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Functions concerned
Fonctions concernées

☐ Safety / Sécurité ☒ EMC / CEM ☐ Environment / Environnement ☐ Quality assurance / Assurance qualité

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Titre : CEI 61000-4-2 : Compatibilité Electromagnétique (CEM) – Partie 4-2 : Techniques d'essai et de mesure – Essais d'immunité aux décharges électrostatiques

Publication fondamentale en CEM

Title : IEC 61000-4-2: Electromagnetic compatibility (EMC) - Part 4-2 : Testing and measurement techniques – Electrostatic discharge immunity test

Basic EMC Publication

Note d'introduction

Introductory note

ATTENTION	**ATTENTION**
CDV soumis en parallèle au vote (CEI) et à l'enquête (CENELEC)	**Parallel IEC CDV/CENELEC Enquiry**

FORM CDV (IEC)
2002-08-09

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IEC 61000: Electromagnetic compatibility (EMC)
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FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organisation for standardisation comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardisation in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organisations liasing with the IEC also participate in this preparation. The IEC collaborates closely with the International Organisation for Standardisation (ISO) in accordance with conditions determined by agreement between the two organisations.
2) The formal decisions or agreements of the IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested National Committees.
3) The documents produced have the form of recommendations for international use and are published in the form of standards, technical specifications, technical reports or guides and they are accepted by the National Committees in that sense.
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5) The IEC provides no marking procedure to indicate its approval and cannot be rendered responsible for any equipment declared to be in conformity with one of its standards.
6) Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. The IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 61000-4-2 has been prepared by subcommittee 77B: High-frequency phenomena, of IEC technical committee 77: Electromagnetic compatibility.

This standard forms Part 4-2 of IEC 61000. It has the status of a basic EMC publication, in accordance with IEC Guide 107.

The text of this standard is based on the following documents:

FDIS	Report on voting
77B/XXX/FDIS	77B/XXX/RVD

Full information on the voting for the approval of this standard can be found in the reports on voting indicated in the above table.

Annex A forms an integral part of this standard.

Annexes B to H are for information only.

The committee has decided that the contents of the base publication and its amendment will remain unchanged until 2006. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

INTRODUCTION

This standard is a part of IEC 61000 series, according to the following structure:

Part 1: General

General considerations (introduction, fundamental principles)

Definitions, terminology

Part 2: Environment

Description of the environment

Classification of the environment

Compatibility levels

Part 3: Limits

Emission limits

Immunity limits (in so far as they do not fall under the responsibility of the product committees)

Part 4: Testing and measurement techniques

Measurement techniques

Testing techniques

Part 5: Installation and mitigation guidelines

Installation guidelines

Mitigation methods and devices

Part 6: Generic standards

Part 9: Miscellaneous

Each part is further subdivided into several parts, published either as international standards or as technical specifications or technical reports, some of which have already been published as sections. Others will be published with the part number followed by a dash and a second number identifying the subdivision (example : 61000-6-1).

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-2: Testing and measurement techniques – Electrostatic discharge immunity test

1 Scope

This International Standard relates to the immunity requirements and test methods for electrical and electronic equipment subjected to electrostatic discharges, from operators directly, and to adjacent objects. It additionally defines ranges of test levels that relate to different environmental and installation conditions and establishes test procedures.

The object of this standard is to establish a common and reproducible basis for evaluating the performance of electrical and electronic equipment when subjected to electrostatic discharges. In addition, it includes electrostatic discharges that may occur from personnel to objects near vital equipment.

This standard defines:

- typical waveform of the discharge current;
- range of test levels;
- test equipment;
- test set-up;
- test procedure.

This standard gives specifications for test performed in laboratories and “post installation tests” performed on equipment in the final installation.

The test method documented in this part of IEC 61000 describes a consistent method to assess the immunity of an equipment or system against a defined phenomenon.

NOTE: As described in IEC guide 107, this is a basic EMC publication for use by product committees of the IEC. As also stated in Guide 107, the IEC product committees are responsible for determining whether this immunity test standard should be applied or not, and if applied, they are responsible for determining the appropriate test levels and performance criteria. TC 77 and its sub-committees are prepared to co-operate with product committees in the evaluation of the value of particular immunity tests for their products.

2 Normative References

This standard shall be used in conjunction with the following standards. When the following standards are superseded by an approved revision, the revision shall apply. Informative references are shown in [], while normative references are denoted in { }.

[1] IEC 50(161): International Electrotechnical Vocabulary (IEV) – Chapter 161: Electro-magnetic compatibility

3 Definitions

This section references the IEC 50 (161) [IEV] and IEEE standard dictionary. The only terms that will be defined here will be those that 1) are not in the IEV and IEEE dictionary or 2) have a different meaning in this document from what is in IEV and IEEE dictionary.

3.1 actual ESD events:
Non-simulated electrostatic discharges that occur in the environment of the electronic equipment.

3.2 air discharge method: A method of ESD testing in which the charged electrode of the ESD generator approaches the EUT regardless of the conductivity of the surface being subjected to the ESD event. A spark in air to the EUT actuates the discharge.

3.3 anti-static material: Material exhibiting properties which minimise charge generation when rubbed against or separated from the same or other similar materials.

3.4 bleeder wire: Conductive wire with high impedance, high voltage series resistors to dissipate applied electric charge from HCP, VCP and EUT slowly. Further technical description is given in clause 6.6.

3.5 contact discharge method: A method of ESD testing in which the electrode of the ESD generator is in firm electrical contact with a conductive surface of the EUT or coupling plane prior to discharge. A switching device (i.e., a relay) within the ESD generator actuates the discharge.

3.6 coupling plane: A metal plate to which discharges are applied to simulate electrostatic discharge to objects adjacent to the EUT. *See also:* HCP and VCP.

3.7 degradation of performance: An undesired departure in the operational performance of any device, equipment or system from its intended performance. [IEV 161-01-19]
NOTE - The term "degradation" can apply to temporary or permanent failure.

3.8 direct ESD test: A test in which ESD is applied directly to the surface or structure of the EUT.

3.9 electrostatic discharge (ESD): The sudden transfer of charge between bodies of differing electrostatic potentials.

3.10 ESD event: The occurrence of a single ESD.

3.11 ESD generator: A testing device used to simulate an actual ESD event.

3.12 ESD target adapter: Adapter used to connect reference discharge or sinusoidal generators to the ESD target.

3.13 ESD test voltage: The amplitude (usually expressed in kV) of the electrostatic voltage that exists prior to discharge.

3.14 ground reference plane (GRP): A flat conductive surface whose potential is used as a common reference. Where applicable, the operating voltage of the EUT and the operator ground should also be referenced to the ground plane.

3.15 holding time: The interval of time within which the decrease of the test voltage due to leakage, prior to the discharge, is 10%. Care must be taken that the measurement method does not significantly influence the holding time.

3.16 HCP: Horizontal coupling plane

3.17 human ESD: The ESD that occurs directly from a human fingertip.

3.18 indirect ESD test: A test in which ESD is applied to a coupling plane in the vicinity of the EUT in order to simulate discharges which occur to other conductive objects in the vicinity of the EUT.

3.19 simulated ESD: An ESD that originates from an ESD generator.

3.20 ESD generator approach speed: The rate at which an air discharge ESD generator approaches the EUT.

3.21 transfer impedance: The measured output voltage from the target-cable-attenuator chain divided by a known input current injected into the target. The target, any attenuators and terminators are taken into account in this calculation.

3.22 VCP: Vertical coupling plane.

4 General

This standard relates to equipment, systems, sub-systems and peripheral which may be involved in static electricity discharges owing to environmental and installation conditions, such as low relative humidity, use of low-conductive (artificial-fibre) carpets, vinyl garments, etc., which may exist in locations classified in standards relative to electrical and electronic equipment.

ESD occurs when the static electric field between two objects exceeds the dielectric strength of the air between them. The discharge is a complex event involving a localised transfer of charge at the point of discharge, electromagnetic near field coupling between the objects involved, induced current flow in the object receiving the discharge and radiated electromagnetic energy from the charged object as well as from the arc of the discharge. All of these phenomena are capable of causing malfunctions and, in some cases, damage in electronic equipment.

During the electrostatic discharge event, electric charge is exchanged between two objects. Even though ESD may be a series of multiple discharges occurring very close together in time, the ESD event will be considered a single event in this standard. For the sake of testing, the repetition rate of ESD discharges may be increased. However, the repetition rate must be kept slow enough such that successive discharge are not applied until:

- the EUT (Equipment Under Test) has completed a complete error recovery or retry cycle and
- any charge imparted on the EUT is allowed to dissipate.

Two discharge modes are used in ESD testing:

1. Air discharge
2. Contact discharge.

The goal in both cases is to determine the immunity of the equipment under test (EUT) to ESD. Each test mode has its own advantages and disadvantages.

The air discharge test method attempts to recreate the actual ESD occurrence by creating an arc in the air. This approach may not produce repeatable waveforms due to variations of the arc length, which can sometimes yield variable test results. The contact discharge test method reduces some of the variability by creating the arc under controlled conditions, usually inside a relay, which results in repeatable waveforms, but it does not recreate the characteristics unique to the arc of an actual ESD event.

This standard specifies both air and contact discharge methods for different equipment installations and applications.

5 ESD Test levels

5.1 Test levels

The EUT shall be tested against the applicable test levels for its installation environment or environment of usage.

Contact discharge testing is the preferred test method, as it results in a more repeatable test than air discharge testing does. Air discharges shall be applied only to those test points to which contact discharges cannot be applied.

The contact discharge tests will be applied at the test level only. Air discharge tests will be applied from the lower test levels up to the required test level, and the EUT shall not experience response types other than those specified for those levels. Responses other than those allowed will be considered as test errors.

Table 1 - Open circuit voltages of the ESD generator

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	special	X	special

NOTES:

1. The level "X" is an open level to be negotiated between the manufacturer and the purchaser or to be defined by the product committee.

2. The test levels given in table 1; contact and air discharge, are NOT related by severity level. The response to the applied type of discharge and test level will be EUT dependent.

Contact discharge is considered to be the preferred method as the test is more repeatable than the air discharge test.

6 Test site and test equipment

6.1 General

Care should be exercised when selecting a site to perform ESD testing. A broad spectral distribution of energy is produced by the ESD discharge and is emitted; the emission of this energy during the ESD test may cause damage to or malfunction of unprotected equipment in the immediate area. Further the presence of other equipment and activity in the immediate area can interfere with the ESD test. The ESD test site, therefore, should be located in an area of sufficient size and clearance to other equipment to minimise:

- interference to other equipment not part of the test and
- the impact on the test results from other equipment and activity not associated with the ESD test.

Accordingly, a clear-area radius of at least 1 m is to be provided around the EUT and to any other metallic structure, including walls, so as not to impact the ESD test. Where possible, the EUT should be placed in a dedicated room with electrical isolation from unrelated equipment.

With the selection of the test site, the likelihood of any safety hazard shall be taken into account considering the fact that the ESD test will be carried out by qualified personnel. Personnel hazards considered are accidental contact to the charged EUT, ESD generator or possible interference with cardiac pacemakers or other body implanted electronics.

6.2 ESD generator specifications

The ESD generator characteristics shall be as follows:

Table 2 - General ESD generator parameters

Voltage range contact discharge mode	at least 1 - 8 kV
Voltage range air discharge mode	at least 2 -15 kV
Output voltage accuracy	≤ 5%
Output polarity	positive and negative
Rise time of short circuit current in contact discharge mode (10% to 90%)	0,7 – 1,0 ns
Holding time	at least 5 sec.
Typical storage capacitance	150 pF
Typical discharge resistance	330 Ω

NOTE: When an ESD generator is supplied from an external supply source, AC or DC, or controlled by a separate unit and this (these) cable(s) is (are) not combined (bundled) with the ESD generator return current cable, unintended current may flow through this (these) cable(s).

The ESD generator should be able to generate a repetition rate of at least 20 discharges per second down to manual control without any degradation of the discharge current waveform.

In cases where a 2 m length of the discharge return cable is insufficient (e.g. for tall EUTs), a length not exceeding 3 m may be used and compliance with the waveform specifications shall be guaranteed (e.g. by the manufacturer or from calibration).

6.2.1 Contact discharge mode current specifications

For contact mode discharge currents measured as outlined in Annex A, the specifications in 6.2.1.1 and 6.2.1.2 shall be fulfilled. The discharge electrode for contact mode ESD generators is shown in figure 1. The tip is typically made of stainless steel. The contact discharge waveshape is given in figure 2. The contact waveform parameters are given in tables 3 and 4. A mathematical description is given in annex E.

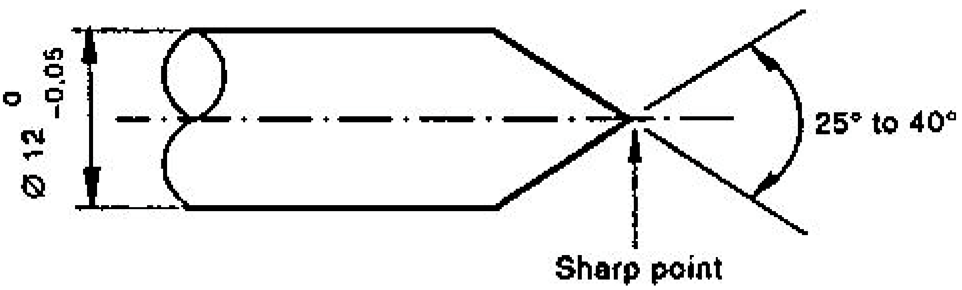


Figure 1 - Contact discharge mode electrode of the ESD generator

Table 3 - Contact discharge mode current specification

Oscilloscope Bandwidth [GHz]	Peak Current [A/kV]	Tolerance [%]	Current at 30 ns [A/kV]	Tolerance [%]	Current at 60 ns [A/kV]	Tolerance [%]
≥ 2	3,75	± 10	2	± 30	1	± 30

NOTES:

1. The peak current level shall be taken from the measurement system without any data interpolation like (sin (X))/X or Cspline. These corrections will cause additional errors referred to the real obtained signal samples.

2. The target used with this measurement system shall fulfil the requirements of clauses A.1 and A.2. An example is defined in Annex B. This target is different from the one defined in the first edition of this ESD standard.

6.2.1.1 Contact discharge current

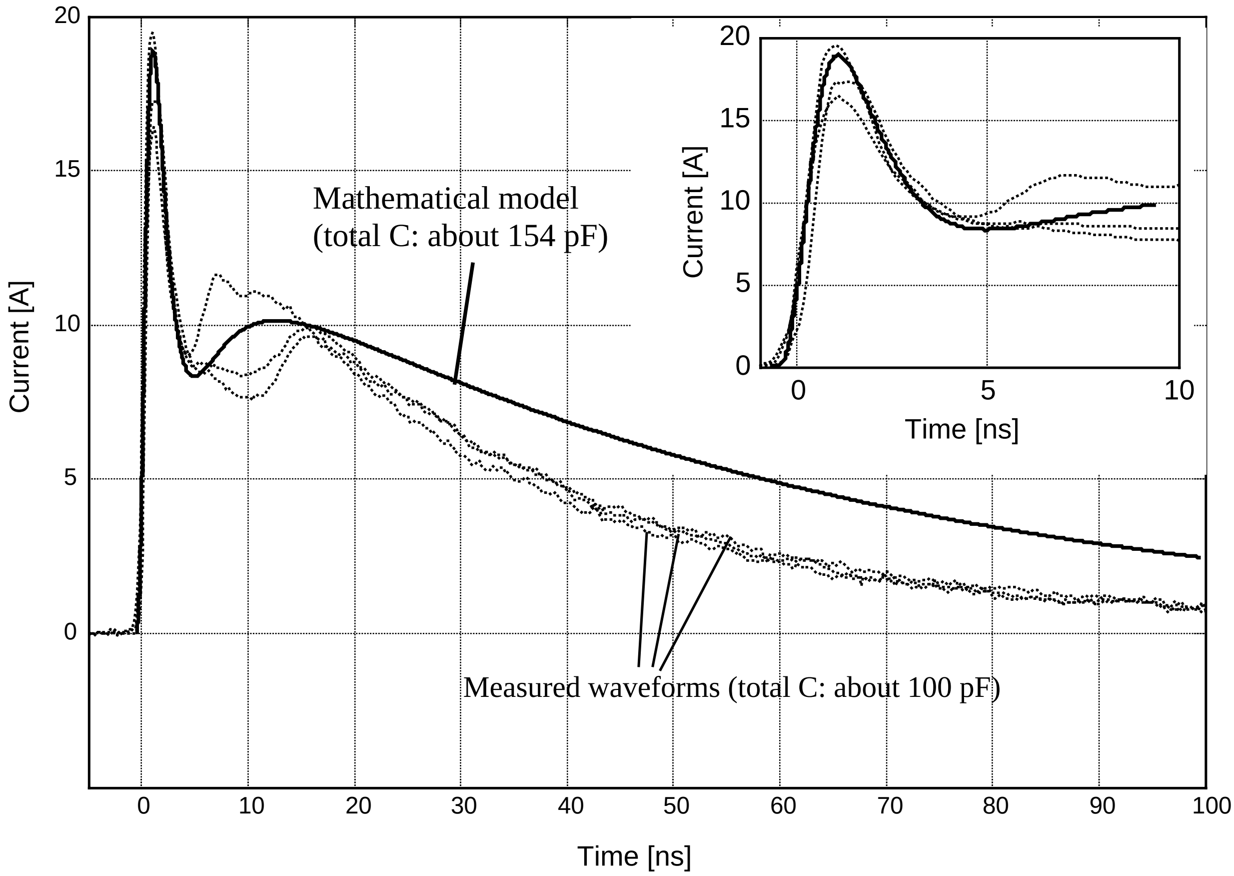


Figure 2 - Contact discharge waveform of ESD generator, charge voltage = 5 kV

6.2.1.2 Contact discharge mode current derivative

In clause A.4.2, the procedure to derive the contact discharge mode current derivative is given in detail.

Table 4 - Contact discharge mode peak current derivative specification

Target and oscilloscope bandwidth [GHz]	Peak current derivative [A / (ns * kV)]	Tolerance [%]
≥ 2	4,2	± 30
NOTES 1. The mean value of 10 individual discharges of the peak current derivative values occurring is assumed not to exceed the mathematical straight line between the 10 – 90 % current levels divided by the minimal rise time interval. 2. Limits on the positive (and negative, 3:1 ratio required) current derivatives are given to ensure a smooth rise and to avoid ringing an ESD generator may exhibit. The negative dI/dt limit prevents the falling slope of this spike from being too steep.		

6.2.1.3 Procedure for testing ESD generator contact discharge waveform

Calibration shall be performed as needed or as recommended by the ESD generator manufacturer and/or quality system of the user.

Prior to calibrating the discharge current, the amplitude of the ESD generator's charging voltage should be determined using a high-voltage meter. The accuracy of the voltage measurement shall be as specified in table 2.

For the contact discharge current waveshape calibration, the ESD generator is discharged into a current transducer (target) located in the centre of a vertical metal plate with minimum size of 1,2 by 1,2 m.

Specifications for the calibration set-up and the calibration procedures are given in Annex A.

Additional information, which is not mandatory, is given in:

Annex B: provides a description of an example for the current target.

Annex E: provides information on the reference ESD event.

Annex F: provides information on the effect of tolerances to the ESD characteristics

Annex G: provides rationale for air discharge generator calibration.

Annex H: provides a bibliography of publications and documents related to some of the changes made in this standard and the reasons for them.

To ensure comparability of test results obtained from different ESD generators, contact mode generators must generate discharge waveforms that meet the specifications in tables 3 and 4 when tested as specified in Annex A. The following environmental conditions at the time calibration is performed shall be recorded:

- temperature
- relative humidity
- barometric pressure

These factors should be within the limits specified in clause 8.1.

6.2.2 Air discharge generators

For the air discharge test, the same ESD generator may be used with the discharge switch closed or a different front added. The ESD generator is then fitted with the round tip shown in figure 3. Calibration is done in the contact mode only. See Annex A for details of the calibration procedure and Annex G for information relative to air discharge generator calibration.

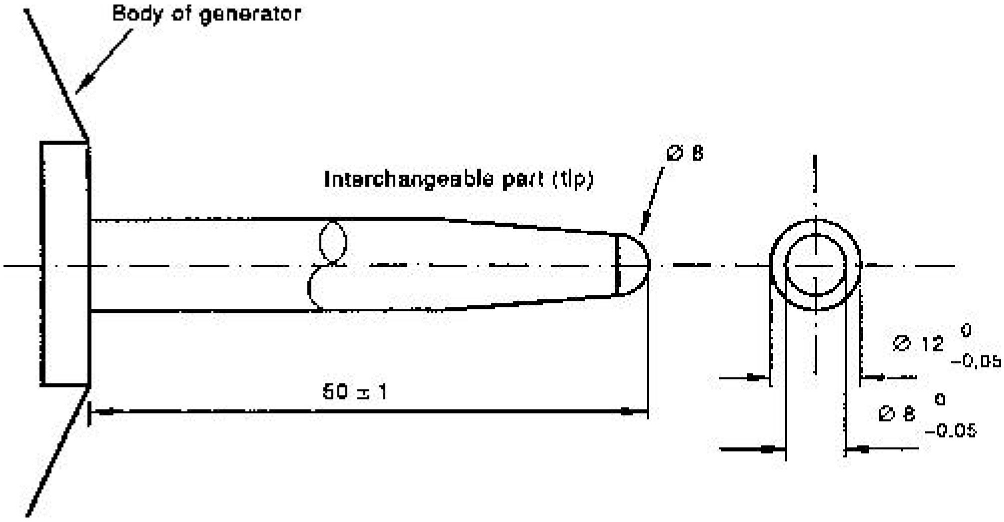


Figure 3 - Air discharge mode electrode of the ESD generator

6.3 Ground reference plane

A ground reference plane (GRP) of sufficient size to provide a continuous reference for the EUT, ESD generator and HCP (when used) is required as part of the test site. The GRP on the floor is extended beyond the edges of the EUT (in case of floor-standing) or of the HCP by at least 0,5 m on all sides. To capture all edge effects for equipment over 1 m in height (including its support), the GRP should extend beyond the EUT at least 50% of the height of the EUT. The GRP, as well as the HCP and VCP, shall be a metallic sheet (copper or aluminium) of 0,25 mm minimum thickness; other metallic materials may be used, but they shall have 0,65 mm minimum thickness.

The GRP shall be connected to the protective earth grounding system. Local safety regulations should always be met. An optional insulator, not to exceed 5 mm in thickness, may be placed over the GRP.

See clause 7.1 and Annex D for EUT ground connections.

6.4 Horizontal coupling plane

The horizontal coupling plane (HCP) is connected to the GRP via a bleeder wire. The size of the metallic HCP is 1,6 m x 0,8 m. The HCP shall be a metallic sheet (copper or aluminium) of 0,25 mm minimum thickness; other metallic materials may be used, but they shall have 0,65 mm minimum thickness. It shall be mounted on top of a wooden table 0,8 high.

6.5 Vertical coupling plane

The vertical coupling plane (VCP) is connected to the GRP via a bleeder wire. The size of the metallic VCP is 0,5 x 0,5 m. The VCP shall be a metallic sheet (copper or aluminium) of 0,25 mm minimum thickness; other metallic materials may be used, but they shall have 0,65 mm minimum thickness. It shall be mounted in a vertical plane at a distance of 0,1 m from the EUT surface to be tested. Where possible, the minimum distance between the VCP and the cables connected to the EUT shall be 0,1 m.

The minimum separation between the VCP and the GRP or HCP shall be 0,05 m to control the capacitance over the gap between the VCP and the GRP or HCP.

6.6 Bleeder wire

A bleeder wire is used to slowly discharge the VCP and if necessary the EUT. At both ends of the wire, 470-kΩ resistors shall be added (one at each end). The high voltage resistors should have a sufficient withstand voltage.

The wire length from the high voltage resistor to the part to be contacted shall be short, ≤ 20 mm, see figure 6, to minimise the additional stray capacitance from the wire. During testing, the bleeder wire shall not be held in hand neither at the resistor nearest to the EUT nor the wire length in-between.

NOTE: Holding the wire or the high voltage resistor in hand will increase the stray capacitance from the bleeder wire to the GRP or even from the EUT to the GRP due to the presence of the operator’s hand.

7 Test set-up

The test set-up 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:

- contact discharge to the conductive surfaces and to coupling planes;
- 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.

7.1 Test set-up for tests performed in laboratories

The following requirements apply to tests performed in a laboratory under environmental reference conditions outlined in clause 8.1.

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

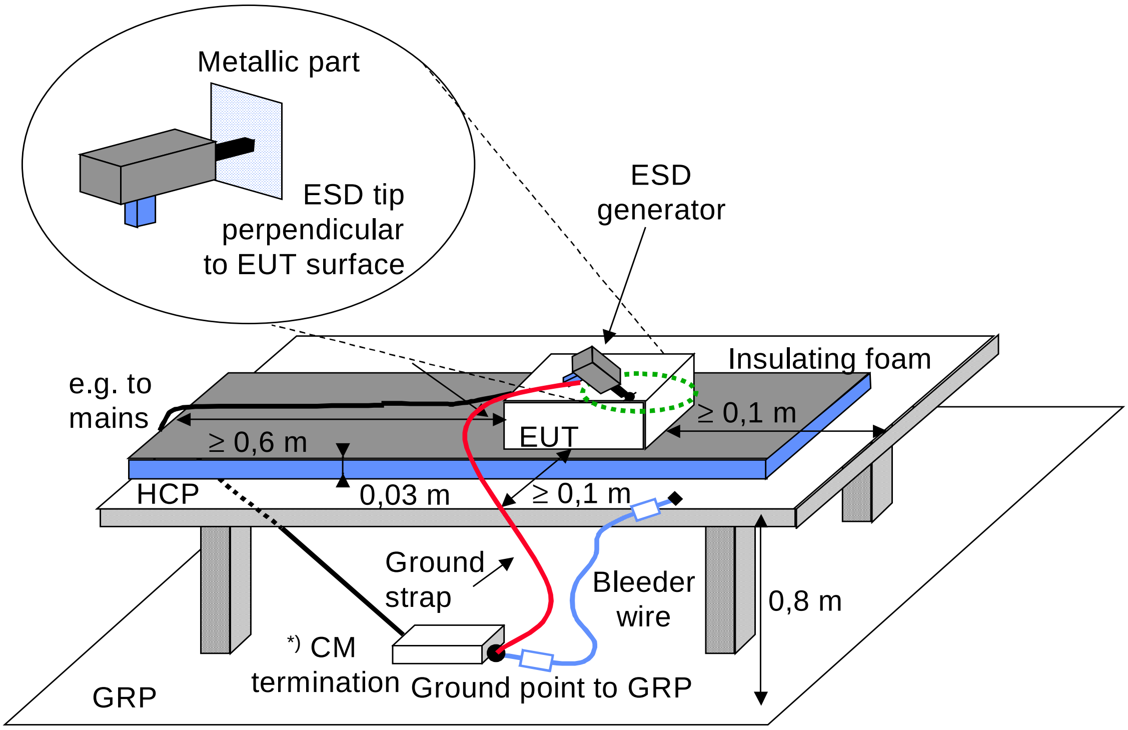
All cables connected to the EUT (e.g. power cords and I/O cables to auxiliary equipment) shall be routed at 30 ± 5 mm above the metal plane. Additional specifications for the different types of equipment are given below. See Annex D for additional information regarding test set-up and treatment of cables.

7.1.1 Table-top equipment

When testing EUTs normally installed on a desk or table, a table with an HCP is used. The wooden table shall be positioned in the center of the ground reference plane (GRP). The GRP shall extend at least 0,5 m beyond the HCP on all sides. The test set-up can also be established by using the conductive floor of a shielded enclosure as GRP.

A horizontal coupling plane (HCP), 1,6 m x 0,8 m, shall be placed on the table. The HCP shall be mounted 0,8 ± 0,1 m above the GRP. A distance from the HCP to the metal walls of at least 1 m shall be maintained. The EUT and cables shall be isolated from the coupling plane by an insulating support 0,03 ± 0,01 m thick, for example using polystyrene foam blocks. Any mounting feet associated with the EUT shall remain in place, see figure 4.

All cables connected to the EUT shall be isolated from the HCP by an insulating support of 0,03 ± 0,01 m thick**,** e.g. using polystyrene foam blocks. For cables connected to the EUT and leaving the HCP, it is recommended that a length of at least 0,6 m be routed above the HCP before dropping to the GRP. See also Annex D.



*) The optional common-mode termination shall preferably be an RF short-circuit to the GRP, see also Annex D.

Figure 4 - Test set-up for grounded tabletop equipment

NOTE: When units of a larger system or EUT can be tested separately this will be the preferred method. These (non-tested) parts will be connected as AE (auxiliary equipment) typically. In cases where this is impractical or unfeasible (for functional reasons) an ESD test to a system as a whole should be performed.

When an electrically isolated metallic accessible part, to which the ESD discharge is to be applied, is available with the EUT, only this metallic part shall be discharged to the GRP via a bleeder wire, see clause 6.6 and clause 7.1.4.

7.1.2 Floor-standing equipment

The EUT shall be isolated from the GRP by an insulating support of 0,1 ± 0,05 m thick. The cables shall be isolated from the GRP by an insulating support of 0,03 ± 0,01 m thick**,** e.g. using polystyrene foam blocks. It is recommended that a length of at approximately 0,6 m of cable is exposed over the GRP. Any mounting feet associated with the EUT shall remain in place, see figure 5.

NOTE: In case the EUT is placed on a pallet for transportation, the pallet (considered to be of an insulating material, typically 0,1 m high) may be used as insulating support.

When an electrically isolated metallic accessible part, to which the ESD discharge is to be applied, is available with the EUT, only this metallic part shall be discharged to the GRP via a bleeder wire, see clause 6.6 and clause 7.1.4.

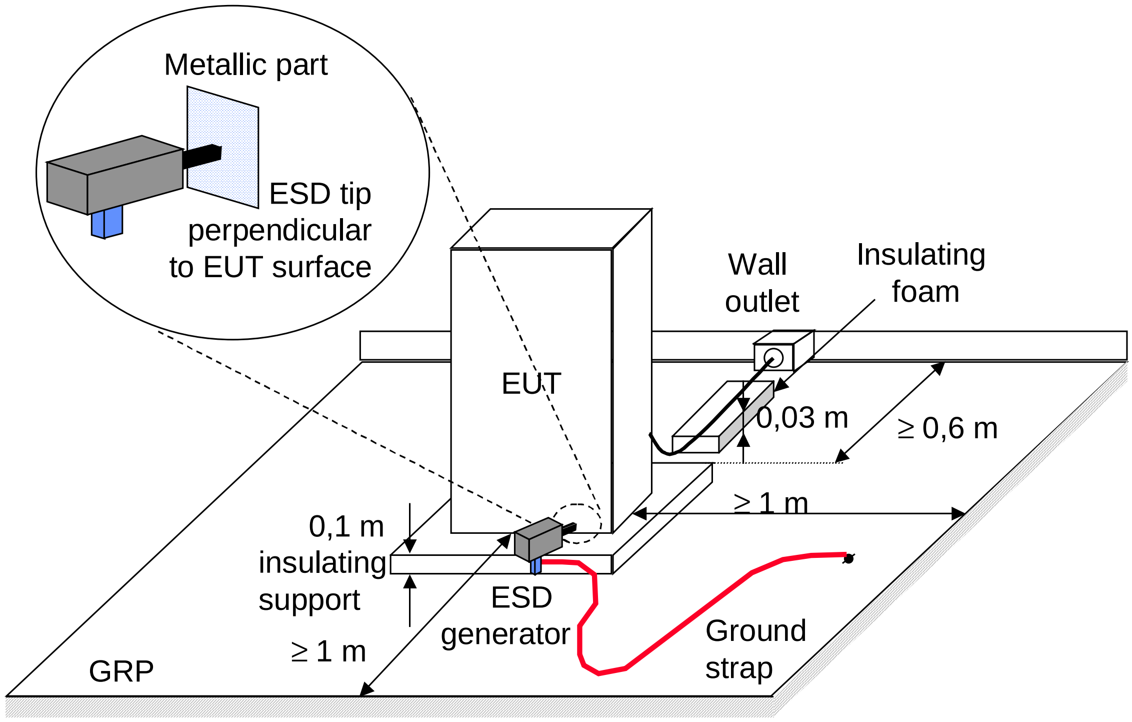


Figure 5 - Test set-up for grounded floor standing equipment.

7.1.3 Wall mounted equipment

Where possible, wall-mounted equipment shall be rotated such that the surface normally installed against a wall is placed parallel to the HCP and tested following the test procedure for table-top equipment (see clause 7.1.1).

When the EUT has to remain in its vertical orientation, a metal coupling plane of dimensions 0,8 m high and 1,6 m wide (similar to the HCP) shall be mounted vertically at a height of 0,8 m above the center of the GRP. The EUT and cables shall be isolated from this coupling plane by an insulating support 0,03 m thick. Any mounting feet associated with the EUT shall remain in place. Basically, this test set up can be thought of as a table-top test turned on its side, allowing the EUT to remain in its typical installation orientation.

7.1.4 Test set-up for ungrounded equipment.

The test method in this clause is applicable to equipment or part(s) of equipment whose installation specifications or design preclude connection to any earthing system.

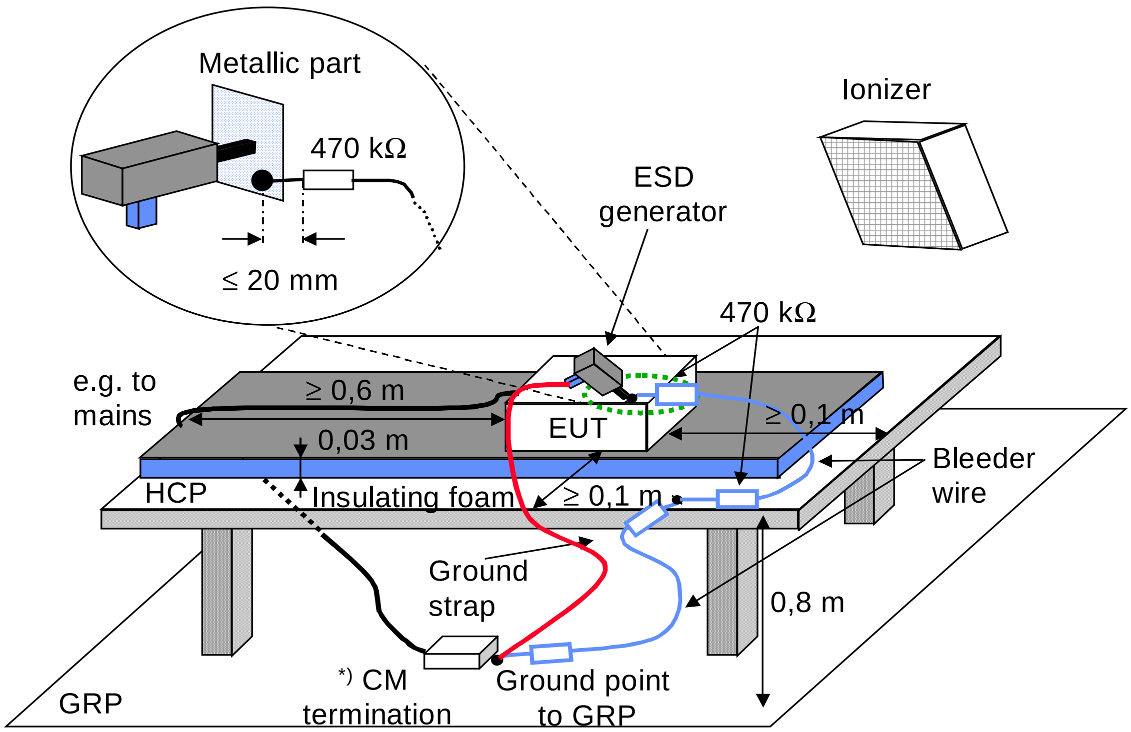
Examples include the following types of equipment or parts thereof: portable, battery-operated and double insulated equipment (safety class II equipment).

Rationale: Ungrounded equipment or ungrounded part(s) of equipment cannot discharge itself in the same way as class I mains supplied equipment.

If the charge is not removed before the next ESD discharge is applied, it is possible that the EUT or part(s) of the EUT could be stressed up to twice the intended test voltage. Double insulated equipment could acquire an unrealistic 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 test set-up shall be identical to the ones described in clause 7.1.1 for table-top, 7.1.2 for floor standing and 7.1.3 for wall mounted equipment.

To simulate a single ESD event, the charge shall be removed from the metallic point or part of the EUT to which the pulse is applied prior to the application of each subsequent pulse. A bleeder wire (see clause 6.6) shall be connected to the metallic part to remove the charge, see Figure 6. The bleeder wire may be momentarily connected between the test point and the HCP after each single discharge; in this case, the bleeder wire will be disconnected from the test point prior to the next discharge. The bleeder wire may remain installed during the test when functionally allowed and the test results are not impacted by its presence.



*) The optional common-mode termination shall preferably be an RF short-circuit to the GRP, see also Annex D.

Figure 6 - Test set-up for ungrounded tabletop equipment

As an alternative, the following options can 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.
- A carbon fibre brush with earth wire.
- Air-ionizers, to speed-up the 'natural' discharging process of the EUT to its environment. The ionizer shall be turned off when applying an air-discharge test.

The use of any alternative discharging method shall be reported in the test report.

NOTE: In case of dispute concerning the charge decay the charge on the EUT can be monitored. A non-contacting electrostatic voltmeter may be required for this measurement. When the charge has decayed below 10% of the initial value, the EUT is considered to be discharged.

7.2 Test set-up for post-installation tests

On-site ESD tests are commonly not preferred and are not mandatory. These tests should be applied only when laboratory tests cannot be performed because of a unique equipment installation. The manufacturer and the customer must agree to in-situ tests too. The results are applicable only to the unique installation tested.

NOTE: It should be considered that other collocated equipment might be adversely affected during these tests.

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 metal not less than 1 mm thick. 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 at a point close to the EUT. Where the EUT is installed on a metal table, the conductive surface of the table shall be connected to the ground reference plane via bleeder wire to prevent a build-up of charge.

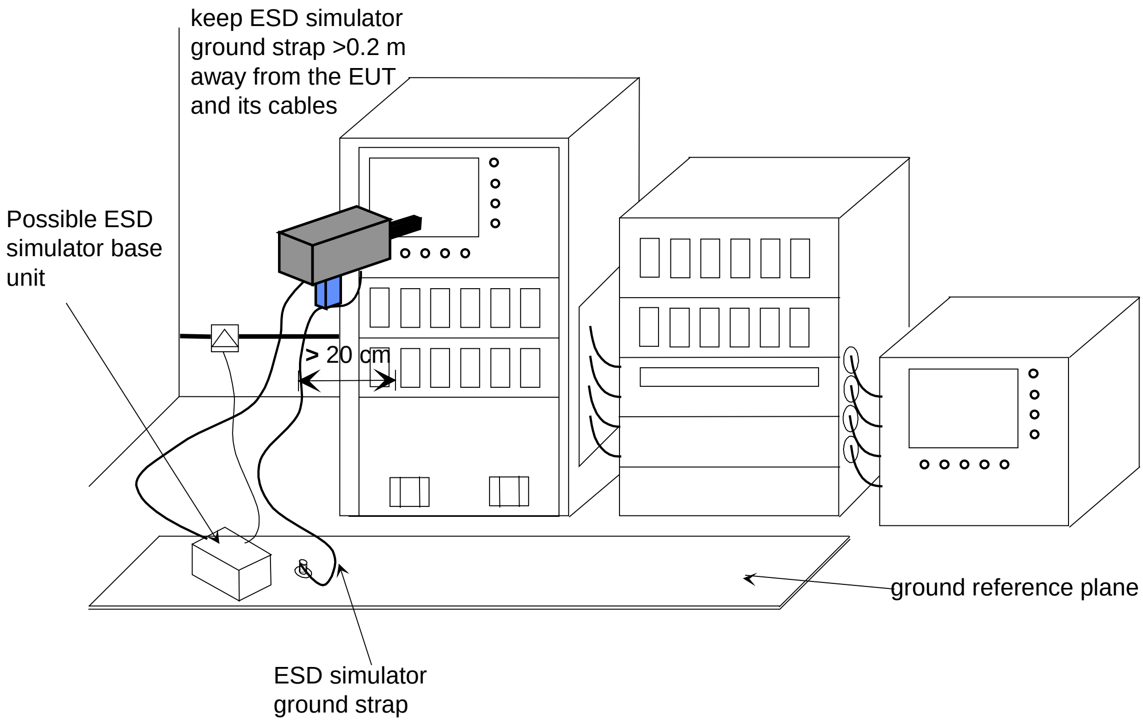


Figure 7 - Example of test set-up for equipment - Post-installation tests

7.3 ESD generator return cable

The discharge return cable required in air and contact ESD generators is connected to the GRP as shown in figures 4 to 7 and has a typical length of 2 m. A discharge return cable longer than 2 m may be necessary to apply discharges to all selected points.

NOTE: It is assumed that the discharge return cable shall not be extended to lengths beyond 3 m as it is unlikely that human ESD events can take place at these high distances above the GRP.

The connection of the ESD generator return cable to the GRP and all bonding should be of low impedance at high frequencies. The discharge return cable of the ESD generator should be positioned at least 0,2 m from the EUT while the discharge is being applied. The discharge return cable shall also be kept at least 0,2 m away from any cable connected to the EUT and from the edge of the HCP; see also figure A5. These measures are needed to reduce radiation of this cable from affecting the test results. The end of the discharge return cable connected to the ESD generator may be closer to the EUT.

8 ESD test procedures

Testing shall consist of direct and indirect application of discharges to the EUT. Direct discharges are applied directly to the EUT. Indirect discharges simulate discharges that occur to other conductive objects in the vicinity of the EUT and are applied through an intervening metal, such as an HCP or VCP.

The test shall subject the EUT to simulated discharges from humans. Discharges shall be applied to areas that are accessible by operating personnel during normal operation. See clause 8.5, Selection of test points.

8.1 Laboratory test conditions

The intent of ESD testing in the laboratory is to simulate both the level and type of ESD occurrences that are experienced by the product in the field in a manner that is representative of, but not necessarily identical to, actual ESD.

In order to minimise the effect of environmental parameters on the test results, ESD testing should be carried out under the conditions defined in this clause.

8.1.1 Climatic conditions

Unless otherwise specified by the committee responsible for the generic or product standard, the climatic conditions in the laboratory shall be within any limits specified for the operation of the EUT and the test equipment by their respective manufacturers.

Tests shall not be performed if the relative humidity is so high as to cause condensation on the EUT or the test equipment.

To ensure reproducibility of the test results, ESD testing should be performed under the following climatic conditions:

a) Temperature: 15-35ºC (59-98ºF)

b) Relative humidity: 30% to 60%

c) Atmospheric pressure: 68-106 kPa

NOTES

1. Standard conditions are defined as sea level (101,3 kPa and 15^{o}C). Then 106 kPa is -383 m and 68 kPa is +3236 m altitude. International conversion for 1 kPa is 0,145 lbs/in^2 or 0.2953 in Hg (typical reported atmospheric pressure measurement in the USA) and 10 mbar.

2. Tests can be performed outside the recommended climatic conditions. However, the results may be significantly affected with increased RH and variations in temperature**.** In case of dispute, testing at 21 degrees C and 50% relative humidity at sea level takes precedence.

3. The actual environmental conditions existing during the test should be recorded in the test report. Instead of the atmospheric pressure, the altitude can be noted. Due to weather systems, the barometric pressure at a constant altitude changes only by typically +/- 3 %. If the barometric pressure is recorded, care must be taken that it is the true barometric pressure and not the barometric pressure converted to sea level.

4. Air breakdown voltage at a fixed distance between electrodes is approximately proportional to atmospheric pressure and inversely proportional to absolute (K) temperature. Therefore, when testing EUTs for air breakdown (external or internal with either test method), the ESD test voltage level should be changed to reflect the test equipment specification and the environmental test conditions. Typically, air breakdown voltage at sea level will be about 40% higher than at 3000 m for the same gap distance. Failure to change the test voltage to account for pressure variation will create site-to-site immunity variations in the EUT air breakdown values. A correction of the test voltage shall only be applied to air discharge testing if a dielectric barrier is tested. The correction may lead to incorrect results if the failure mechanism is related to the energy of the current of the ESD discharge.

8.1.2 Electromagnetic conditions

The ambient electromagnetic conditions should be such as not to influence the results of this test.

8.2 EUT set-up

8.2.1 EUT software and/or mode of operation

Choose test software for the EUT that will exercise all modes of normal operation.

Where it is cost prohibitive to exercise all normal modes of operation because of EUT complexity, specific modes expected or known to exhibit the most susceptibility should be exercised. Good engineering judgement shall be used in selecting the operating modes to be tested. The modes exercised and the rationale for their selection shall be documented in the test report.

As the complexity of the machine operating system decreases, the probability of evaluating all or most modes of operation increases.

8.2.2 Auxiliary equipment

If the EUT needs to interface with auxiliary equipment (AE) to operate in a realistic way, this auxiliary equipment shall have proven to be immune at an equal or greater level than aimed for the EUT. If this is not the case, the I/O cables can be fitted with filters or ferrite toroids very close to the AE; see Annex D.

8.3 Discharge Modes

Discharges can be applied to the EUT by two discharge modes: contact and air. Conductive surfaces are to be tested using contact mode discharges. Non-conductive surfaces are to be tested using air discharges. Air discharges shall be applied to those parts of the EUT to which it is not possible to apply contact discharges. Examples are non-conductive surfaces, conductive parts or surfaces covered by insulating material or behind seams or slots and places where it is not physically possible to position the contact discharge tip. Indirect discharge testing shall be performed using contact mode discharges only. See Annex C for guidance on air versus contact discharge modes.

In contact discharge mode, the tip of the ESD generator’s discharge electrode is brought in contact with the EUT before the discharge switch is actuated to apply the discharge. In air discharge mode, the discharge electrode is charged to the test voltage and then brought rapidly to the EUT, applying the discharge through an arc that happens when the tip approaches close enough to the EUT to break down the dielectric between the tip and test point. See also clause 8.4.4.2.

8.4 Application of the discharges

Discharges shall be applied to all selected test points with the equipment operating normally. However, test points are to be limited to those areas that are likely to be contacted during normal operation of the EUT; see clause 8.5.

The test shall consist of at least 50 contact discharges of each polarity applied to each defined test point for the test level specified. Those defined test points to which contact discharge cannot be applied (eg, covered by insulating material), shall be tested by applying at least 10 air discharges of each polarity at the defined test level and all lower test levels. Air discharges need not be applied at test levels below the voltage at which arcing does not occur. (For example, if no arc occurs at 8 kV, then air discharges do not need to be applied at 2 and 4 kV.)

8.4.1 Test voltage steps

8.4.1.1 Contact Discharge Method

Because the discharge current of ESD generators in contact mode is linear with respect to the charge voltage, it is permissible to test at only the severity level required for the product and not at all lower voltage levels. See Annex C.

8.4.1.2 Air Discharge Method

Some products have the tendency to exhibit susceptibility responses when exposed to specific ESD voltages, but not necessarily at higher voltage levels. Because of this and the nonlinear relationship between charge voltage and discharge current in the air discharge method, test points subjected to air discharges must be tested at lower test levels up to the severity level required for the EUT. In the absence of other requirements, the test levels given in Table 1 should be used.

For example, an EUT required to meet test level 3 (8 kV for air discharge method of testing) shall be tested at 2 kV, 4 kV and 8 kV, unless discharges do not occur at the lower levels.

NOTE: When no discharges (can) take place at these lower test levels, the product is deemed to comply with the requirement to test at the lower levels.

8.4.2 Time between ESD events

The time interval between successive single discharges should be as long as necessary to determine whether the EUT has completed an error recovery or retry cycle. Every discharge should be considered individually; therefore, time needs to be allowed between discharges to ensure that a failure is not due to sequencing, but due to the individual ESD event and that any charge imparted on the EUT is allowed to dissipate.

The time interval between successive single discharges is recommended to be 1 s. Faster repetition rates, e.g. up to 20 discharges/s, are allowed to make the test time shorter, provided the faster rate does not influence test results. By using the EUT charge removing measures as described in clause 7.1.4, a maximum time of 10 s should be used as slowest limit considering automated repetitive testing.

NOTES

1. Higher repetition rates are advantageous to those who want to perform multiple trial ESD testing in order to expedite the test time. However, when the EUT passes the test at the level with the lower repetition rate, the EUT is considered to comply.

2. Where it is possible for the application of the discharges to be synchronous with the EUT operation cycle, consideration should be given to vary the discharge repetition frequency randomly.

3. All 50 contact discharges can be applied in a single sequence. After this sequence, it can be verified whether the EUT operating as intended, as it is irrelevant for the test whether an error after the first or the last discharge.

8.4.3 Orientation of ESD generator

For direct discharges to the EUT, the ESD generator’s discharge tip is held perpendicular to the surface of the EUT or HCP when a small EUT is considered, see annex D. For discharges to coupling planes (i.e., indirect discharges), the discharge tip is in the same plane as the HCP or VCP while making contact with the plane’s edge. No discharges are made to either side of the flat surfaces of the HCP and/or VCP.

8.4.4 Direct application of discharge to the EUT

8.4.4.1 Electrode connections for contact discharge method

In the case of direct contact discharges, the tip of the discharge electrode must touch a conducting point on the EUT before the discharge switch is actuated.

Where painted surfaces cover a conducting substrate, the following procedure is used. If the coating is not declared to be an insulating coating by the equipment manufacturer, then the pointed tip of the ESD generator penetrates the coating so as to make contact with the conducting substrate. If the coating is declared to be an insulating coating, then the surface is tested as an insulating surface using the air discharge method and no electrical contact shall be made with the conducting substrate.

8.4.4.2 Speed of approach for air discharge method

The speed of approach of the discharge electrode is a critical factor in the rise time and amplitude of the injected current during an air discharge. The speed of approach should be between 0,1 - 0,5 m/s for any test. Because the approach speed is not trivial to measure, in practice the ESD generator should approach the EUT as quickly as possible without causing damage to the EUT or ESD generator. The ESD generator should not be stopped when the arc occurs, but rather should be followed through until the electrode touches the surface.

8.4.5 Indirect application of the discharge using the HCP or VCP

Discharges to objects placed or installed near the EUT are simulated by applying contact discharges of the ESD generator to the HCP or VCP that is connected to the GRP via a bleeder wire. The bleeder wire prevents a charge build-up on the coupling plane, see clause 6.6.

Contact discharges shall be applied to the centre of one vertical edge of the VCP while the VCP is positioned parallel to and 0,1 m from the EUT surface and/or cables connected thereto. With a tall or broad EUT, the VCP shall have its centre at the centre of the EUT. If the height of the EUT is greater than 0,5 m, consideration should be given to applying indirect discharges with the VCP at different heights and positions corresponding to the location of the sensitive circuitry of the EUT. Discharges using the VCP should be made to all four sides of all equipment.

With indirect contact discharges to the HCP the discharges shall be applied to each centre position (front, back and sides) of the EUT on the HCP. The EUT shall be kept at 0,1 m from the edge of the HCP. It may be necessary to move the EUT on the HCP for each face tested.

8.5 Selection of test points

The discharges shall be applied to the EUT at operator accessible points and to the vertical edge of the VCP. Examples of operator accessible points include any point in the control or keyboard area and any other point of human-machine communication devices such as switches, knobs, and buttons.

NOTE: If the normal product installation will always have a protective ESD cover or cable connected, then the application of electrostatic discharges to open connector pins is not required by this standard.

The discharges shall be applied only to those points and surfaces of the EUT, which are accessible to persons during normal use of the intended functions. All points tested shall be listed in the test report. All other points and surfaces, which the manufacturer does not consider to be normally accessible by an operator when the EUT is in normal use, shall be excluded from the test.

The following exclusions apply:

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

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

- Those points and surfaces of equipment which are no longer accessible after installation or to which the instructions for use prohibit access, e.g. the bottom and-/-or wall-side of an equipment or areas behind fitted connectors.

- 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 that connector.

- Those contacts of connectors or other accessible parts that are ESD sensitive because of functional reasons and are provided with an ESD warning label, e.g. RF 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, band-pass filters may be a solution. Overvoltage protecting diodes have too much stray capacitance to be useful at the frequencies where the EUT is designed to operate.

Contacts within a non-conductive, e.g. plastic, connector and which are accessible to persons during normal use of the intended functions shall be tested by the air-discharge test only. This test has to be carried out by using the rounded tip finger on the ESD generator.

Table 5 - Test point cases to be considered

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	shell	--
5	Insulated	Insulated	cover	--
6	Insulated	Metallic	--	Cover

Discharges should be applied to all equipment and peripherals that form the EUT system. Ungrounded conductive surfaces should be tested for subsequent breakdowns at the desired test levels.

No restriction is placed on the number of pre-selected points to be tested. However, air discharge to the test points which allow direct contact ESD testing is not a requirement. The application of discharges to any point of the equipment that is accessible only during maintenance is not required unless agreed upon by the manufacturer and the user.

8.6 Escalation Strategy

Experience has shown that during ESD testing, occasionally errors occur which can hardly be reproduced. To allow the user a pass/fail judgement the following strategy is suggested:

If an error occurs at a particular test level at a particular test point and the operator expects this to be a random event (note: the operator may declare any error as a "random" event), the operator may repeat the test at this point according to the following procedure.

If more than 1 error occurs in the first 50 discharges, the EUT fails the test at that test point and test level. The error is considered to be caused by an ESD event.

If 1 error occurs in the first 50 discharges and the operator suspects this to be a random event, a second test is run at that test point applying 100 new discharges. If no errors occur in this set of 100 discharges, the EUT passes the test at that test point. If more than one error occurs in this set of 100 discharges, the EUT fails the test. If exactly 1 error occurs in this set of 100 discharges, a third test is performed.

The third test is to apply 200 new discharges at that test point. If no errors occur in this set of 200 discharges, the EUT passes the test at that test point. If 1 or more errors occur in this set of 200 discharges, the EUT fails the test.

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:

- normal performance within limits specified by the manufacturer, requestor or purchaser;
- 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;
- temporary loss of function or degradation of performance, the correction of which requires operator intervention;
- 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 that 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 the 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 condition in which the test was performed, for example a 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 operation conditions, which are required to achieve compliance.

Annex A
(Normative)

Calibration of the Current Measurement System and Measurement of the Discharge Current

A.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 DC.

NOTE: 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 would be taken, parasitic inductance will become more severe.

A.2 Current target specification – insertion loss

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:

+/- 0,3 dB, up to 1 GHz

+/- 1 dB, 1 to 4 GHz.

The variation of the insertion loss of the target alone may not exceed:

+/- 0,3 dB, up to 1 GHz

+/- 1 dB, 1 to 4 GHz.

NOTES

1. If the variation limits of the insertion loss are exceeded, then by means of complex FFT and inverse-FFT, this response can be compensated for. However, this is NOT recommended.

2. Different calibration time intervals can be used for the DC transfer impedance and the more involved insertion loss measurements. If a repeated DC 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.

A.2.1 Target adapter line

The target adapter line shown in figure A 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 impedance calculated from the diameter ratio d to D (see figure A 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 has to be calculated using the dielectric constant of the material that fills the conical adapter line (typically air). The target adapter line shall maintain

50 Ω ± 2% within a 4 GHz bandwidth. The reflection coefficient 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. The insertion loss of the two target adapter lines placed face to face shall be less than 0,3 dB up to 4 GHz.

NOTE: As the inner and outer diameters of the ESD target can be chosen freely (only an example of an ESD target is given), instead of a conical adapter an Aphrodite Precision Connector e.g. APC-7 or similar type can be used.

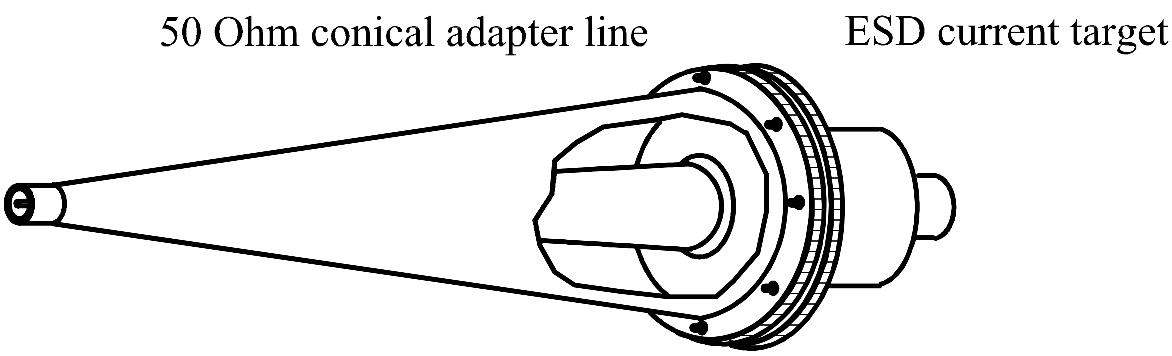


Figure A.1 - Target adapter line attached to current target.

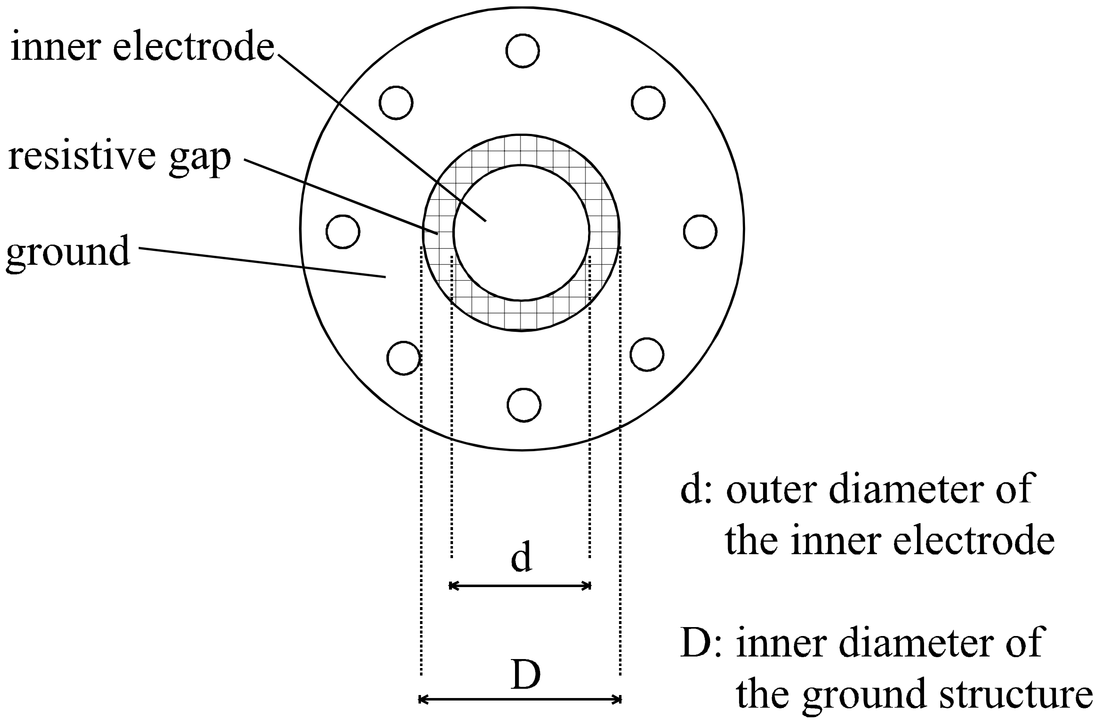
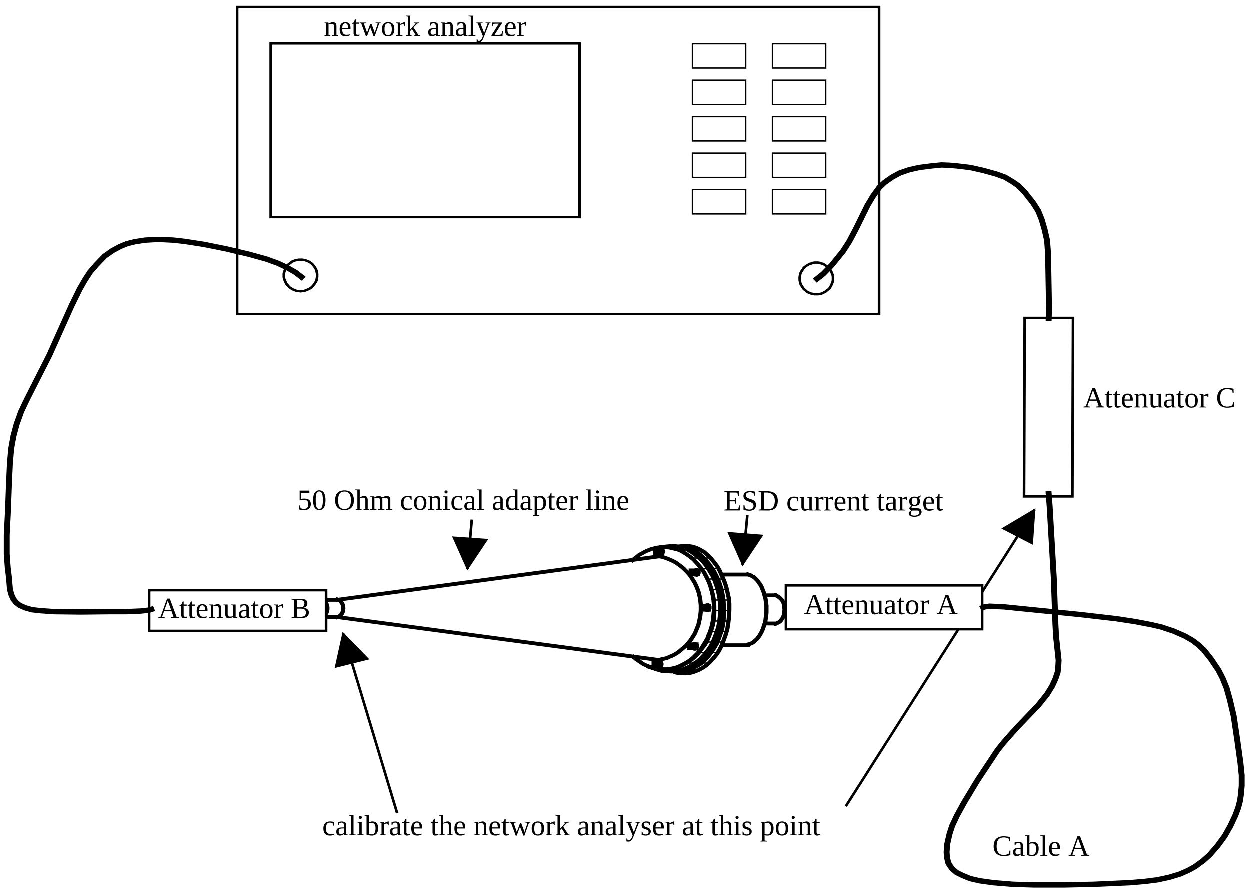


Figure A.2 - Front side of a current target

A.2.2 Determining the insertion loss of a current target-attenuator-cable chain

The insertion loss of the chain is determined by comparing a through connection to the chain. The preferred measurement equipment is a network analyser. A spectrum analyser with tracking generator or other systems to measure magnitude insertion loss may also be used.

To avoid reflections between the moderately matched signal sources and the highly reflecting target it may be necessary to insert well-matched attenuators between the signal source and the target. Typically a 20 dB attenuator on each side is sufficient. It is also important to avoid coax adapters between the attenuator and the target or the target adapter line as they may introduce reflections. By changing the cable lengths between the measurement system and the target it can be determined if reflections are sufficiently suppressed. Those reflections will show up as periodic undulations on the insertion loss versus frequency curve.



The ESD current target, Attenuator A and cable A are the target-attenuator-cable chain which is calibrated using this setup. Attenuator B and C may not be needed.

Figure A.3 - Network analyser measurement of the insertion loss of a current target-attenuator-cable chain.

The measurement procedure for the insertion loss is:

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

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

- Connect a target-adapter line to the target-attenuator-cable chain and insert it as shown in figure A 3.

- Measure the insertion loss

The variation of the insertion loss of the target-attenuator-cable chain shall be:

+/- 0,3 dB, between DC and 1 GHz, see note.

+/- 1 dB, between 1 and 4 GHz.

NOTES

1. Instead of DC the lowest frequency available with the network analyser shall be used, The DC characteristics are measured separately.

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

A.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 $Z_{sys.}$

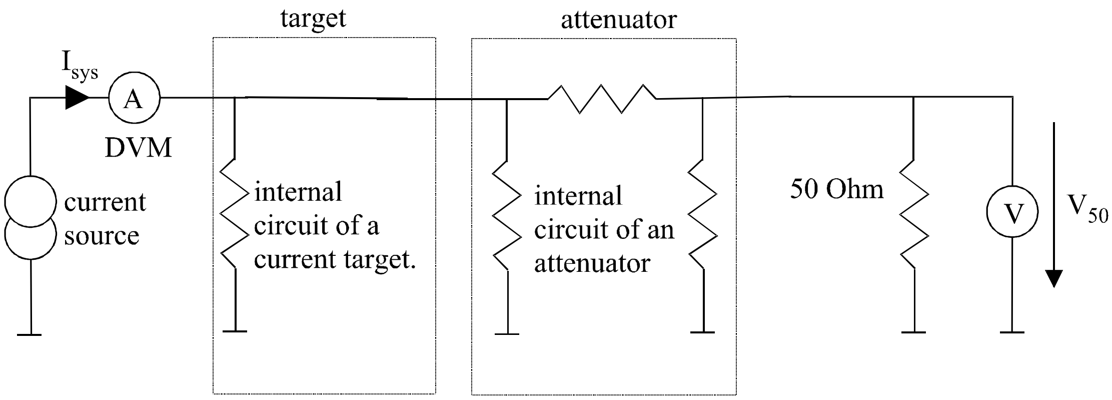


Figure A.4 - Circuit diagram to determine the low frequency system transfer impedance. The internal circuit of the target shown is just an example. Other internal circuits are possible.

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. The current needs to be known within ± 1%. Larger current may be used if they do not thermally stress the target beyond its specifications.

- Measuring the voltage V_{50} across the precision 50 Ω load.

- Calculate the transfer impedance by:

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

NOTE: 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 0,5 % of each other.

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

A.4 Calibration of ESD generator

Correlation of the results of an ESD evaluation is extremely important. This is particularly so 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 defined time periods in accordance with a recognised quality assurance system.

The ESD generators shall meet the specifications of clause 6.2 at any specified repetition rate used for compliance testing.

A.4.1 Test equipment required for ESD generator calibration

The following equipment is required for calibrating ESD generators:

- Oscilloscope with at least 2 GHz analogue bandwidth
- Coaxial current target
- High-voltage meter capable of measuring voltages of at least 15 kV with 5% or better accuracy. It may be necessary to use an electrostatic voltmeter to avoid loading the output voltage.
- Reference plane of dimensions at least 1,2 m by 1,2 m with the coaxial current target mounted in its centre.
- Attenuator(s) as needed

A.4.2 Procedure for contact mode generator calibration

The current target shall be mounted at the centre of the vertical calibration plane of at least 1,2 by 1,2 m. The connection for the ESD generator return current cable (ground strap) to the calibration plane shall be made directly below the target at a distance of 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. The following parameters will be measured or obtained from measured values:

I_p The peak value of the discharge current [A].
I_{30} The value of the current 30 ns after the current has reached 0,1 times I_p [A].
I_{60} The value of the current 60 ns after the current has reached 0,1 times I_p [A].
dt Time step (time interval between two samples or 1/sampling_rate) [s]
D_p Largest value of the current derivative (its largest positive value) [A/ns].
The derivative D is calculated from the current I by: Max Value of all [D(n) = (I(n) - I(n-1)) / dt] values.
D_n The smallest value of the current derivative (its largest negative value) [A/ns].
The derivative D is calculated from the current I by: min value of all [D(n) = (I(n) - I(n-1)) / dt] values.
The absolute value is taken to avoid the negative sign.
τ_r The rise time of the current [ns].

Average values of parameters:

A<$\mathbf{X}_x$> Indicates the average value of the parameter $\mathbf{X}_x$. For example, AI_p signifies the average of the peak current values.

Table A.1 - Contact discharge calibration procedure

Step	Explanation
Discharge the ESD generator at a given voltage 10 times, store each result.	Multiple measurements are done as the acceptance criteria are given for parameters obtained on the average of 10 discharges. This is done because there will be some discharge-to-discharge variations.
Measure I_p, I_{30}, I_{60}, D_p, D_n, τ_r on each waveform.	The parameters have to be checked at each test level
Calculate the averages AI_p, AI_{30}, AI_{60}, AD_p, AD_n, $A\tau_r$ of the measured I_p, I_{30}, I_{60}, D_p, D_n, τ_r values	Average is taken on the parameters, not by averaging the waveforms. This way any jitter on the trigger will not influence the averaging.
Current at 30 ns Check if AI_{30} is 2 A/kV ± 30 %	Again, compliance of the ESD generator is verified on the average of the parameter.
Current at 60 ns Check if AI_{60} is 1 A/kV ± 30 %	
Peak current Check if AI_P is 3,75 A/kV ± 10 %	
Rise time Check if $A\tau_r$ is within 0,7 - 1 ns	By calculating the rise time distribution, the repeatability is shown
Positive current derivative: Check if the current derivative (≥ 2 GHz bandwidth) is 4,2 [A / (ns * kV)] ± 30 %	The positive current derivative limit together with the limit on the ratio of the positive to the negative current derivative have been set to enforce smooth waveforms.
Ratio of positive to negative derivative: Check if the ratio of AD_p to AD_n is larger than 3:1	This tests the ratio of the positive to the negative current derivative. The ratio is taken on the averages obtained above.

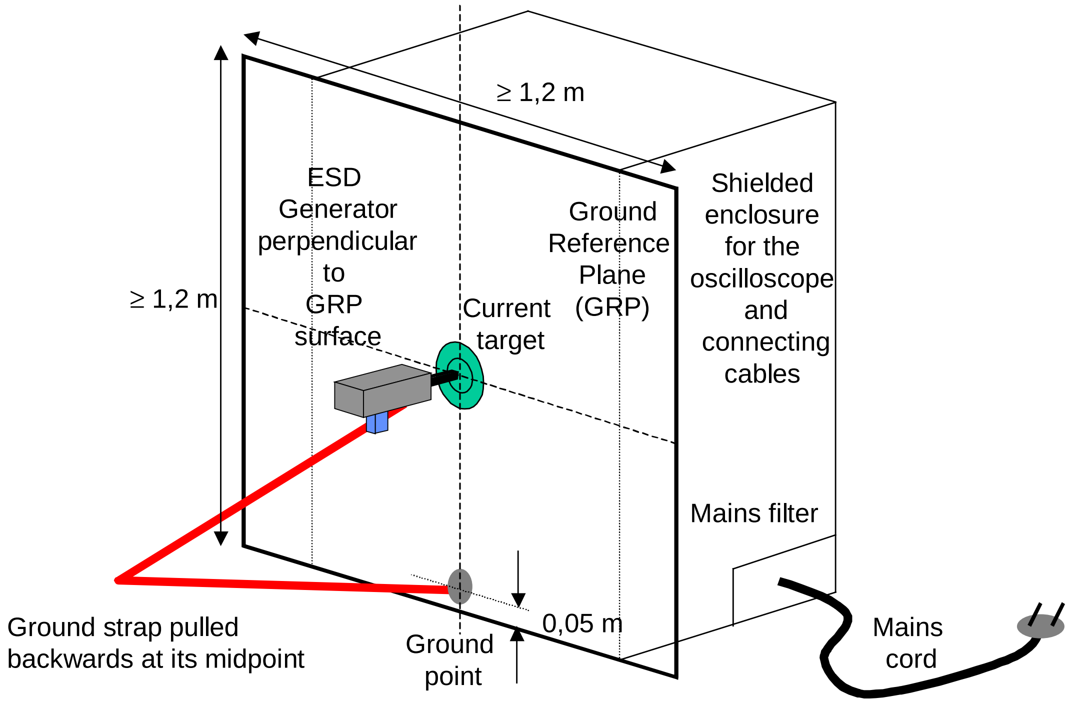


Figure A.5 - Typical arrangement for calibration of ESD generator performance

The shielded enclosure, with a vertical ground reference plane of at least 1,2 x 1,2 m in which the target is mounted, to shield the oscilloscope used may not be necessary if it can be proven by measurement that indirect coupling paths onto the measurement system will not influence the calibration results. When the oscilloscope is set to a ≤10 % trigger level, compared to the resulting peak voltage from the first peak current and the ESD generator is discharged to the outer ring of the target (instead of to the inner ring) and no triggering of the oscilloscope results, then the calibration system can be declared sufficient immune and no shielded enclosure is needed.

Annex B
(Informative)

Standard Target Descriptions

The following drawings give a method or design for a target which meets the requirements of Annex A. With all figures in this annex, the dimensions are given in mm. This target is designed to give a flat insertion loss if 1 m of RG 400 cable is used. It is suggested to connect a 6 dB or larger attenuator directly to the target's output port to avoid multiple reflections. It is not required that the target be made as shown in this Annex.

Central brass-part approx. 1:1

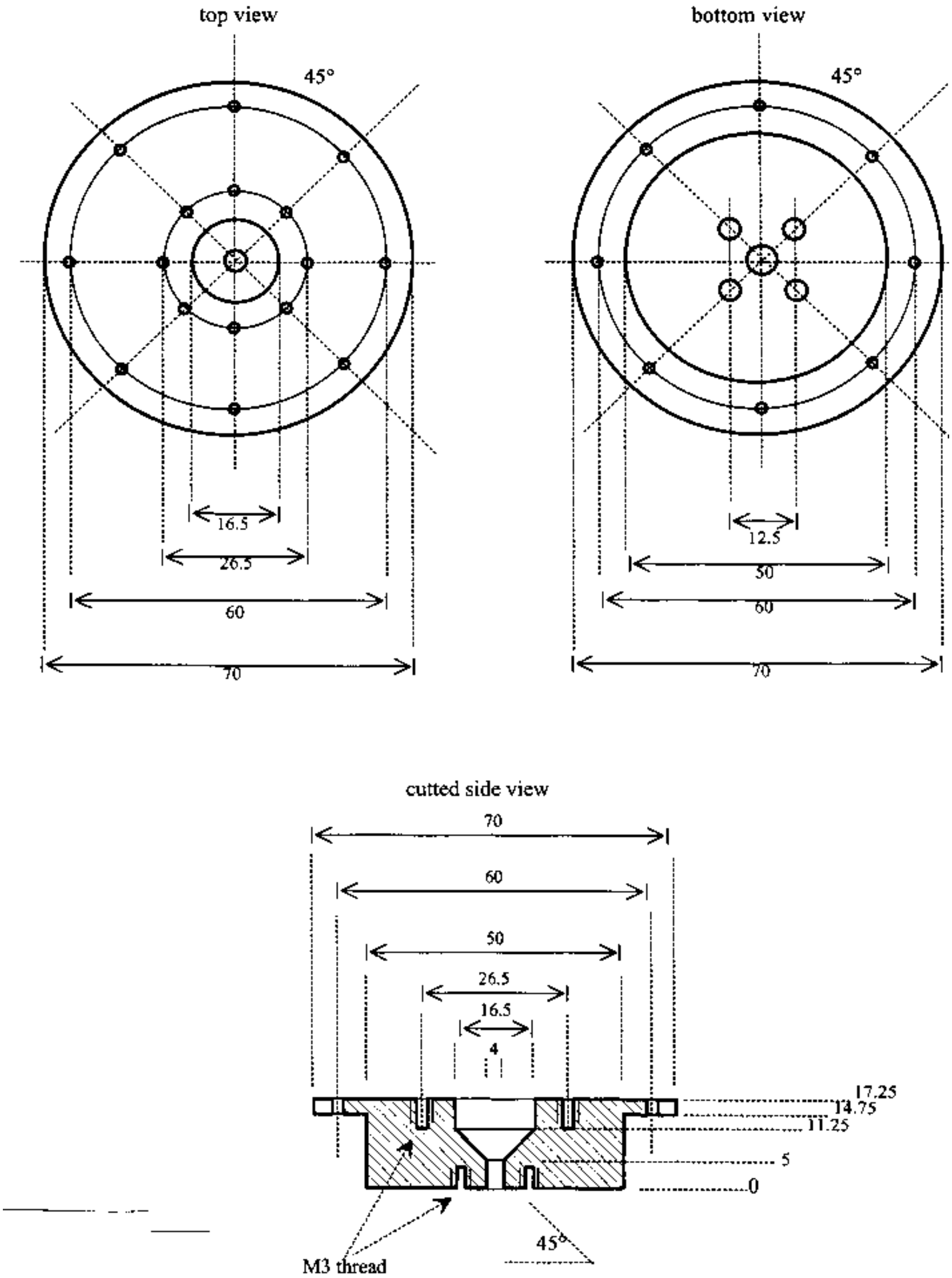
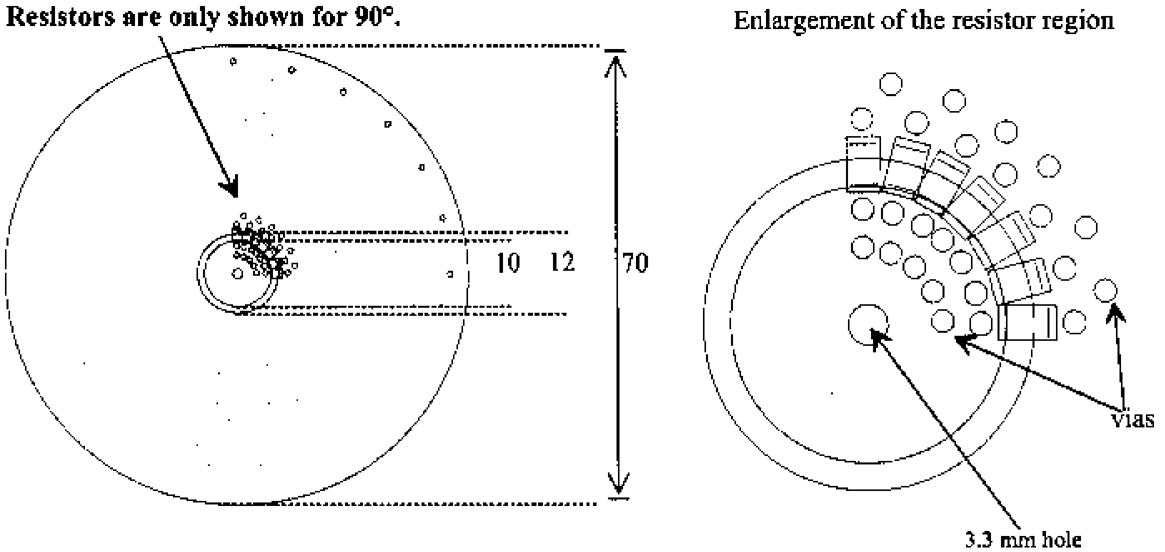


Figure B.1 - Mechanical drawing of a coaxial target, part 1/5

Printed circuit board



Resistorsize: 0805
Value 51 Ohm
Placement: touching, exactly symmetric (use a template)
Material: 0.5 mm FR-4, gold plated
Vias: two rings of vias on each side of the resistors plus one ring close to the outer edge of the pcb.
Approximately 25 resistors are needed.

Figure B.2 - Mechanical drawing of a coaxial target, part 2/5

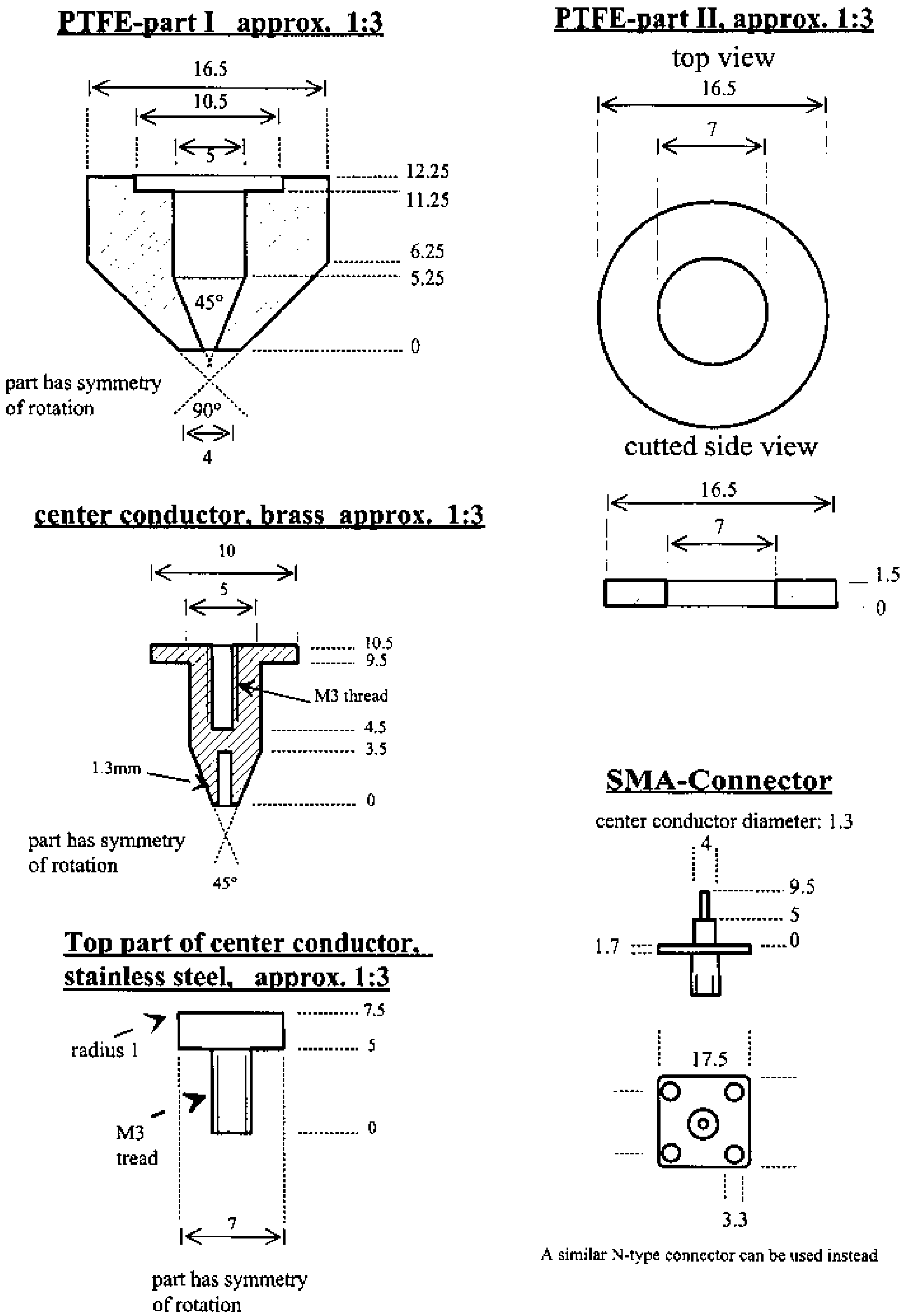


Figure B.3 - Mechanical drawing of a coaxial target, part 3/5

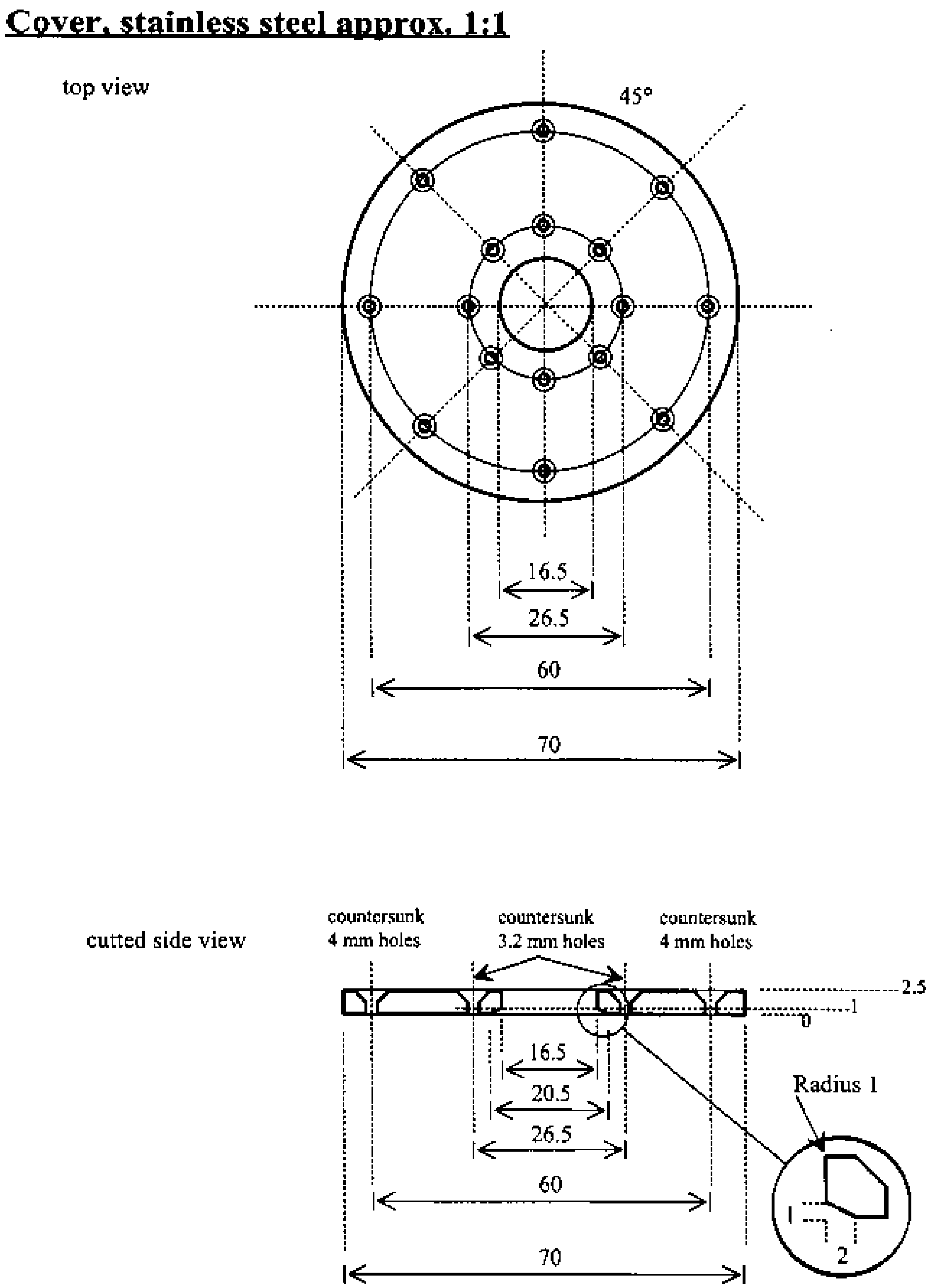


Figure B.4 - Mechanical drawing of a coaxial target, part 4/5

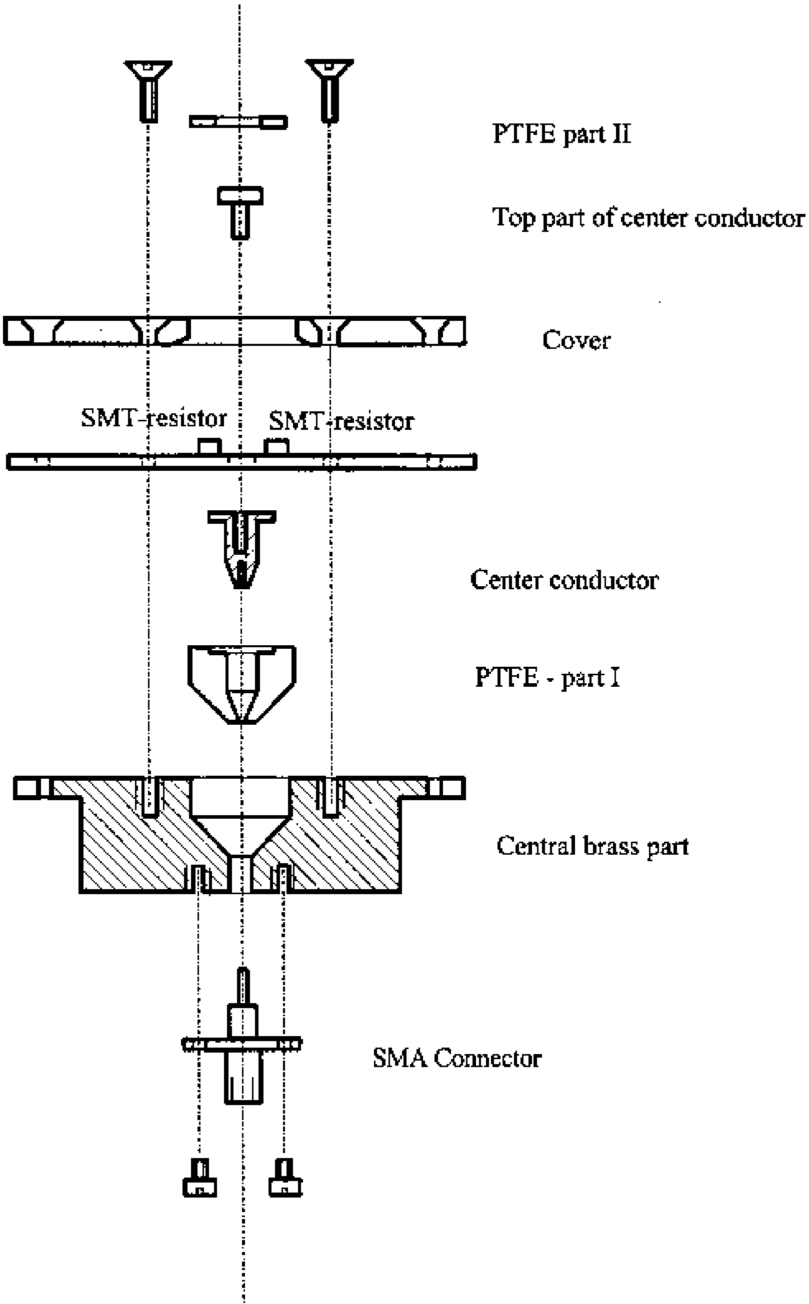


Figure B.5 - Mechanical drawing of a coaxial target, part 5/5

Annex C
(Informative)

Test method guidance - Air or contact discharge

C.1 Test method selection

The particular test method (air or contact) selected as appropriate for EUT evaluation should be determined by first establishing an intended result for the information that will be gained from the ESD test. The following clauses provide an overview of the two approaches, in conjunction with the advantages and disadvantages of each approach.

C.2 Air discharge

The air discharge method virtually replicates ESD as it would occur in the actual environment. In effect, this means the following;

a) The discharge waveforms are allowed (and expected) to vary significantly from discharge to discharge.

b) The discharge current delivered to the EUT will vary from discharge to discharge.

c) The distance of the air gap at the time of breakdown will change depending on the characteristics of the EUT surfaces that, in turn, may alter the actual voltage at which the ESD occurs to the EUT.

C.2.1 Air discharge advantages

The advantage of the air discharge method is that EUT responses will be caused by phenomena that are similar to actual ESD events. This means that for a given ESD test voltage, one ESD discharge may cause an EUT response, while another discharge may not. When the EUT does respond, that response may be different from discharge to discharge. As a result, the test provides an estimate of the performance of the EUT in its actual operating environment. Another benefit is that any insulating surfaces or air gaps in the EUT that prevent ESD can be evaluated for breakdown voltage. Finally, air discharge simulates the non-linear relationship between amplitudes of ESD voltage and current found in natural ESD.

C.2.2 Air discharge disadvantages

The major disadvantage to the air discharge ESD method is that, in practice, performance of the method may result in a tedious test series. The air discharge test may require several hours of test time because of the need to apply (possibly) hundreds of ESD discharges to an EUT in order to fully (adequately) evaluate and understand the responses of the EUT and their probabilities of occurrence. Apart from the disadvantage of test time, the EUT may respond inconsistently to the ESD excitations. This produces serious repeatability errors in the test results, requiring further ESD tests to ultimately determine the performance profile of the EUT.

C.3 Contact discharge

The contact discharge method simulates ESD, but it does not replicate all of the characteristics of the actual ESD phenomena. The contact discharge method provides a more repeatable ESD test simulation. In effect this means the following:

a) The discharge waveforms are controlled to not vary significantly from discharge to discharge.

b) The discharge current delivered to the EUT will remain relatively consistent from discharge to discharge.

c) The variability associated with the air gap at the time of discharge will generally be avoided and will not depend on the characteristics of the EUT surfaces, provided that the EUT surfaces are not fully non-conductive in construction.

C.3.1 Contact discharge advantages

The major advantage of the contact discharge method is that the consistency and repeatability of the ESD test waveforms usually result in consistent and repeatable EUT performance. The contact discharge test method is less tedious than the air discharge method since it can be performed in a more automated manner, with the discharges applied to the EUT at a relatively fast discharge repetition rate. In practice, the use of the contact discharge method permits the evaluation of EUT susceptibility to ESD to be made in a manner that significantly conserves test time.

C.3.2 Contact discharge disadvantages

The major disadvantage of the contact discharge method is that it relies on the surface conductivity at the point of test application and thus does not evaluate the breakdown (stand-off) ESD voltage of EUT surfaces or the air gap distances between the ESD source and internal conductive members. Contact discharge testing also does not provide an estimate of EUT response to actual-use ESD voltages, since the random variations in the ESD waveform that exists in nature are not reproduced. Finally, the ESD voltage and current become directly proportional during these tests, whereas the relationship between voltage and current in naturally occurring ESD is non-linear.

C.4 EUT surfaces

The decision on which test method to use may be based partly on whether the surfaces of the EUT are conductive or non-conductive.

C.4.1 Conductive surfaces

Conductive surfaces and coupling planes may be subjected to either the air or contact discharge test methods. However, contact mode is the preferred method for conductive surfaces. Contact mode discharges are required to such surfaces in this standard.

C.4.2 Non-conductive surfaces

For insulating surfaces, the air discharge method (by its inherent nature) is predominantly used. The air discharge method is also useful in determining the breakdown voltages of surfaces that have a conducting substrate (subsurface), with an insulating surface layer. If the contact discharge method is used in this latter situation by penetrating the insulating surface layer, it may result in excess current being applied to the EUT, compared to the current in air discharge, since the arc path impedance will be missing. For fully insulating surfaces, the contact discharge test method may be used, but it will be an indirect test that is performed by applying the contact ESD to a conductive plane that is adjacent to the non-conductive surface under evaluation.

C.4.3 Indirect ESD tests

When performing indirect ESD testing, either the air or contact method may be used, depending on the compatibility of the test method with the goals established for the simulation as discussed in C.2 and C.3. For this standard, only contact mode discharges are used for indirect ESD testing.

Annex D
(Informative)

Test Set-up Guidance

D.1 Guidance

To ensure better reproducibility of the test results, the following considerations should be made. The influence of these measures may be EUT dependent. It is for this reason that this information is not incorporated into the normative part of the standard.

D.2 Cable layout

Cables that are connected to the EUT during the ESD test should be positioned 30 mm above the GRP or HCP to establish a transmission line with characteristic impedance of approximately 150 Ω. This characteristic impedance of the transmission-line will last until twice the propagation delay of the cable over metal plane, typically 3,3 ns/m in free space ($C_0 = 3.10^8$ m/s). Considering the rise time of the discharge wave shape (0,7 – 1 ns rise time with a decay time of about 3 times the rise time results in 4 ns total discharge time) physical lengths of 0,7 m (2 times 0,7. 3,3 ns/m) will be sufficient to satisfy this requirement.

Meeting this cable geometry for all cables connected to the EUT during the test will enhance reproducibility of test results.

D.3 Cable termination

When the geometrical requirements of D2 for the cable layout are met, the cable currents resulting from the initial discharge will be stabilised. However, additional test set-up measures may be needed to stabilise effects from the bulk current that arrives after the initial discharge. These effects may be stabilised by terminating cables dropped from the HCP to the GRP at the point where each cable reaches the GRP. A short circuit to the GRP or termination with a coupling/decoupling network (CDN) according to IEC 61000-4-6, representing a common mode impedance of 150 Ω, may be used for this purpose.

NOTE: The common-mode termination will only affect EUTs that are sensitive to the bulk discharge current rather than the initial discharge current.

In case the CDNs are not used, all cables connected to the EUT could be short-circuited to the GRP from the high-frequency point of view. In this case, the length of all cables should be at least 1,5 m (= sum of cable length on the table plus the table height). For the purpose of common-mode termination CLC-filters should be used rather than LCL-filter types. Although the length of the cable(s) does NOT account for proper characteristic transmission-line impedance at 30 ns (2 times 1,5. 3,3 ns/m = 10 ns), measurements have proven that with table-top equipment this way of termination is the most suitable alternative.

NOTE: When the cables are left open (in common-mode) at the end, reflections, i.e. resonances, will occur on the cables that may affect the EUT adversely. This condition should be avoided.

In case loaded CDNs are used, both with table-top as with floor standing equipment, the length of the cables connected becomes irrelevant as the transmission-line impedance established geometrically will be terminated resistively. Under this common-mode terminated condition, the CDNs can be located close to the EUT.

D.4 ESD generator orientation

As defined in the main part of the document, the ESD generator shall be held perpendicular to the (large) EUT and/or GRP or HCP that is near to the ESD generator as the waveshape characteristics of the ESD generator are specified accordingly during calibration. Putting the ESD generator under a small angle (< 70 degrees, figure D1) to the EUT, HCP and/or GRP at close distance will influence the stray capacitance between the ESD generator and its environment substantially. Accordingly the waveshape and initial peak current will be affected.

D.4.1 Testing small table-top equipment.

The test set-up will be as defined in clause 7.1.1. However, when applying the direct discharge to a small EUT (maximum dimension 0,2 m), the EUT can be put at maximum in 6 orthogonal orientations with respect to the HCP. The EUT shall be positioned at least 0,1 m from the edge of the HCP. To ensure that the ESD generator will deliver the correct discharge current waveshape to the EUT, the ESD generator's discharge electrode has to remain perpendicular to the surface of the HCP under all test conditions.

It is never allowed to put the ESD generator's discharge electrode in parallel to the HCP at close distance and move the EUT towards the tip such that a discharge can take place to the EUT.

For EUT with dimensions over 0,15 m, it will depend on the size of the ESD generator whether it can be held perpendicular to the surface of the EUT. In case the ESD generator cannot be held away from the HCP by at least 0,1 m, the orientation of the ESD generator shall remain perpendicular to the HCP surface during the test.

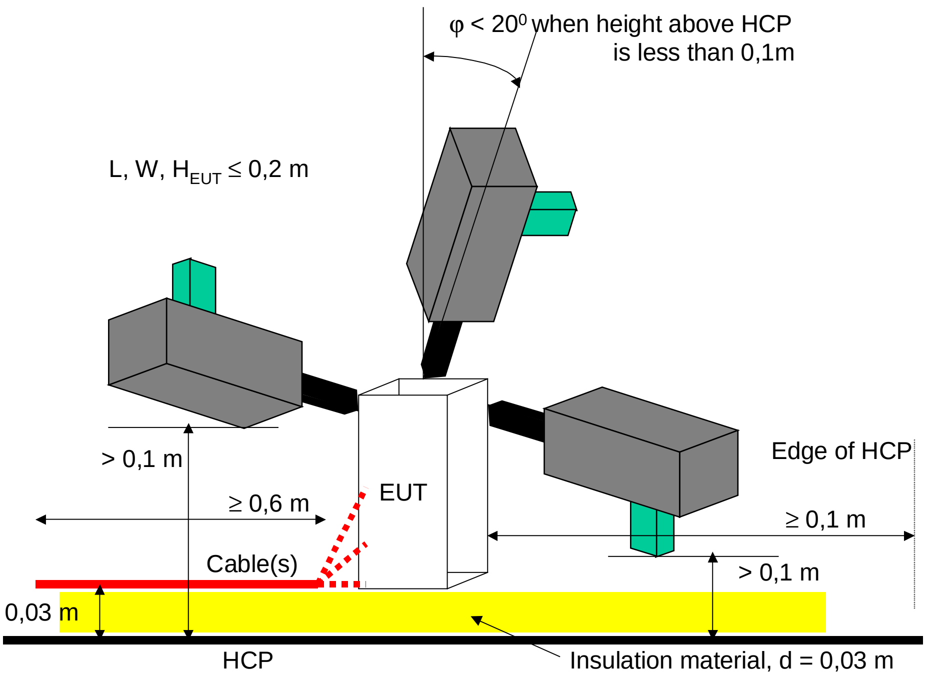


Figure D.1 - ESD generator orientations when testing small products

The accessible point(s) of the EUT can only be touched under certain EUT orientations only. No test should be carried to these accessible points when they cannot be reached without fulfilling the requirements as indicated above.

Annex E
(Informative)

Reference ESD event

This Annex explains properties of the ESD events that has been taken as reference. From this reference the parameters of the discharge waveform have been derived. In addition, parameters that relate to the transient fields are given. These parameters are of informative nature and are intended for ESD generator manufacturers to design equipment that reproduces the reference event as close as possible.

Human/metal ESD: Influence of the arc length

The reference event is a discharge of a human though a small piece of rounded metal into a large ground plane. Every human-metal ESD is an air discharge, i.e., the current is initiated by the spark breakdown of the gap between the metal piece and the ground plane. Without going into details of the physics it is important to understand that the initial part of the discharge current is strongly influenced by the length of the gap in the moment of the discharge. For approaching electrodes, the gap length will vary in spite of constant charge voltage. If the rise time is plotted as a function of the gap length, the tendency as shown in Figure E1 will be observed.

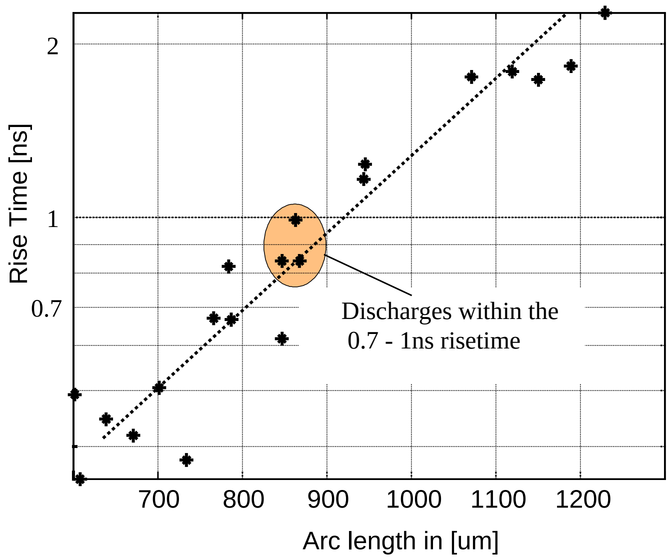


Figure E.1 - Measured Relationship between arc length and rise time for human/metal ESD at 5 kV, sea level.

Typical human-metal discharges at 5 kV having arc lengths of about 0.85 mm will have rise times between 0.7-1ns. Similar relationships have been observed for the peak current and the time derivative of the current. These discharges have been used as reference events. It is well known that the rise time can be much shorter for discharges at lower voltages, or at higher voltages typically under dry conditions and fast approach speeds. It was not the aim to design a standard that protects against every possible ESD event but to provide a moderate level of ESD protection by this standard. Product committees may require further testing if the consequences of an ESD induced failure require obtaining a higher degree of protection.

Discharge waveform

Often a double exponential equation is used to describe the discharge current waveform. This equation is not suitable because the time derivative of the double exponential is non-physical (i.e., its largest value is at time t = 0).

The discharge current for contact mode generators is defined by the following equation:

$$i(t) = \frac{i_1}{k_1} \cdot \frac{\left(\frac{t}{\tau_1}\right)^n}{1+\left(\frac{t}{\tau_1}\right)^n} \cdot \exp\left(\frac{-t}{\tau_2}\right) + \frac{i_2}{k_2} \cdot \frac{\left(\frac{t}{\tau_3}\right)^n}{1+\left(\frac{t}{\tau_3}\right)^n} \cdot \exp\left(\frac{-t}{\tau_4}\right)$$

with the following constants

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

$$k2 = \exp\left(-\frac{\tau_3}{\tau_4}\left(\frac{n\,\tau_4}{\tau_3}\right)^{1/n}\right)$$

and the following parameters with:

Table E.1 - ESD parameters for calculation

Parameter	Value [ns]	Parameter	Value [A]
τ_1	1,3	i_1	21,51
τ_2	1,7	i_2	10,1
τ_3	6,00	n	3,0
τ_4	58,0		
NOTE: n signifies how many times the equation can be differentiated with respect to time.			

Current parameters of the reference waveform are:

- peak current = 3,78 A/kV
- rise time = 863 ps
- total capacitance = 154 pF
- peak positive derivative = 4,26 A/(ns kV)
- peak negative derivative = -1,1 A/(ns kV)

The simulated waveform and measurements are shown in figure E2.

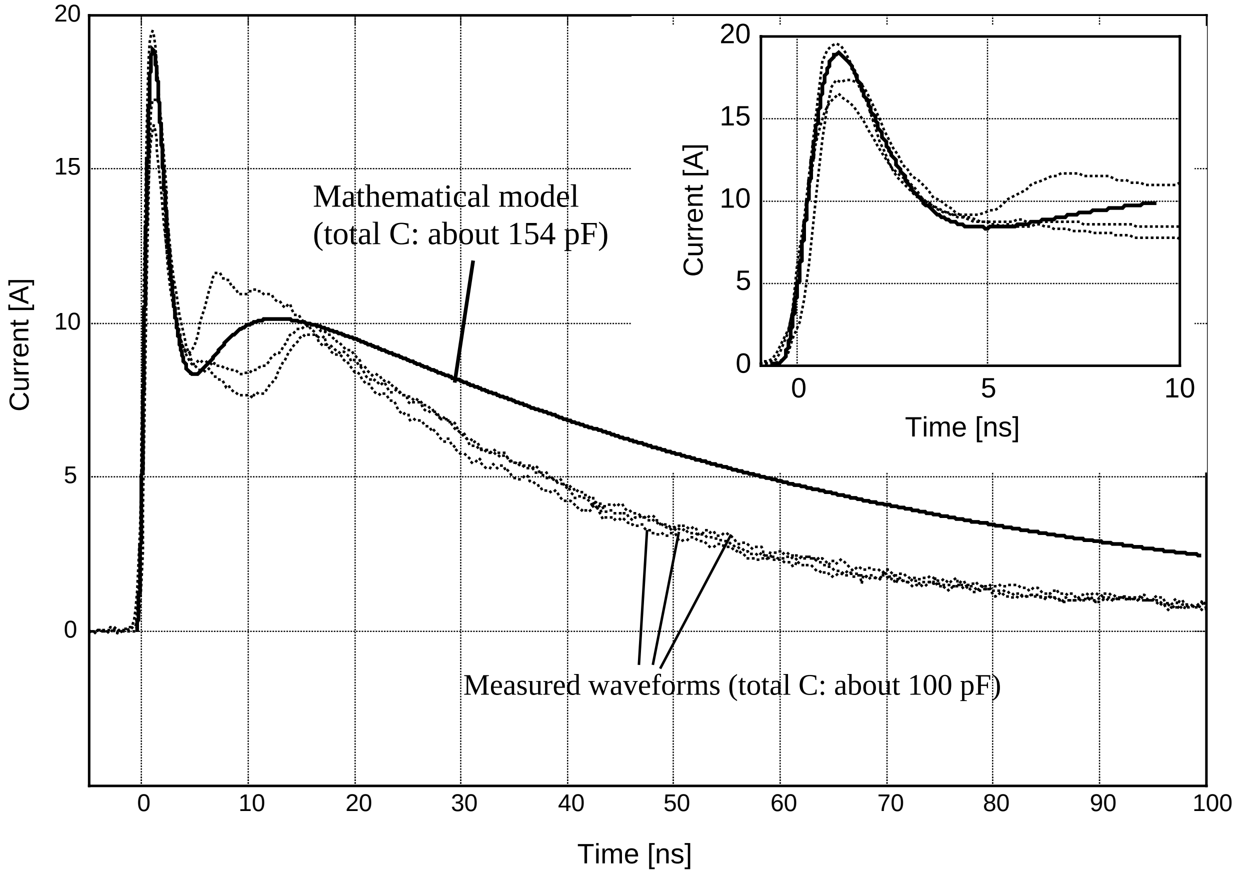


Figure E.2 - Discharge current as simulated by the reference waveform equation compared to measured human-metal ESD at 5 kV at an arc length of approximately 0,7-1ns mm.

NOTE: The difference between the mesured and the simulated waveform at the current tail is caused by the capacitance: The total capacitance of the human who was discharged to obtain the measured waveforms was approx. 95 pF. The total charge of the simulated waveform is equivalent to a capacitance of 154 pF.

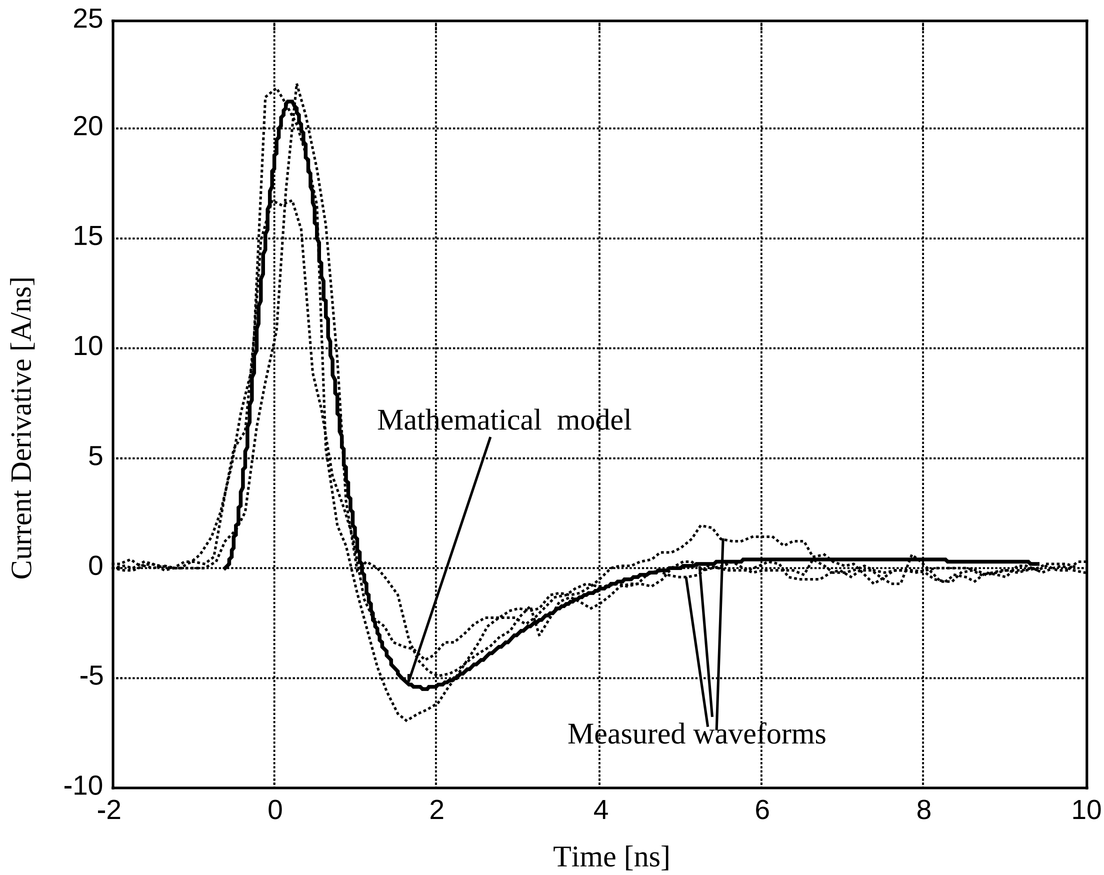


Figure E.3 - Current derivative of the mathematical waveform model and measured human-metal ESD at 5 kV and arc lengths around 850 um.

Transient fields of human/metal ESD

To provide ESD manufacturers a guideline on how strong the transient fields should be, transient fields from human ESD at similar parameters as the reference current waveform are provided. To obtain the data, broadband field sensors have been placed on the vertical reference plane at a distance of 0,4 m from the discharge point, i.e. target position. The fields of human/metal ESD were measured at arc lengths similar to those of the reference waveform.

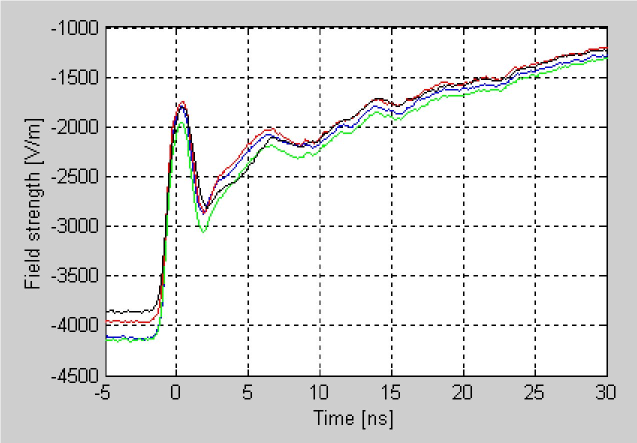


Figure E.4 - Electric field of a real human, holding metal, charged at 5 kV measured at 0,4 m distance and an arc length of about 0.85 mm. Note that the field will approach zero V/m in the following nanoseconds.

The corresponding magnetic field is shown in figure E.5.

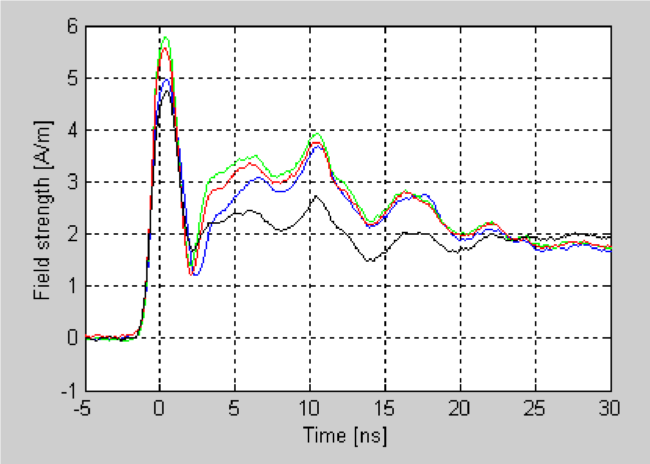


Figure E.5 - Magnetic field of a real human, holding metal, charged at 5 kV, measured at 0,4 m distance and an arc length of approx. 0,85 mm.

The magnetic field waveform follows somewhat the current waveform. A possible problem in field waveforms from ESD generators is ringing. Field values from the ESD generators may be far less or greater than the human/metal field waveforms. This may depend on the angle with which the ESD generator and the ground strap are oriented to the field sensor (for ESD generators that do not exhibit symmetry of revolution). Effects of that nature should be avoided by the design of the ESD generators.

Voltage induced in a loop

If a loop is placed on the ground plane the magnetic field will induce a voltage in the loop. The discharge current and all the currents that flow within the ESD generator and the ground strap cause the magnetic field. The voltage induced in a loop is a simple and effective method to characterize transient fields of an ESD generator without directly measuring the transient field. The induced voltage caused by the ESD generator can be compared to the voltages induced by the reference ESD event as they are shown here.

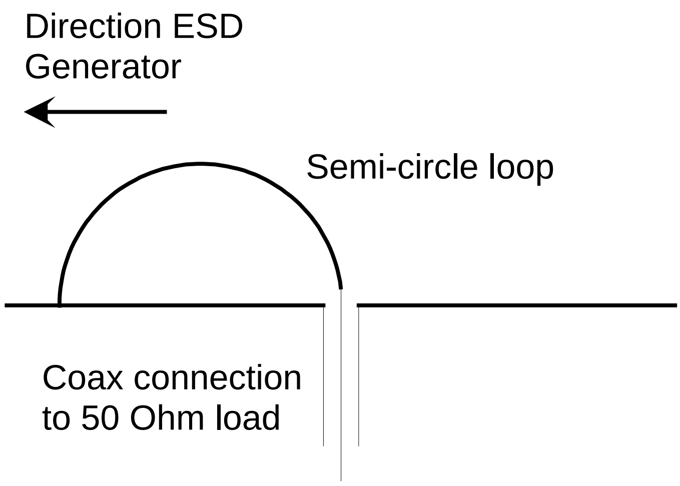


Figure E.6 – Semi circle loop placed on a ground plane. The wire diameter is 0.7 mm, the loop diameter is 28 mm. The loop is placed at a distance of 0.1 or 0.4 m from the ESD generator.

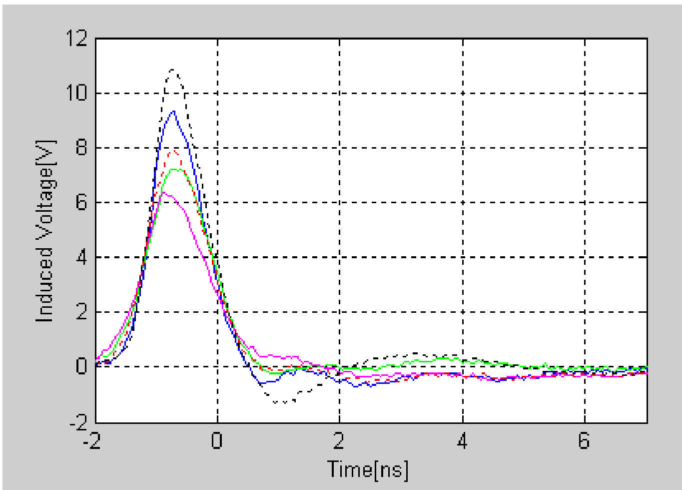


Figure E.7 - Voltage induced for human/metal ESDs that are close to the reference event parameters (5 kV, about 0.85 mm arc length) in a semi-loop of 28 mm diameter at a distance of 0.1 m from the discharge point. The loop is loaded with 50 Ohm.

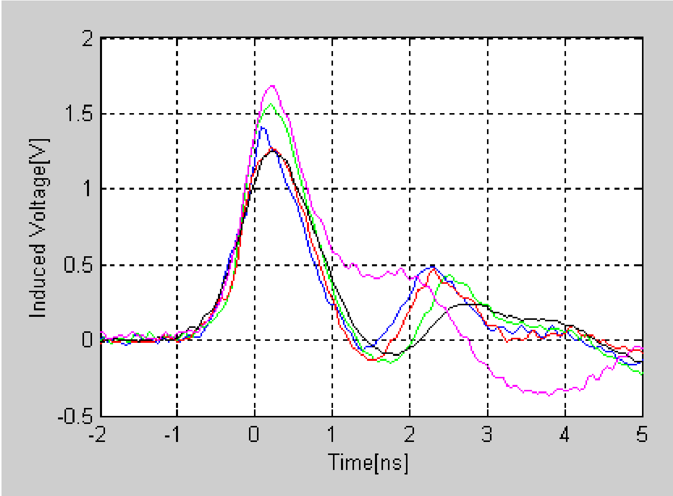


Figure E.8 - Voltage induced for human/metal ESDs that are close to the reference event (5 kV, about 0.85 mm arc length) parameters in a semi-loop of 28 mm diameter at a distance of 0.4 m from the discharge point. The loop is loaded with 50 Ohm.

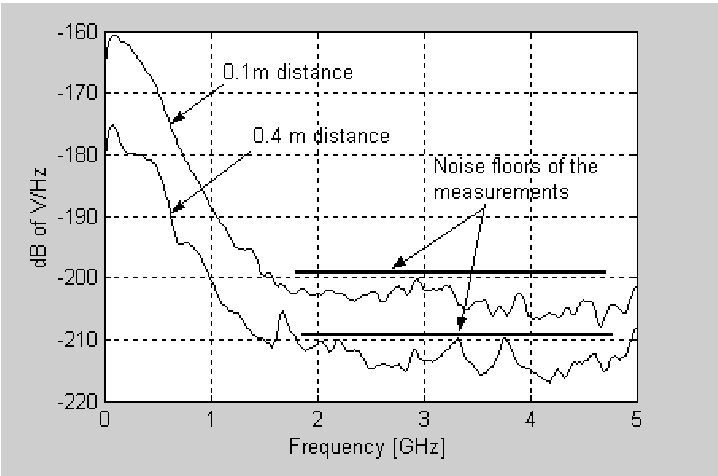


Figure E.9 - Spectral density of voltages induced by human/metal ESDs that are close to the reference event parameters (5 kV, about 0.85 mm arc length) in a semi-loop of 28 mm diameter at a distance of 0.1 m and 0.4 m from the discharge point. The loop is loaded with 50 Ω. Note that the spectral density decreases rapidly to be below the noise floor of the measurement system for frequencies above 2 GHz. The measurement was done using about 5 GHz bandwidth at 20 GS/sec.

Annex F
(Informative)

Effect of tolerances to the ESD characteristics

F.1 Correction of the oscilloscope's frequency response

When the analogue bandwidth of the oscilloscope is chosen to be ≥ 2 GHz, no corrections on the waveshape are required.

F.2 Uncertainty estimation during calibration

None of the ESD discharges generated by an ESD simulation will be completely identical in shape and amplitude. This will depend on previous events, temperature in the relay, hand position, angle of the ESD generator towards the target plane, position of the ground strap, etc. As such, the calibration data of the ESD generator shall be taken from individual discharges only.

After taking 10 individual discharges from the ESD generator, the statistical data characteristics from the ESD generator can be drawn.

Care should also be taken with the interpretation of measured results as the resolution of the measurement system, i.e. calibration system, is no more to 6 or 8 bits = 64 or 256 discrete levels over the full range of the A/D-converter. When typically 80% of the full range is used, the absolute reading may have a tolerance of 2 to 4 %.

Due to the sample rate, only a limited number of samples is taken from an individual discharge wave shape. When the discharge signal is taken with 10 Gs/s only 7 to 10 samples are taken at the rising edge of the discharge. Sampling will take place unsynchronised with the ESD event such that samples may be taken at the ultimate peak level (best case) or on each side of the peak (worst-case). No interpolation algorithm like (sin (x))/x or Cspline shall be used as this will result in additional overshoot as mentioned above.

As each obtained amplitude sample has a window of ± ½ LSB (Least Significant Bit), together with some jitter (≈ 10 ps) on the sampling clock, conclusions regarding the discharge current derivative have to be drawn with care.

F.2.1 Calibration uncertainty and test result uncertainty

Calibration uncertainty characterises the confidence in quantities measured during the calibration of an ESD generator, expressed for example as, "peak current 7,48 A".

Test result uncertainty characterises the confidence in a test result expressed for example, as "error threshold 2,7 kV". Calibration uncertainty is typically part of the test result uncertainty.

Driving force for the new edition of this standard was the large variation seen in ESD-test results. The committee's effort was focused on reducing these variations. In doing so, parameters have been identified for which it either could be proven that they contribute to these errors or for which at least a substantial set of experimental data or test results pointed at their influence on test results.

The committee does not attempt to quantify the calibration or test result uncertainty. The uncertainties are influenced by the implementation of the calibration or test at each test laboratory. Additionally, it is not possible with present knowledge to calculate test result uncertainty in a rigorous mathematical fashion due to possible dependencies on the EUT tested.

Instead lists of contribution to the uncertainties are given and the users are encouraged to minimise them.

F.2.1.1 Parameters to the ESD generator calibration uncertainty

Table F.1 - Parameters that affect the measurement uncertainty with ESD calibration

Parameters	Influence on			
	I_p	dI_p/dt	τ_r	I_{30}, I_{60}
Voltage	X	X		X
DC transfer impedance of the target-cable attenuator chain	X	X		X
Reflections between the target and the oscilloscope	X			
Frequency response of the target-cable attenuator chain	X	More	X	Little
Frequency response of the oscilloscope	X	More	X	Little
Amplitude uncertainty of the oscilloscope	X	X	Little	X
Discharge to discharge repeatability	X	More	X	Little
Time and Amplitude discretization	X	More	X	Little
Input impedance of the target	X	More	X	Little
Ground strap position and routing				X
Sampling rate and interpolation method	X	More	X	

F.2.1.2 Parameters that influence the test result uncertainty

Table F.2 - Parameters that influence the test result uncertainty

Parameters	**Methods to control them**
ESD generator parameters given as a requirement (e.g., peak current)	Formal ESD generator calibration, informal ESD generator verifications (e.g., before each test series).
ESD generator parameters specified as an aim (e.g., waveform shape, currents on ground straps, transient field magnitude, rotational symmetry)	ESD generator design and selection which approaches the aim as close as possible.
Time dependence of EUT sensitivity	Apply a sufficient number of discharges to uncover susceptible time intervals. Operate EUT and analyse it for errors in such a way that these time intervals can be uncovered.
Coupling between the ground strap and the EUT	Keep the distance as far as possible, at least 0,2 m.
Air pressure, temperature, humidity, speed of approach (Influences air discharge testing)	Keep the ambient conditions within the specified ranges.
EUT set-up	Document set-up, exercising software etc. sufficiently to reproduce the test.
Common mode termination devices	Apply common mode termination devices that suppress oscillations on cables as good as possible.

F.2.2 EUT responses to ESD parameter tolerances

Whether the above given tolerances will have an impact on the EUT is mainly determined by the EUT itself. Three causes of interference can be given:

- Direct coupling with signal lines, considering the corner frequency for the high-pass characteristic of the ESD disturbance with the signal line has been exceeded. In this case, the peak amplitude is of dominant importance.
- Direct coupling with signal lines, considering the corner frequency for the high-pass characteristic of the ESD disturbance with the signal line has **NOT** been exceeded. In this case, the **BOTH** the current derivative and the peak amplitude are of dominant importance.
- Indirect coupling onto signal lines where a low-pass function, either integrated by passive components or by reduced bandwidth of the active electronics involved. In this case it is assumed that the corner frequency of the low-pass is less than the $1/(\pi.\tau_R)$ of the ESD event, then the peak current and the current at 30 and 60 ns become of importance. In this case the current rise time has a negligible effect on the response of the system.

Annex G
(Informative)

Rationale for Air Discharge Generator Calibration

The discharge current characteristics for air mode discharges can vary greatly from discharge to discharge for a number of reasons [19]. Discharging the ESD generator to metal and observing the discharge current may suffice as an ESD generator air discharge calibration. An ESD current target like the one required for contact mode calibration may be used to facilitate this process. Before the spark from the air discharge generator reaches any metal surface, it will break down a dielectric barrier, such as the air or a gap between plastic parts. The surface conditions of such a dielectric barrier, the path shape and length and the dielectric material will influence the time-dependent arc resistance and, thus, the discharge current. This is one reason why an air discharge calibration into a current target will only partially reflect the real application of the ESD generator.

It is possible, nevertheless, to characterise the behaviour of the ESD generator in air discharge calibration. Achieving results that are predictable and repeatable is subject to the same conditions of an air discharge ESD test, as discussed in Clause C.2 of Annex C. One major problem is the approach speed of the charged ESD generator electrode towards the uncharged calibration target. Even with all other critical parameters (i.e., humidity, temperature, barometric pressure and approach speed) held constant, the stochastic nature of the statistical time lag may create large changes in the rise time and peak current [24]. Specifying large tolerances on the measured current, as was done in ANSI C63.16, is objectionable to many people.

In air discharge, the current will always be determined by:

a) The time-dependent arc resistance and
b) The electrical and mechanical design of the ESD generator.

As the breakdown physics are independent of the ESD generator design, there is no need to "calibrate" them. This allows two options on how to handle the time-dependent arc resistance: either choose the discharge parameters (voltage, approach speed, humidity, etc.) and the measurement parameters (time domain, frequency domain, bandwidth, etc.) such that the remaining influence of the arc is so small that it can be neglected (i.e., it approaches an ideal switch) or chose the parameters such that the arc influences the discharge current in a known manner. In both these cases, one is able to investigate the electrical and mechanical design of the ESD generator.

There are many methods for characterising the ESD generator design having limited or at least known influence of the arc. Three methods are discussed below.

The ESD generator can be held against a large ground plane in air discharge mode and its feed point impedance can be measured using e.g., a network analyser [6]. Once the feed point impedance has been obtained, it can be transformed into the time domain to obtain the discharge response. By integration of the discharge response, the step response is obtained. The step response will equal the discharge current at zero ohm arc resistance. As the rise-time approaches zero for an ideally switching arc no useful current rise-time can be obtained this way.

If the discharge voltage is low enough (e.g., 500 V) at fast approach speeds, the arc behaviour approaches that of an ideal switch as seen within a 1.5 GHz bandwidth. If the ESD generator is discharged against the target at such a low voltage, the displayed waveform will be determined by the measurement system (rise-time and somewhat the peak value) and the ESD generator design. Using this method, one would typically discharge the ESD generator at 500 V against the target at fast approach speeds a couple of times and select the waveform which has the fastest rise-time (during this discharge the arc approached an ideal switch the best). The obtained waveform can then be compared against a reference discharge waveform knowing that the displayed rise-time may be totally determined by the measurement system, not the ESD generator design.

Air discharge can be reproduced very well if the voltage, air pressure and the arc length (i.e., the gap distance at the moment of the break down) are kept constant. This can be achieved using a constant air gap while slowly (maybe as slow as 20V/sec) increasing the voltage. The breakdown will occur at a voltage given by the Paschen law, i.e., the current rise-time will be slower than during most air discharges having fast approach speed. To use this method, one would set the gap length to e.g., 0.2 mm and slowly ramp up the voltage. The discharge current could be compared to a reference current, taking into account that the rise-time is determined by the arc and the peak value is somewhat influenced by the arc resistance.

Due to the complexity of air discharge, the IEC SC77B/WG-9 standardisation committee could not find a satisfactory calibration method. Therefore it was decided not to require an air discharge calibration. The operator should be aware that using a fully compliant contact mode generator in the air discharge testing mode can result in a small or very large rate of ESD current change for the same ESD generator electrode charge voltage from discharge to discharge. This is exactly what happens in realistic air discharge ESD events (see Annex C).

Annex H
(Informative)

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