdot \times \Gamma_O$, with U-shaped distribution, yielding the divisor $\sqrt{2}$.

This mismatch uncertainty formula assumes that the oscilloscope's amplitude response has been calibrated according to radio-frequency calibration concepts, i.e. the voltage error is referenced to the incident voltage from a 50 Ω source and not to the actual voltage at the input. This should be verified in the certificate, else a different formula has to be applied.

NOTE 3 It is assumed that the laboratory has a separate calibration instruction, with an uncertainty assessment that yields the extended uncertainty U of this calibration.

NOTE 4 The repeatability is normally taken from at least 5 consecutive measurements. This is a type A evaluation and the formula for the standard deviation $s(\bar{q})$ for a set of n repeated measurements is given by

$$s(\bar{q}) = \sqrt{\frac{1}{n(n-1)} \sum_{j=1}^{n} (q_j - \bar{q})^2}$$

with q_j: result of the j^{th} measurement and $\bar{q}$ arithmetic mean of the results.

Table E.3 – Example of uncertainty budget for ESD I_{30}, I_{60} calibration

Contributor	Distribution	Value %	$u_i(y)$ %	$u_i(y)^2$ $\%^2$	Comment
Uncertainty of Table E.2	Normal $k = 2$	6,3	3,15	9,92	Uncertainty of peak current (Table E.2)
Reading of time at 30 ns or 60 ns	Rectangular $k = \sqrt{3}$	0,17	0,098	0,0096	Sensitivity of current reading at 30 ns or 60 ns, for a measurement at time interval between the 10 % peak current value and 30 ns or 60 ns. 20 GS/s oscilloscope sampling rate (two readings each with 60 ps uncertainty)
			Sum	9,93	
u_c			Root	3,15 %	
Expanded uncertainty U on I_{30} and I_{60}	Normal $k = 2$	6,3 %			Confidence level 95 %

Product committees or accreditation bodies may impose other interpretations.

E.8 Application of uncertainties in the ESD generator compliance criterion

Generally, in order to be sure the generator is within its specifications, the calibration results should be within the specified limits of this standard (tolerances are not reduced by MU).

The following MU are recommended for laboratories which perform calibrations:

Rise time t_r	MU ≤ 15 %
Peak current I_p	MU ≤ 7 %
Current at 30 ns	MU ≤ 7 %
Current at 60 ns	MU ≤ 7 %

Annex F
(informative)

Variation in test results and escalation strategy

F.1 Variations in test results

As a result of the complex nature of ESD and the necessary tolerances on test equipment, some variation in the results of ESD tests can be expected. Often, these variations are differences in the test levels at which errors occur or the types of errors that the EUT experiences during the test. Depending on the test level at which they occur, such test result variations can affect the decision whether the EUT passed or failed the test.

In the case of differences in test results, the following steps should normally be taken to determine the source of the differences.

- Verify the test setup; examine all the details, including the position of each cable and the condition of the EUT (e.g., covers, doors).
- Verify the test procedure, including the EUT operation mode, position and location of auxiliary equipment, operator position, software state, application of discharges to the EUT.
- Verify the test generator; is it operating correctly? When was it calibrated last? Is it operating within specifications? Are test result differences due to the use of different generators?

If differences in test results are caused by the use of different ESD generators, then the results with any generator that meets the requirements of 6.2 can be used for determining compliance with this standard.

F.2 Escalation strategy

If differences in test results occur when all conditions of the test, including the ESD generator, are the same, then the following escalation strategy may be applied to determine compliance with the standard. This strategy would be applied individually to each test point experiencing variable test results.

a) The first test is (was) to apply the prescribed number of discharges to a test point according to 8.3 (for example 50 discharges) with the intended test level. If no unacceptable effect occurs in this first set of discharges, the EUT passes the test at that test point. If one unacceptable effect occurs in this set of discharges, a further test according to the following point b) is performed. If more than one unacceptable effect occurs in this set of discharges, the EUT fails the test at that test point.

b) The second test is to apply a new set with doubled number of discharges at that test point with the intended test level. If no unacceptable effect occurs in this set of discharges, the EUT passes the test at that test point and test level. If one unacceptable effect occurs in this set of discharges, a further test according to the following point c), may be performed; otherwise the EUT fails the test at that test point. If more than one unacceptable effect occurs in this set of discharges, the EUT fails the test at that test point.

c) The third test is to apply a new set with the same number of discharges as in point b) at that test point with the intended test level. If no unacceptable effect occurs in this set of discharges, the EUT passes the test at that test point. If one or more unacceptable effect occurs in this set of discharges, the EUT fails the test at that test point.