

INTERNATIONAL STANDARD

NORME INTERNATIONALE

BASIC EMC PUBLICATION

PUBLICATION FONDAMENTALE EN CEM

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

**Compatibilité électromagnétique (CEM) –
Partie 4-2: Techniques d'essai et de mesure – Essai d'immunité aux décharges
électrostatiques**



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ELECTROMAGNETIC COMPATIBILITY (EMC) –**Part 4-2: Testing and measurement techniques –
Electrostatic discharge immunity test**

FOREWORD

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

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

This third edition cancels and replaces the second edition published in 2008. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) added a calibration requirement for ESD generators with air discharge tip;
- b) added a normative annex for test setups for particular kind of equipment (see Annex I);

- c) added an informative annex for wearable devices (see Annex J);
- d) added an informative annex on how to select test points and give guidance on how to specify the number of pulses for direct contact discharges (see Annex E);
- e) moved Clause 9 into a new informative annex (see Annex K);
- f) improved current calibration procedure;
- g) improved measurement uncertainty considerations with examples of uncertainty budgets;
- h) moved post-installation tests into a new informative Annex G since they cannot be performed in a controlled environment.

The text of this International Standard is based on the following documents:

Draft	Report on voting
77B/896/FDIS	77B/897/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 61000 series, published under the general title *Electromagnetic compatibility (EMC)*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

INTRODUCTION

IEC 61000-4 is a part of the IEC 61000 series, according to the following structure:

Part 1: General

General consideration (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: IEC 61000-6-1).

This part of IEC 61000 is an International Standard which gives immunity requirements and test procedures related to electrostatic discharge.

ELECTROMAGNETIC COMPATIBILITY (EMC) –

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

1 Scope

This part of IEC 61000 relates to the immunity requirements and test methods for electrical and electronic equipment subjected to static electricity discharges from operators directly and from personnel to adjacent objects. It additionally specifies ranges of test levels which relate to different environmental, and installation conditions and establishes test procedures.

The objective of this document 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 which can occur from personnel to objects near the equipment.

This document specifies:

- ideal waveform of the discharge current;
- range of test levels;
- test equipment;
- test setup;
- test procedure;
- calibration procedure;
- measurement uncertainty.

This document gives specifications for tests performed in laboratories and guidance to post-installation tests.

This document is not intended to specify the tests to be applied to particular apparatus or systems. The main aim is to give a general basic reference to all concerned product committees. The product committees remain responsible for the appropriate choice of the tests and the severity level to be applied to their equipment.

This document excludes tests intended to evaluate the ESD sensitivity of devices during handling and packaging. It is not intended for use in characterizing the performance of ESD protection circuits.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at <https://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp>

3.1.1

accessible

surfaces of the EUT which can be touched by means of the air discharge tip of the ESD generator

[SOURCE: IEC 60050-442:1998, 442-01-15, modified – “part” has been replaced by “surfaces of the EUT” and “standard test finger” has been replaced by “air discharge tip of the ESD generator”.]

3.1.2

air discharge method

method of testing in which the charged tip of the test generator is moved towards the EUT until it touches the EUT

3.1.3

calibration

set of operations which establishes, by reference to standards, the relationship which exists, under specified conditions, between an indication and a result of a measurement

Note 1 to entry: This term is based on the "uncertainty" approach.

Note 2 to entry: The relationship between the indications and the results of measurement can be expressed, in principle, by a calibration diagram.

[SOURCE: IEC 60050-311:2001, 311-01-09]

3.1.4

contact discharge method

method of testing in which the tip of the test generator is kept in contact with the EUT or coupling plane and the discharge is actuated by the discharge switch within the generator

3.1.5

coupling plane

metal sheet or plate, to which discharges are applied to simulate electrostatic discharge to objects adjacent to the EUT

3.1.6

degradation (in performance)

undesired departure in the operational performance of any device, equipment or system from its intended performance

Note 1 to entry: The term "degradation" can apply to temporary or permanent failure.

[SOURCE: IEC 60050-161:1990, 161-01-19]

3.1.7**direct application**

application of the discharge directly to the EUT

3.1.8**electromagnetic compatibility****EMC**

ability of equipment or a system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment

[SOURCE: IEC 60050-161:2018, 161-01-07]

3.1.9**electrostatic discharge****ESD**

transfer of electric charge between bodies of different electric potential in proximity or through direct contact

Note 1 to entry: Literature and teaching generally refer to transfers of charge, although strictly speaking charge carriers (IEV 113-06-25) are transferred.

[SOURCE: IEC 60050-161:2014, 161-01-22]

3.1.10**energy storage capacitor**

capacitor of the ESD generator representing the capacity of a human body charged to the test voltage value

Note 1 to entry: This element can be provided as a discrete component or a distributed capacitance.

3.1.11**holding time**

interval of time within which the decrease of the test voltage due to leakage, prior to the discharge, is not greater than 10 %

3.1.12**immunity (to a disturbance)**

ability of a device, equipment or system to perform without degradation in the presence of an electromagnetic disturbance

[SOURCE: IEC 60050-161:1990, 161-01-20]

3.1.13**indirect application**

application of the discharge to a coupling plane in the vicinity of the EUT to simulate personnel discharge to objects which are adjacent to the EUT

3.1.14**reference ground plane****RGP**

flat conductive surface that is at the same electric potential as reference ground, which is used as a common reference, and which contributes to a reproducible parasitic capacitance with the surroundings of the equipment under test (EUT)

Note 1 to entry: In some regions, the term 'earth' is used in place of 'ground'.

[SOURCE: IEC 60050-161:2014, 161-04-36, modified – Note 1 has been removed.]

3.1.15**rise time**

interval of time between the instants at which the instantaneous value of a pulse first reaches the specified lower and upper limits

Note 1 to entry: Unless otherwise specified, the lower and upper values are fixed at 10 % and 90 % of the pulse magnitude.

[SOURCE: IEC 60050-161:1990, 161-02-05, modified, modified – the domain has been deleted and, in the definition, "value and then a specified upper value" has been deleted and "and upper limits" has been added.]

3.1.16**verification**

set of operations which is used to check the test equipment system (e.g. the test generator and the interconnecting cables) and to gain confidence that the test system is functioning

Note 1 to entry: Details of verification are given in 7.2.2.

Note 2 to entry: The methods used for verification can be different from those used for calibration.

Note 3 to entry: For the purpose of this document this definition is different from the definition given in IEC 311-01-13.

3.2 Abbreviated terms

AD	Air discharge
AE	Auxiliary equipment
CD	Contact discharge
EMC	Electromagnetic compatibility
ESD	Electrostatic discharge
EUT	Equipment under test
FT	Fourier transform
HCP	Horizontal coupling plane
HV	High voltage
IC	Integrated circuit
IFT	Inverse Fourier transform
MU	Measurement uncertainty
PE	Protective earth
RGP	Reference ground plane
VCP	Vertical coupling plane
VNA	Vector network analyzer

4 General

This document relates to equipment, systems, subsystems and peripherals which can be involved in static electricity discharges as a result of environmental and installation conditions, such as low relative humidity, use of low-conductivity (artificial-fibre) carpets, synthetic-fabric garments, etc., which can exist in all locations classified in standards relevant to electrical and electronic equipment. Detailed information is specified in Annex A.

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

Electrostatic discharges are categorized as contact discharges and air discharges. In addition, contact discharges are categorized as direct discharges and indirect discharges. Direct discharges are applied to conductive surfaces while indirect discharges are applied to coupling planes in the vicinity of EUTs.

5 Test levels

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

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

Details concerning the various parameters which can influence the voltage to which the human body can be subjected are given in Clause A.2. Clause A.8 also contains examples of the application of the test levels related to environmental (installation) classes.

For air discharge testing, the test shall be applied at all test levels in Table 1 up to and including the specified test level. For contact and indirect discharge testing, the test shall be applied at the specified test level.

For further information on test level variations and applications between air and contact discharge, refer to Annex A, specifically Clause A.3 through Clause A.7.

Table 1 – Test levels

Level	Test voltage	
	Contact discharge	Air discharge
1	2 kV	2 kV
2	4 kV	4 kV
3	6 kV	8 kV
4	8 kV	15 kV
NOTE Product committees can specify different test levels.		

6 Test equipment

6.1 Overview

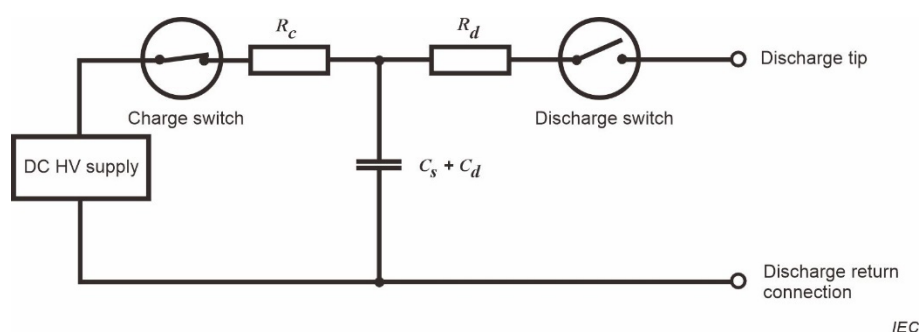
The ESD generator is designed to meet the characteristics in 6.2.2 and shall be calibrated in accordance with the procedure in 6.3 using a current measurement system calibrated in accordance with Annex B.

6.2 ESD generator

6.2.1 General

A simplified circuit diagram of an ESD generator is shown in Figure 1. Although construction details (shape, size, weight, materials, etc.) of the generator are not specified, the following main items are used in the design of an ESD generator:

- charging resistor R_c ;
- energy-storage capacitor C_s ;
- distributed capacitance C_d ;
- discharge resistor R_d ;
- voltage indicator;
- discharge switch;
- charge switch;
- interchangeable discharge tips (see Figure 3 and Figure 4);
- discharge return cable;
- power supply unit.



Components

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

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

R_d has a typical value of 330 Ω .

Figure 1 – Simplified diagram of the ESD generator

The ESD generator shall meet the requirements specified in 6.2.2 and indicated in Figure 2 when evaluated in accordance with the procedures in 6.3. Therefore, neither the diagram in Figure 1, nor the component values are specified in detail.

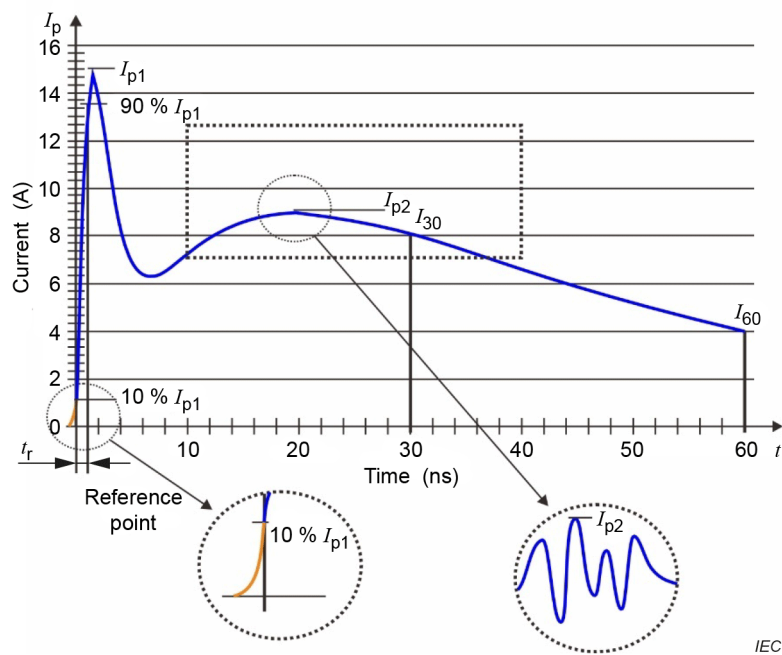


Figure 2 – Ideal contact discharge current waveform at 4 kV

A formula to generate the waveform in Figure 2, $I(t)$, is as follows:

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

where

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

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

and

$\tau_1 = 1,1$ ns; $\tau_2 = 2,0$ ns; $\tau_3 = 12,0$ ns; $\tau_4 = 37,0$ ns;

$I_1 = 16,6$ A (at 4 kV); $I_2 = 9,3$ A (at 4 kV);

$n = 1,8$.

6.2.2 General characteristics

6.2.2.1 Specifications of the ESD generator

The parameters of the ESD generator are specified in Table 2 and Table 3.

Table 2 – General ESD generator parameters

Parameters	Values
Output voltage, contact discharge mode	At least 2 kV to 8 kV, nominal
Output voltage, air discharge mode	At least 2 kV to 15 kV, nominal ^a
Tolerance of output voltage	±5 %
Polarity of output voltage	Positive and negative
Holding time, air discharge mode	≥ 5 s
Discharge mode of operation	Single discharges ^b

The "open-circuit" voltage is measured at the discharge tip of the ESD generator.

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

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

Table 3 – Discharge current waveform parameters

Level		Associated voltage level (Table 2)	First peak current I_{p1} of discharge (±15 %)	Rise time ^a t_r (±25 %)	Second peak current ^b I_{p2} of discharge (-20 %/+40 %)	Current I_{30} at 30 ns (±30 %)	Current I_{60} at 60 ns (±30 %)
CD	AD	kV	A	ns	A	A	A
1	1	2	7,5	0,8	4,5	4,0	2,0
2	2	4	15,0	0,8	9,0	8,0	4,0
3	---	6	22,5	0,8	13,5	12,0	6,0
4	3	8	30,0	0,8	18,0	16,0	8,0
---	4	15	56,3	0,8	33,8	30,0	15,0

The reference point for the time values is the instant when the current first reaches 10 % of the 1st peak of the discharge current.

All current and voltage values are given as absolute values. The respective polarity of the discharge applies to all values.

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

^b This is the maximum current which occurs in the time frame of 10 ns to 40 ns from the reference point.

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

The discharge return cable of the ESD generator shall be at least 2 m long. In cases where a 2 m length of the discharge return cable is insufficient, (e.g. for tall EUTs), a longer cable (e.g. 3 m) may be used. The length of the discharge return cable shall be measured from the ESD generator body to the end of the connecting point. It shall be sufficiently insulated to prevent the flow of the discharge current during the ESD test to personnel or conducting surfaces other than via its termination.

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

6.2.2.2 Characteristics of the contact discharge tip

The contact discharge tip shall be constructed in accordance with Figure 3. The discharge tip with the dimensions in Figure 3 may be covered with insulated coatings, provided the discharge current waveform specifications are met.

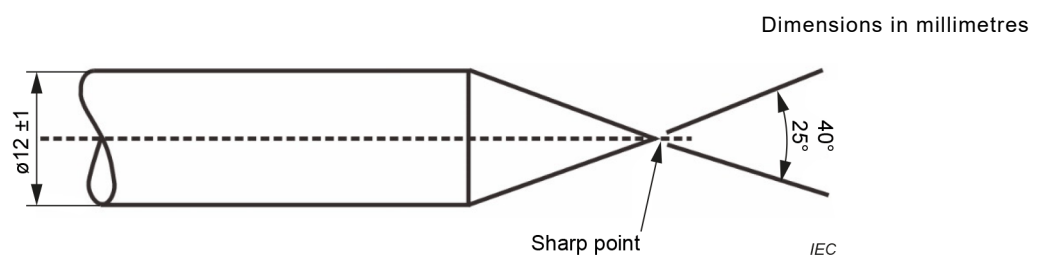


Figure 3 – Contact discharge tip of the ESD generator

6.2.2.3 Characteristics of the air discharge tip

The air discharge tip shall be constructed according to Figure 4. The discharge tip with the dimensions in Figure 4 may be covered with insulated coatings, provided the discharge current waveform specifications are met.

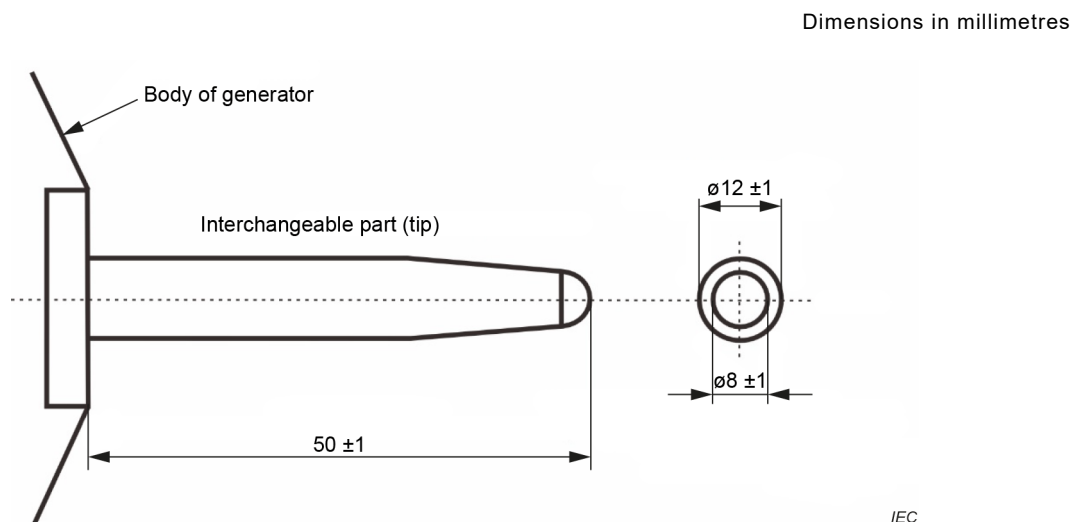


Figure 4 – Air discharge tip of the ESD generator

6.3 Calibration of the characteristics of the ESD generator

6.3.1 General

The ESD generator including the respective discharge tips (air and contact) shall be calibrated to ensure that they meet the specifications given in Table 2 and Table 3. It shall be demonstrated that these specifications are fulfilled using the test equipment specified in 6.3.2 with the test setup described in 6.3.3 and the calibration method specified in 6.3.4.

The calibration of the ESD generator shall be performed within the range of the climatic conditions as specified in 8.2.1. The ESD generator shall be powered in the same way as it is used for testing, i.e. two calibrations are applicable for ESD generators that may be powered by either mains or battery when both supplies are used for testing.

ESD generators shall be calibrated at test levels 1 through 4 as specified in Table 1 with both polarities.

For contact discharge, the complete calibration procedure as specified in 6.3.4 shall be performed at all test levels stated above with the contact discharge tip mounted.

For air discharge, if the contact and air discharge tips consist of a conductor with no additional active or passive electronic components, the calibration can be limited to the measurement of the open circuit voltage at the air discharge tip at the maximum test voltage used for air discharge. Otherwise, it is sufficient to additionally perform the air discharge calibration according to 6.3.4.3 at one of the levels specified in Table 1 with the ESD generator used in contact discharge mode but with the air discharge tip mounted.

NOTE 1 Some generators cannot be calibrated at 15 kV air discharge. If air discharge calibration cannot be performed at 15 kV, then the next lower air discharge voltage level specified in Table 3 can be used for calibration.

NOTE 2 The process in 6.3 is specified for calibration purposes. A procedure for verification of the generator before testing is specified in 7.2.2.

NOTE 3 Information of the components used within the discharge tips can be obtained from the manufacturer.

NOTE 4 Comparable calibration results of an ESD evaluation is extremely important. This is particularly the case when tests are 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. It is useful for the ESD generator to be calibrated periodically.

6.3.2 Equipment required for ESD generator calibration

The following equipment is required for calibrating ESD generators:

- high-voltage meter capable of measuring voltages of at least 15 kV. For open circuit output voltage calibration, a resistive high voltage divider connected to a voltmeter shall be used. The overall accuracy of the high voltage divider including voltmeter shall be ± 1 % of reading. The minimum input resistance of the high voltage divider depends on the model of ESD generator and shall be specified by the manufacturer of the generator. Alternatively, an electrostatic voltmeter with the same accuracy can be used.

NOTE 1 A typical value for high voltage divider input resistance is in the range of 10 G Ω to 100 G Ω

NOTE 2 Protective measures can be taken so that no corona discharges occur within the measuring setup, as they would influence the measuring result.

- oscilloscope with a bandwidth of ≥ 2 GHz and a sampling rate of ≥ 8 GS/s;
- coaxial current target-attenuator-cable chain with the coaxial current target calibrated in accordance with Annex B.

NOTE 3 An example of a suitable target is specified in Annex C.

- attenuator(s) with sufficient power capability as necessary.

6.3.3 Setup for ESD generator current waveform calibration

The coaxial current target shall be mounted in a vertical calibration plane as shown in Figure 5. The RGP with dimensions as specified in Figure 5 and which encompasses the projection of the pulled back discharge return cable onto the RGP shall be electrically connected to the vertical calibration plane.

The generator shall be installed on a tripod or on an equivalent non-conductive support. The discharge tip shall be perpendicular to the vertical calibration plane.

The ESD generator shall make contact with the centre conductor of the coaxial current target to ensure electrical contact.

The connection for the discharge return cable shall be made as shown in Figure 5. The discharge return cable shall be pulled backwards at the middle of the cable, forming a triangle. During calibration, the discharge return cable shall not lay on the RGP or be held by operators.

Any external power supply of the ESD generator shall be placed on the RGP as shown in Figure 5. No conductive objects shall be placed within the dimensions (e.g. 1,5 m × 1,2 m) of the calibration setup in Figure 5. The cable between the power supply and the ESD generator shall be routed along the RGP and the vertical calibration plane.

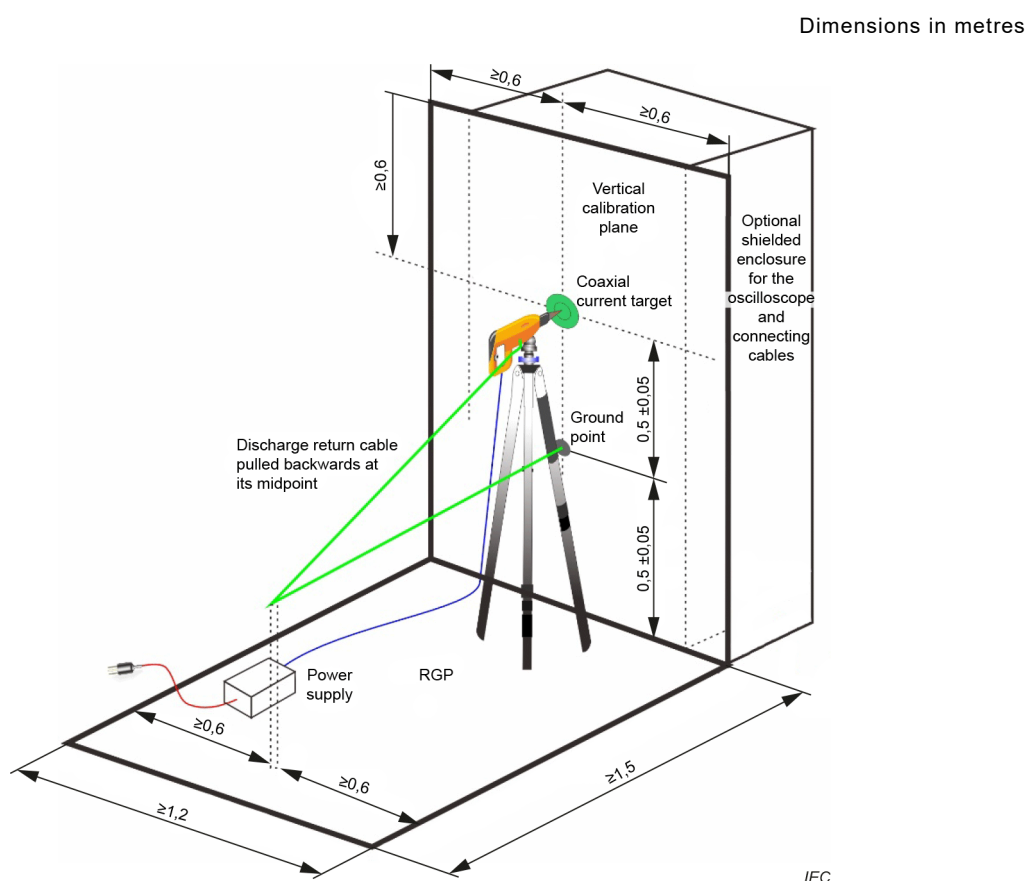


Figure 5 – Arrangement for calibration of ESD generator performance

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

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

- the oscilloscope trigger level is set to $\leq 10\%$ of the lowest test level, and
- the ESD generator is discharged with the highest test level to the outer ring of the coaxial current target (instead of to the centre conductor).

6.3.4 Procedure for the ESD generator calibration

6.3.4.1 General

All measured values and at least one discharge current waveform shall be recorded in the calibration report.

6.3.4.2 Measuring the open-circuit output voltage

Measure the open-circuit output voltage of the ESD generator with the discharge switch activated and verify that it meets the requirements specified in Table 2.

6.3.4.3 Measuring the current waveform parameters

Follow the steps specified below to verify if the current waveform of an ESD generator is within specifications. Record the waveform of five discharges for both polarities and measure the following parameters (see Figure 2 and Table 3) for each discharge:

- I_{p1} 1st peak value of the discharge current [A];
- I_{p2} 2nd peak value of the discharge current [A];
- I_{30} value of the current 30 ns after the reference point (10 % of I_{p1}) [A];
- I_{60} value of the current 60 ns after the reference point (10 % of I_{p1}) [A];
- t_r rise time of the current [ns];

Verify that each value is within the limits specified in Table 3.

At least one recorded waveform of a contact discharge at 8 kV positive polarity shall be included in the calibration report.

7 Test setup

7.1 General

The test setup consists of the EUT and AE as well as the ESD generator necessary to perform direct and indirect application of discharges to the EUT in the following manner:

- a) contact discharge to conductive surfaces and to coupling planes;
- b) air discharge to non-conductive surfaces.

The EUT shall be set up and operated in accordance with the product's specifications.

7.2 Test equipment

7.2.1 General

The ESD test setup includes:

- the ESD generator;
- the discharge tips;
- the discharge return cable;
- the bleeder resistor cables;
- the HCP (if applicable) and VCP;
- the insulating support;
- the RGP.

Examples of the ESD test setup for table-top equipment are shown in Figure 6 and Figure 8 and for floor-standing equipment in Figure 7 and Figure 9.

7.2.2 Verification of the ESD test equipment

The purpose of verification is to ensure that the ESD test equipment is operating as intended. One verification method can be to observe that at low voltage settings, a small spark is created during the approach of the discharge tip to the coupling plane and a larger spark is created at higher voltage settings. Both discharge tips shall be verified. Other methods of verification may be applied, for example self-verification.

NOTE Current waveform parameters from ESD generators do not typically change, for example rise time drift and drift of the duration of the waveform. The most likely ESD generator failures would be that no voltage is delivered to the discharge tip or that no voltage control is present. Any of the cables, resistors or connections along the discharge path can be damaged, loose or missing, resulting in no discharge.

7.3 Test setup for tests performed in laboratories

7.3.1 General

The test setups specified in 7.3 are basic test setups for table-top equipment and floor-standing equipment. For other kinds of equipment, if applicable, Annex I shall apply in addition to the requirements in 7.3.

7.3.2 Test conditions

The following requirements apply to tests performed in laboratories under environmental reference conditions specified in 8.2.

The RGP shall be a copper or aluminium sheet or plate of 0,25 mm minimum thickness; other metallic materials may be used but they shall have 0,65 mm minimum thickness.

The RGP shall project beyond the EUT and the horizontal coupling plane (where applicable) by at least 0,5 m on all sides and shall be connected to the protective grounding system. Local safety regulations can apply.

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

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

Any external power supply of the ESD generator shall be placed on the RGP.

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

The discharge return cable of the ESD generator shall be connected to the RGP. In cases where the length of the cable exceeds the length necessary to apply the discharges to the selected points, the excess length shall be kept off the RGP and shall not be bundled or wound. The discharge return cable shall not come closer than 0,1 m to other conductive parts in the test setup.

The discharge return cable may be connected to the metallic wall of the test laboratory provided that wall is electrically bonded to the RGP.

The connections to the RGP and all bondings shall be of low impedance (e.g. $\leq 0,1 \Omega$), for example by using mechanical clamping devices.

Where coupling planes are specified, for example to allow indirect application of the discharge, they shall be constructed from a copper or aluminium sheet of 0,25 mm minimum thickness. Other metallic materials may be used but they shall have 0,65 mm minimum thickness. The coupling planes shall be connected to the RGP via a cable with two $(470 \pm 10 \%)$ k Ω resistors located up to 10 cm from each end (i.e. bleeder resistor cable). These resistors shall be capable of withstanding the discharge voltage. The resistors and cables shall be insulated to avoid short circuits to the RGP when the cable lies on the RGP.

NOTE 1 The $(470 \pm 10 \%)$ k Ω resistors which are contained in the bleeder resistor cables of the HCP and VCP (see Figure 6, Figure 7, Figure 8, Figure 9, Figure I.1, Figure I.2) are used to prevent the charge applied to the planes disappearing instantly after the discharge of the ESD generator to the plane. This increases the impact of the ESD event to the EUT. They are positioned close to each end of the grounding cable in order to create a distributed resistance.

NOTE 2 Unless product committees decide otherwise, ESD tests on ceiling-mounted equipment are generally not applicable because such equipment is not touched by the user after installation.

Any mounting feet associated with the EUT shall remain in place. Any AE can be placed anywhere (e.g. outside the test environment, RGP, HCP). Interconnecting cables between the EUT and the AE may be decoupled either to protect the AE from discharges or because the EUT specification requires decoupled cables.

7.3.3 Table-top equipment

The test setup shall consist of a non-conductive support, $(0,8 \pm 0,08)$ m high, standing on the RGP. The table may be replaced by any non-conductive support.

The HCP shall be placed on the table and connected to the RGP with the HCP bleeder resistor cable. The bleeder resistor cable shall have a maximum length of 1,5 m and shall be held apart from the HCP and RGP.

NOTE Generally the HCP bleeder resistor cable assembly is connected to the edge of the HCP in a vertical line to the RGP i.e. short connection (refer to Figure 6).

The HCP shall have a minimum area of 1,23 m² and shall be large enough to ensure that the EUT can be placed at least 0,1 m from the periphery of the HCP. The HCP may have different shapes (e.g. square, rectangular, circular). The HCP may be a combination of different HCPs that shall be bonded together with a low impedance; i.e. continuous connection along the edge.

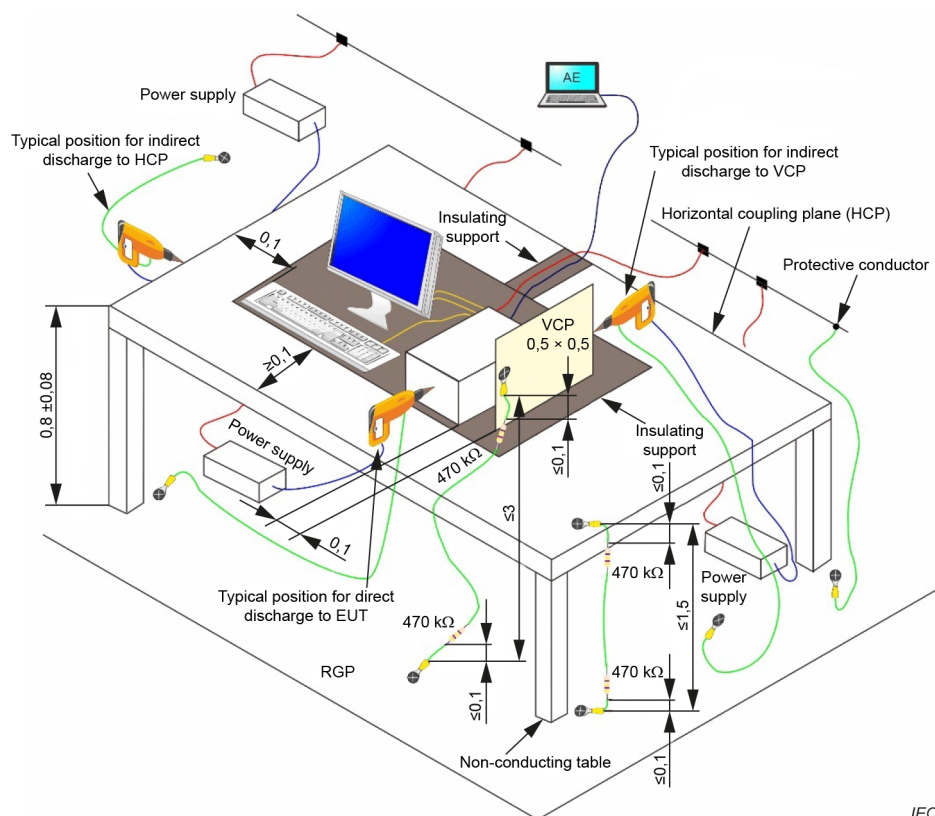
The size of the HCP shall correlate with the size of the EUT; i.e. the HCP shall not project more than 0,8 m beyond any edge of the EUT.

The EUT and its cables shall be separated from the HCP by an insulation with a thickness of $(0,5 \pm 0,05)$ mm. The HCP bleeder resistor cable shall be connected to the HCP.

When performing indirect discharges, a square VCP of side length of $(0,5 \pm 0,005)$ m shall be placed on a non-conductive support and shall be located $(0,1 \pm 0,01)$ m from the side of the EUT. The VCP shall be isolated from the HCP and only be connected to the RGP by the VCP bleeder resistor cable. The VCP bleeder resistor cable assembly shall have a maximum length of 3 m and shall not be bundled.

An example of the test setup for table-top equipment is shown in Figure 6.

Dimensions in metres



IEC

Figure 6 – Example test setup for table-top equipment

7.3.4 Floor-standing equipment

The EUT shall be isolated from the RGP by a non-conductive support with a height of $(0,1 \pm 0,05)$ m. The EUT cables shall be isolated from the RGP by an insulating support of $(0,5 \pm 0,05)$ mm.

When performing indirect discharges, a square VCP of side length of $(0,5 \pm 0,005)$ m shall be placed on the table and shall be located $(0,1 \pm 0,01)$ m from the side of the EUT. The VCP shall be connected to the RGP by the VCP bleeder resistor cable. The VCP bleeder resistor cable assembly shall have a maximum length of 3 m and shall not be bundled.

An example test setup for floor-standing equipment is shown in Figure 7.

Dimensions in metres

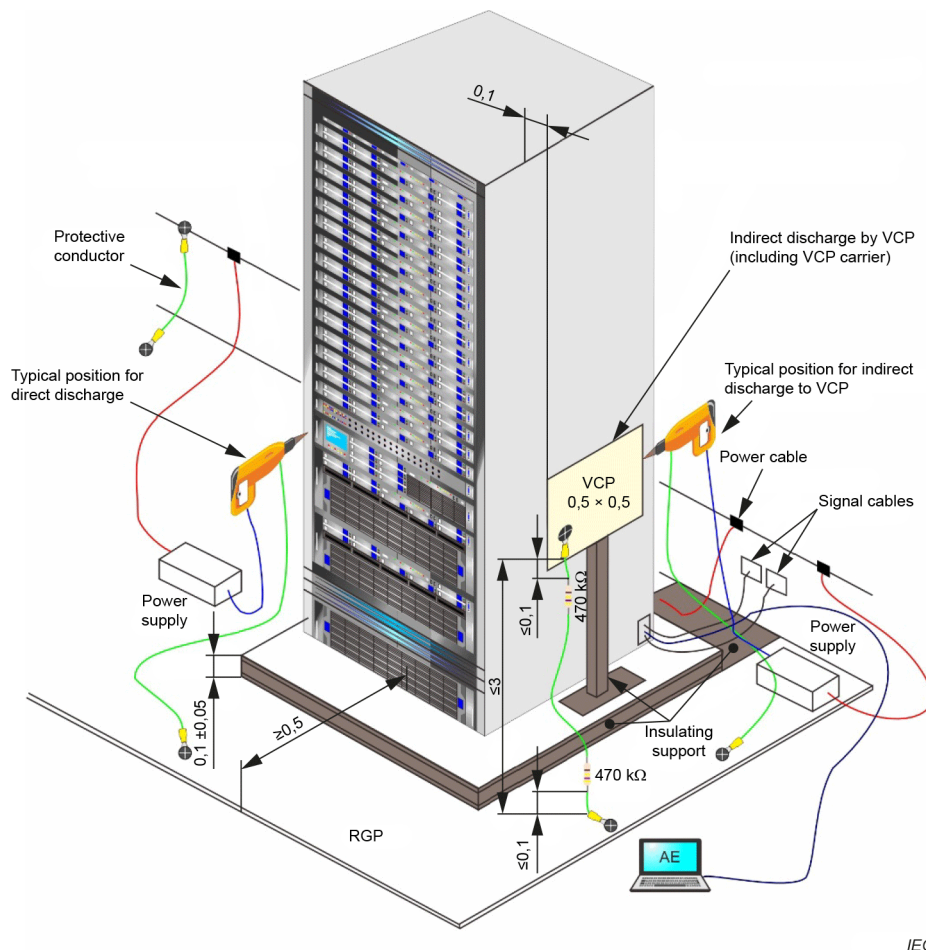


Figure 7 – Example test setup for floor-standing equipment

Any mounting feet associated with the EUT shall remain in place. Post-installation tests may be used as an alternative test method for large-sized equipment or systems, which do not fit into laboratories, see Annex G for details.

7.3.5 Particular requirements for ungrounded equipment

The test setup specified in 7.3.5 is applicable to equipment or part(s) of equipment where installation specifications or design precludes connection to any grounding system. This includes portable, battery-operated (internal and external) with or without charger (ungrounded power cable) and double-insulated equipment (e.g. class II equipment, defined in IEC 62368-1). It covers table-top equipment (see Figure 8) and floor-standing equipment (see Figure 9).

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

NOTE 1 For products that have user-accessible floating pieces of metal, contact discharge to the floating metal could result in a secondary discharge inside the product and cause failures. Depending on the size of the gap between the floating exposed metal and internal ground structures, sometimes at lower voltage levels the secondary discharge can be directed closer to sensitive electronics or be more pronounced than higher levels. This is also true in cases where a grounding path that relies on a thin insulation layer like conductive adhesive exists. At higher voltage levels, ESD can arc through the thin adhesive but at lower levels the spark can be forced to take a different path and cause failures. For products such as hand-held devices, Product committees can specify for contact discharges also to be applied at lower test levels.

The general test setup shall be identical to the ones specified in 7.3.3, 7.3.4 and, if applicable, Annex I, respectively.

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

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

A cable with 470 kΩ bleeder resistors, similar to the one used with the HCP and VCP, is the preferred device to remove charges (see 7.3.2).

As the capacitance between the EUT and HCP (table-top) and between the EUT and RGP (floor-standing) is determined by the size of the EUT, the cable with bleeder resistors can remain installed between the EUT and RGP during the ESD test when it will not affect EUT functioning.

The presence of the cable with the bleeder resistors can influence the test results. In case the test result is influenced by bleeder resistors, a test with the cable disconnected during the ESD pulse takes precedence over the test with the cable installed during the test, provided that the charge has sufficiently decayed between successive discharges.

Therefore, 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;
- sweeping of the EUT with a grounded carbon fibre brush with bleeder resistors (for example, $2 \times 470 \text{ k}\Omega$) in the grounding cable;
- using an automatic discharge function if included in the ESD generator.

NOTE 2 To ensure the charge has decayed, the charge on the EUT can be monitored by a non-contacting electric field meter. When the charge has decayed below 10 % of the test voltage, the EUT is considered to be discharged.

NOTE 3 The "dotted" connection (i.e. "A") shown in Figure 8 and Figure 9 applies to the discharge process during a short period of time, while the "un-dotted" connection (i.e. "B") represents the position during the application of the ESD tests ("normal" situation).

Dimensions in metres

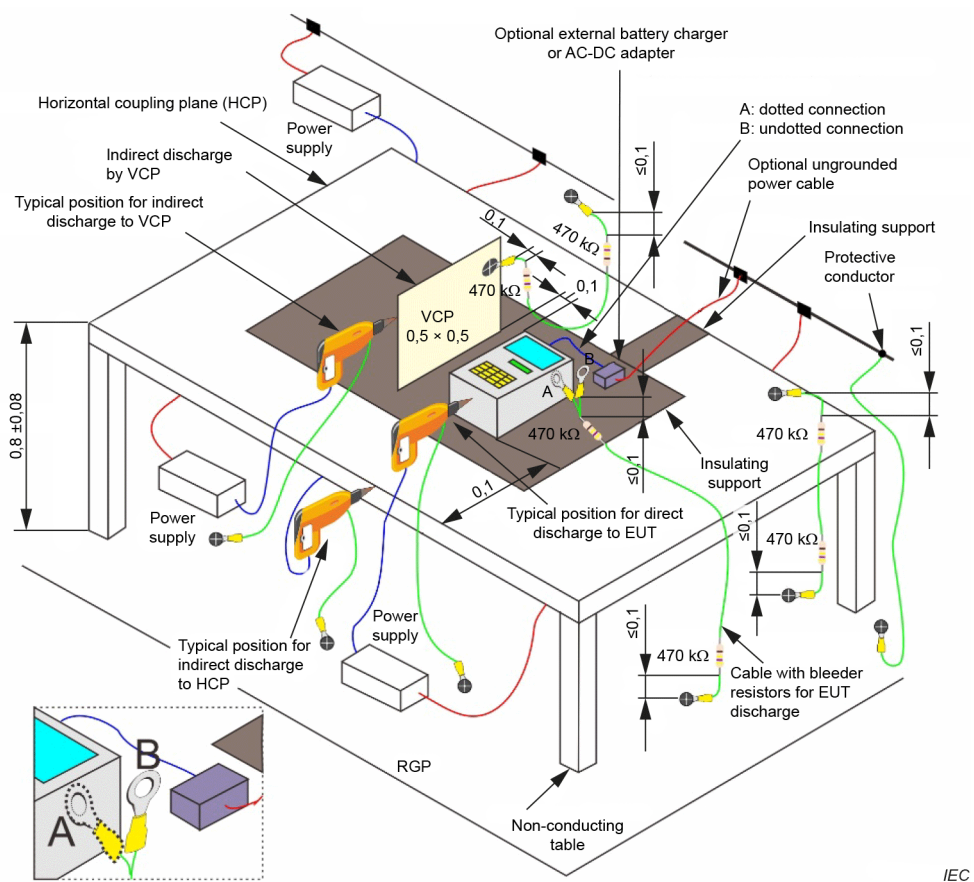


Figure 8 – Example test setup for ungrounded table-top equipment

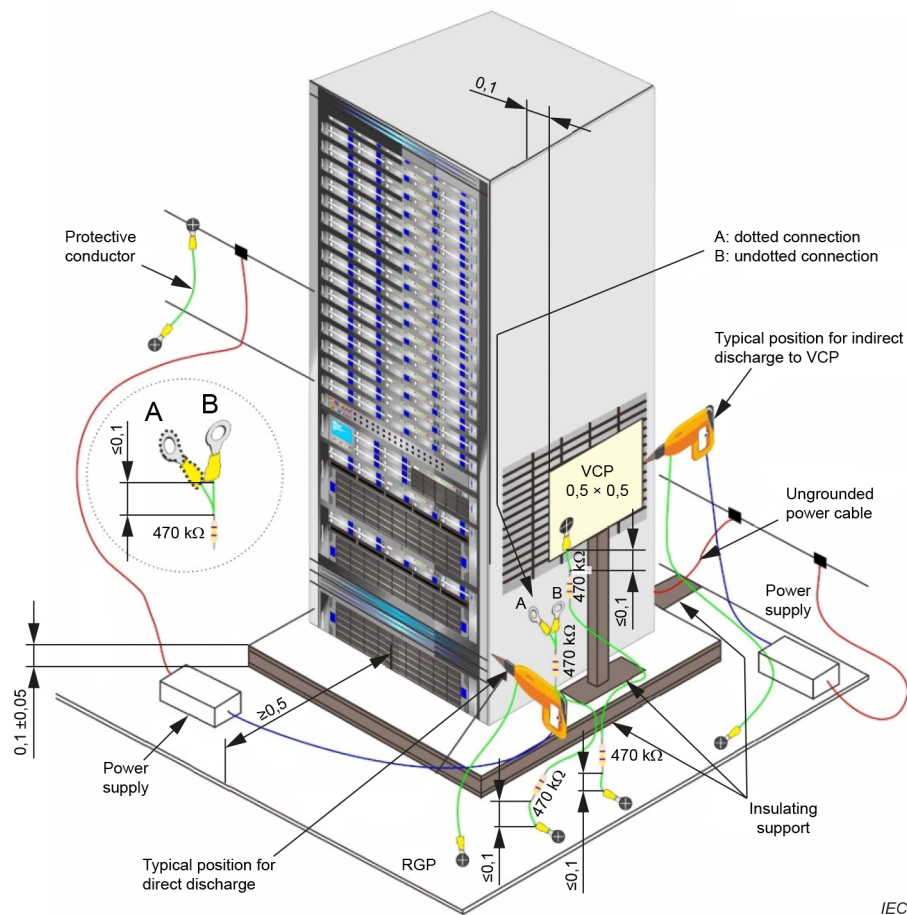


Figure 9 – Example test setup for ungrounded floor-standing equipment

8 Test procedure

8.1 General

The test procedure includes:

- the verification of the test instrumentation according to 7.2.2;
- the confirmation of the laboratory reference conditions;
- the functional check to ensure the correct operation of the EUT;
- the execution of the test.

8.2 Laboratory reference conditions

8.2.1 Climatic conditions

The EUT shall be operated within its intended climatic conditions.

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

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

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

ESD testing may be performed at a relative humidity below 30 %. If the EUT meets the specified performance criteria within these conditions, no further action is required. Otherwise, the test shall be performed within the relative humidity range specified above.

NOTE When the relative humidity decreases, the current value of the first peak increases and the rise time decreases.

The absolute value (not corrected to sea level) of the atmospheric pressure at the time of testing can be obtained from a local meteorological station. Therefore, it is not necessary for test laboratories to have the test instrumentation for atmospheric pressure.

8.2.2 Electromagnetic conditions

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

8.3 Execution of the test

8.3.1 EUT exercising

The test should be performed on the basis of a test plan that shall include the performance criteria of the EUT according to its technical specifications.

Any test program and software shall be chosen so as to exercise all normal modes of operation of the EUT. If monitoring equipment is required, it should not be affected by the ESD. The testing shall be performed by direct or indirect application, or both, of discharges to the EUT and should be according to the test plan.

The test plan should specify:

- test location;
- representative operating conditions of the EUT;
- EUT test setup arrangement;
- test level and polarity;
- the location of HCP and VCP if applicable;
- the number and type of discharges to be applied at each point;
- the time interval between successive discharges;
- the points at which discharges are to be applied;

NOTE 1 The test points to which the discharges are applied can be selected by means of an exploration.

- coating declared as insulating material for the specific points if applicable;
- auxiliary equipment (AE) including grounding and decoupling equipment if used.

It can be necessary to carry out some investigatory testing to establish some aspects of the items above.

NOTE 2 Refer to Annex F for examples of uncertainty budgets in case of necessity to provide measurement uncertainty.

Test results shall be evaluated after the tests. Annex K gives guidance and information on how to formulate specific product performance criteria as applicable.

8.3.2 Direct application of discharges to the EUT

Unless product committees decide otherwise, the electrostatic discharges shall be applied only to those points and surfaces of the EUT which are accessible to persons during normal use; refer to Annex E.

The test shall be performed with single discharges. A specified number of discharges shall be applied on each selected test point for both polarities. The total number of discharges applied to an EUT depends on how many test points are identified on the EUT. Product committees should specify the number of discharges per discharge point and consider whether it is necessary to give guidance on longer time intervals between pulses.

Clause E.7 gives guidance on how to determine the number of pulses including the time interval between successive single discharges. If not specified by product committees, 10 discharges per polarity shall be applied.

If an EUT has varying performance during the application of the discharges and it is not possible to decide whether the variation is due to the application of discharges, the escalation strategy in Annex H shall be applied.

NOTE Annex H is not applicable when an EUT consistently performs in the same manner due to application of discharges and therefore a test result can be determined.

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

The generator discharge return cable shall be drawn away from the EUT and then kept at a distance of at least 0,1 m from the EUT whilst the discharge is being applied and shall not be held by the operator.

In the case of contact discharge, the contact discharge tip shall touch the conductive part of the EUT before the discharge switch is operated. In the case of painted surfaces covering a conducting substrate, the contact discharge tip shall penetrate the coating to make contact with the substrate unless the coating is declared to be insulating material. Where the coating is declared as insulating, only air discharges shall be applied to that surface.

In the case of an air discharge, the discharge switch in the ESD generator (see Figure 1) shall be closed before applying the discharge to the EUT. The ESD generator shall approach the EUT as fast as possible until contact between the discharge tip and the EUT is made (without causing mechanical damage) to ensure the possibility of a discharge. After each approach, the ESD generator (discharge tip) shall be removed from the EUT. The generator is then retriggered for a new single discharge.

At each test point, the specified number of discharges (for each polarity) shall be applied at the specified test level with a time interval between successive single discharges of 1 s minimum. This procedure shall be repeated for all specified test points.

8.3.3 Indirect application of the discharge

8.3.3.1 Discharges to objects near the EUT

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

If the time interval between pulses is not specified by product committees, at least 1 s shall apply.

The long axis of the discharge tip shall be in the plane of the HCP or VCP and perpendicular to its front edge during the discharge.

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

Discharges on the coupling plane facing an EUT's metal structures which have no openings are not required.

8.3.3.2 Horizontal coupling plane (HCP)

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

If the number of pulses is not specified by product committees, 10 discharges for each polarity shall be applied at the front edge of the HCP opposite the centre point of each unit, if applicable, of the EUT and 0,1 m from the front and one side of the EUT (for examples see Figure 6 and Figure 8).

The discharge tip shall be in contact with the edge of the HCP before the discharge switch is operated (see Figure 6).

All sides of the EUT which are subject to an indirect discharge to the HCP during its normal intended use shall be exposed to this test.

8.3.3.3 Vertical coupling plane (VCP)

If the number of pulses is not specified by product committees, 10 discharges for each polarity shall be applied to the centre of one vertical edge of the coupling plane (for examples see Figure 6 and Figure 7).

Discharges on the VCP shall be applied to all accessible vertical surfaces of the EUT except for grounded metal surfaces where direct discharges are applicable. Discharges shall be applied to the coupling plane with sufficient different positions such that all accessible vertical surfaces are completely illuminated. One VCP position is considered to illuminate an 0,5 m × 0,5 m area of the EUT surface.

9 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 8.3.1 of this document except for verification records;
- identification of the EUT and AE, for example, brand name, product type, serial number, software version;
- test level;
- identification of the test equipment, for example, brand name, product type, serial number;
- the length of the discharge return cable;
- any special environmental conditions in which the test was performed, for example, shielded enclosure;
- any special conditions necessary in order to enable the test to be performed;
- performance criteria 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 specified performance criteria);
- any specific conditions of use, for example cable length or type, shielding or grounding, or EUT operating conditions;
- test setup;
- climatic conditions (for air discharges);
- drawing or pictures, or both, of the test setup and EUT arrangement;
- diagrams or photographs indicating the discharge points;
- number of discharges per discharge point;
- HCP dimensions and shape, if used;
- escalation strategy, if used.

Annex A (informative)

Explanatory notes

A.1 General considerations

The problem of protecting equipment against the discharge of static electricity has gained considerable importance for manufacturers and users.

The extensive use of microelectronic components has emphasized the need to specify the aspects of the problem and to seek a solution in order to enhance product/system reliability.

The problem of static electricity accumulation and subsequent discharges becomes more relevant for uncontrolled environments and the widespread application of equipment and systems.

Equipment can also be subjected to electromagnetic energies whenever discharges occur from personnel to nearby objects. Additionally, discharges can occur between metal objects, such as chairs and tables, in the proximity of equipment. It is considered that the tests specified in this document do not adequately simulate the effects of the latter phenomenon.

The effects of the operator discharge can be a simple malfunction of the equipment or damage of electronic components. The dominant effects can be attributed to the parameters of the discharge current (rise time, duration, etc.).

The knowledge of the problem and the necessity to have a tool to assist in the prevention of undesirable effects due to the discharge of static electricity on equipment, have initiated the development of the standard testing procedure specified in this document.

A.2 Influences of the environmental conditions on the levels of charge

The generation of electrostatic charges is especially favoured by the combination of synthetic fabrics and dry atmosphere. There are many possible variations in the charging process. A common situation is one in which an operator walks over a carpet and at each step loses or gains electrons from their body to the fabric. Friction between the operator's clothing and their chair can also produce an exchange of charges. The operator's body can be charged either directly or by electrostatic inductions; in the latter case a conducting carpet will give no protection unless the operator is adequately earthed to it.

The graphic representation of Figure A.1 shows the voltage values to which different fabrics can be charged depending on the relative humidity of the atmosphere.

The graphic representation of Figure A.1 shows typical observed maximum non-linear voltage values to which an operator and different fabrics can be charged depending on the relative humidity of the atmosphere. Tribocharging events are not easy to repeat and initial voltage values typically decrease due to charge dissipation after the initial charging phase. Therefore, observed maximum voltage values can vary from case to case and in time by nature as presented in references [9] to [17]¹.

¹ Numbers in square brackets refer to the Bibliography.

Equipment can be directly subjected to discharges of voltage values up to several kilovolts in a typical usage scenario, depending on the type of used materials and the relative humidity of the atmosphere. In environmental conditions with relative humidity below 30 % equipment can be directly subjected to discharges of voltage values up to several kilovolts.

Air discharges above 15 kV generate sparks over a long distance, but the discharge current flowing to the EUT can be limited due to the large spark resistance, and the rise time is slower (see Clause A.4 and Clause A.8).

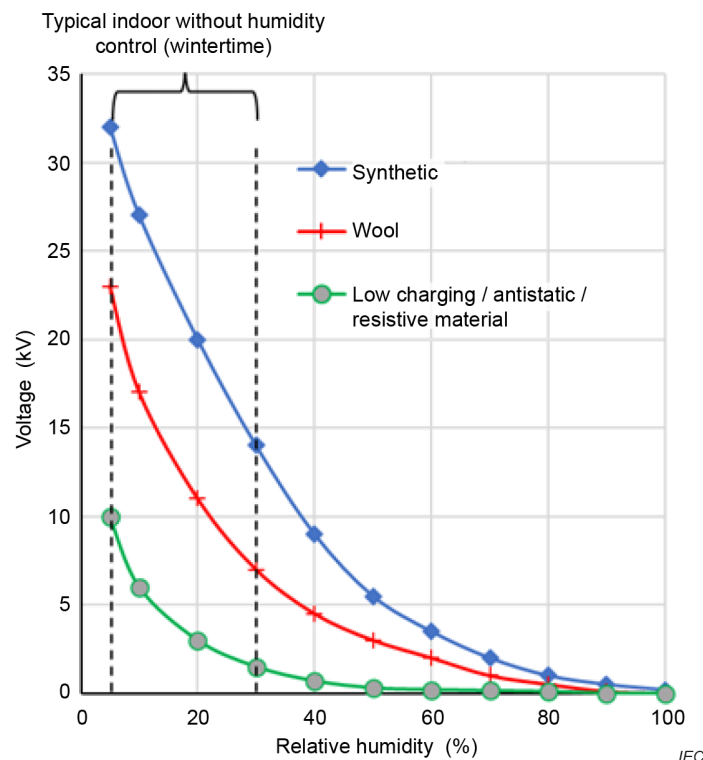


Figure A.1 – Typical maximum values of electrostatic voltages to which operators and materials can be charged while operating in different environments outside an electrostatic protective area

A.3 ESD phenomenon from charged human body

Generally the capacitance between earth and the human body is in the order of 100 pF, and the capacitance is dominant at the contact surface of the foot with the earth. The human body is resistive, and all parts of the charged human body are almost equipotential surfaces. When the charged human hand approaches a conductive object (e.g. electronic equipment) at a different potential, a discharge occurs due to dielectric breakdown of air and a discharge current flows. Due to the parasitic capacitance of a few pico-farads between the charged hand and the object a discharge current flows. The discharge path is a very short current loop and the discharge current rise time will be of the order of 1 ns or less in some cases. Following this first discharge current, a second discharge current due to transfer of large electric charge from the electrostatic capacitance of the whole of human body will occur.

A.4 Air discharge phenomena

Paschen's law is known as the relationship between the charge voltage and the initial distance at which a discharge begins due to the dielectric breakdown of air. This law can be adapted under static conditions using large spherical tip whose surface conditions maintain a stationary state. For a charged human body approaching another body, the discharge distance is shorter than the discharge distance according to Paschen's law due to the delay of the spark initiation. In addition, when an object is sharp or has a rough surface, the discharge distance is longer due to the higher charge density causing easier breakdown of the air. If the body surface has an oil film, discharge is difficult and the discharge distance shortens. The spark caused by dielectric breakdown of air has a spark resistance that varies with time depending on discharge distance, and its value is representative of Rompe-Weizel's spark resistance law:

$$r(t) = \frac{\delta}{\sqrt{\frac{2\alpha}{\rho} \int_{-\infty}^t i^2(t') dt'}}$$

where

$\alpha \doteq 1,1 \times 10^{-4} \text{ atm m}^2 \text{ V}^{-2} \text{ s}^{-1}$ (constant in atmosphere);

p is the air pressure (atm);

δ is the discharge distance (m).

This means the spark resistance significantly affects the first peak of the ESD. The peak current becomes large and the rise time becomes fast if the discharge distance is short. As the discharge distance increases, the peak current decreases and the rise time also decreases, therefore a first peak current does not exist as a result.

At discharge voltages of several kilovolts or less, a peak current larger than the contact discharge and a fast rise time are obtained. At a voltage of 5 kV to 8 kV or more, the rise time becomes slower and the peak current decreases. A long and bright spark will occur at higher voltages, however the discharge current and the rise time do not become a severe phenomenon proportional to the applied voltage.

A.5 Variations in air discharge

The factors that vary the air discharge current include charging voltage, approach speed, temperature, humidity, atmospheric pressure, shapes and the surface state of the discharge tip and the EUT shape, which affect the discharge distance. In particular, the peak current and rise time of the first peak will change. By altering the conditions of these factors, it is possible to control the discharge current, but it will still be variable. Although the variation is reduced depending on the condition, unpredictable variations also occur, and it is impossible to control the discharge current to the accuracy within several tens of percent.

A.6 Temperature and humidity of air discharge

It is well known that air discharge is affected by humidity. Relative humidity depends on air temperature, and the relationship with the amount of water vapour in the air should also be taken into consideration in order to elucidate discharge phenomena. In recent studies, the absolute humidity (mass of water in 1 m³: unit g/m³) has also been shown to have an effect. The larger the amount of water vapour in the air, the easier it becomes to initiate a discharge and the longer the discharge distance. As a result, higher humidity gives lower discharge currents and slower rise times due to higher spark resistance. When reproducing the severe ESD test in which the first peak is fast and large, it is desirable to conduct the test at an ambient temperature of 20 °C or less and with a relative humidity of 30 % or less (absolute humidity, about 5 g/m³ or less).

In an environment with a temperature of 15 °C or less and relative humidity of 30 % or less (absolute humidity of about 4 g/m³ or less), the discharge current variation tends to be small, with 0,5 ns or less high-speed first peaks and 100 A or higher peak currents at higher test voltages such as 15 kV observed.

A.7 Relevance of contact discharge test

The ESD phenomenon caused by a charged human body is only air discharge. As described above, however, it has been found that it is impossible to obtain reproducibility of the discharge accompanied by the dielectric breakdown phenomenon of air, even if various conditions of the environment and the ESD generator are carefully controlled. In the contact discharge method, the discharge tip makes contact with the EUT first and a stabilized micro-gap discharge on a high-speed moving contact in high pressure inert gas is generated in the high voltage relay built into the ESD generator.

The first peak of the contact discharge specified in this document is a proportion of 3,75 A/kV and is a setting of a discharge current lower than several kilovolts for air discharge, but above 5 kV, so that it always exceeds the air discharge current. For the second peak, discharge current due to charge transfer which is approximately equivalent to that of both air discharge and contact discharge is obtained.

When there are good conditions for air discharge, a discharge current rise time of very high speed of about 0,3 ns has been observed, but the discharge distance is very short with a low charging voltage.

Since air discharge which is applied to the conductive parts inside an enclosure which will possibly not be accessible as specified in this document, an air discharge gap between the discharge tip and inner object is at least 1 mm, so there will not be a high-speed rise time. The contact discharge maintains 0,8 ns at any applied voltage which is a sufficiently severe condition.

At low voltage, the discharge current of the first peak increases the current of the air discharge, but this can be countered by raising the applied voltage. In normal environments, a contact discharge of 8 kV can be applied instead of a 15 kV air discharge because the discharge distance is long and the peak current decreases due to spark resistance. However, a 15 kV air discharge in good environmental conditions such as low humidity and clean discharge tip surfaces, is sometimes impossible to contain with an 8 kV contact discharge.

A.8 Selection of test levels

The test levels should be selected in accordance with the most realistic installation and environmental conditions classes 1 to 4; guidelines are given in Table A.1.

Table A.1 – Guidelines for the selection of the air discharge test levels from the human body

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

The test levels outlined in Clause 5 are related to the installation and environmental classes above.

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

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

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

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

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

A.9 Selection of elements for the ESD generator

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

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

ESD generators and their discharge return cables may include ferrite.

A.10 Rationale related to the generator specification

Several reasons have been postulated as being the cause of the reproducibility differences when applying the ESD test to actual EUTs. The test setup, calibration issues, etc. have been considered and proposals to improve the reproducibility of the tests are included in this document.

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

- the discharge current waveform of the generator after the first peak, i.e. between 2 ns and 60 ns;
- the transient H-field and the transient E-field radiated by the generator when the electrostatic discharge is applied to the EUT.

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

A.11 Rationale related to the waveform specification

The specification of the discharge current waveform of contact discharge specified in 6.2.1 simulates the current waveform of air discharge from a charged human body. The first peak of the human body discharge current waveform, which is the nonlinear phenomenon described above, was determined to be representative of the range of test levels. Due to the use of 150 pF energy storage capacitor, which is larger than the average human body capacitance, the second peak current is larger than the actual discharge current from the human body. The reference curve of the discharge current was represented by an ideal waveform, which was created by superimposing the first peak and the second peak using Heidler's double exponential formula.

Annex B (normative)

Calibration of the current measurement system

B.1 Current target specification – input impedance

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

NOTE 1 The target is supposed to measure the ESD current into a perfect ground plane. To minimize error caused by the difference between a perfectly conducting plane and the input impedance of the target, a $2,1\ \Omega$ 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 can cause errors due to coupling into the cables and the oscilloscope. Furthermore, when a much lower resistance value is used, parasitic inductance becomes more severe.

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

B.2 Current target specification – insertion loss

B.2.1 Measurement chain

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

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

$\pm 0,5\ \text{dB}$, up to 1 GHz

$\pm 1,2\ \text{dB}$, 1 to 4 GHz.

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

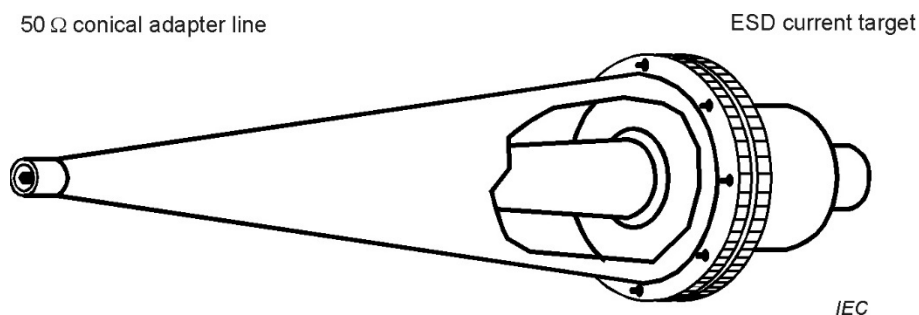
$S_{21} = 20\log [2Z_{\text{sys}}/(R_{\text{in}} + 50\ \Omega)]\ \text{dB}$, where R_{in} is the DC input impedance of the target-attenuator-cable chain, when loaded with $50\ \Omega$.

NOTE 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 can 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.

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

B.2.2 Target adapter line

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



NOTE Other shapes than conical can meet the specifications in Annex B.

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

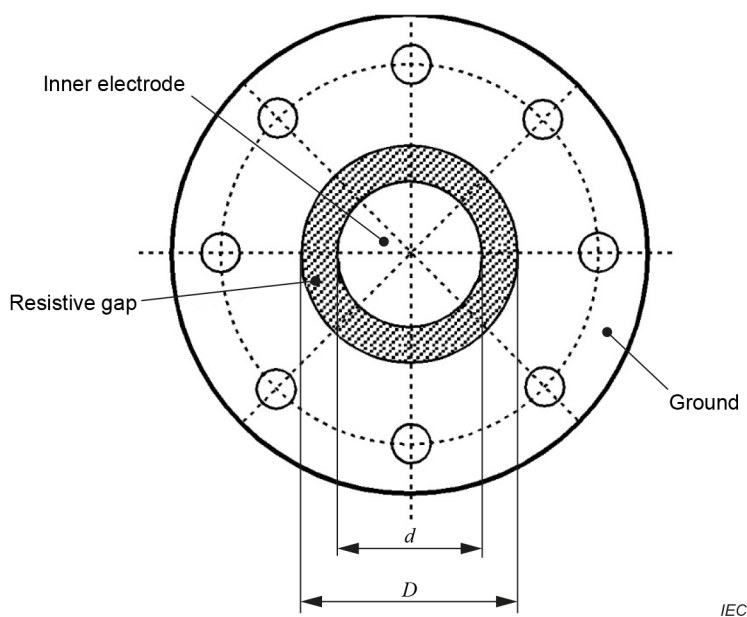


Figure B.2 – Example front side of a current target

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

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

The measurement procedure for the insertion loss is the following:

- Calibrate the network analyzer at the calibration points shown in Figure B.3.

If no network analyzer is used, the procedure should be modified accordingly.

NOTE 1 Instead of direct current the lowest frequency available with the network analyzer will be used. The DC characteristics are measured separately.

NOTE 2 The stability of the centre contact of two adapter lines or of adapter line and target will be verified through repeated measurements, disconnecting and reconnecting the devices using different centre line angles.

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

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

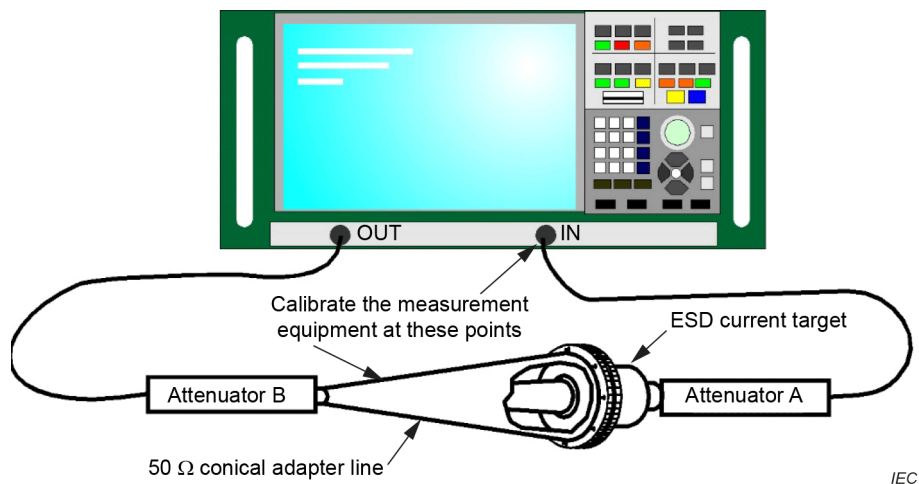


Figure B.3 – Example measurement of the insertion loss of a current target-attenuator-cable chain

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

Figure B.4 represents a circuit diagram for the 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 $50\ \Omega$ 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} .

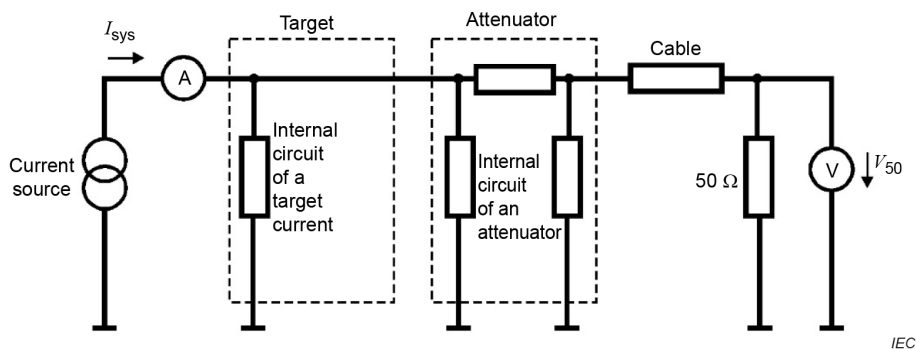


Figure B.4 – Example circuit diagram to determine the low-frequency system transfer impedance

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;
- using Z_{sys} which is the key quantity for the generator calibration. The 50 Ω load shall have a tolerance of maximum of ± 1 %;
- measuring the voltage V_{50} across the precision 50 Ω load;
- calculating the transfer impedance as follows:

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

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

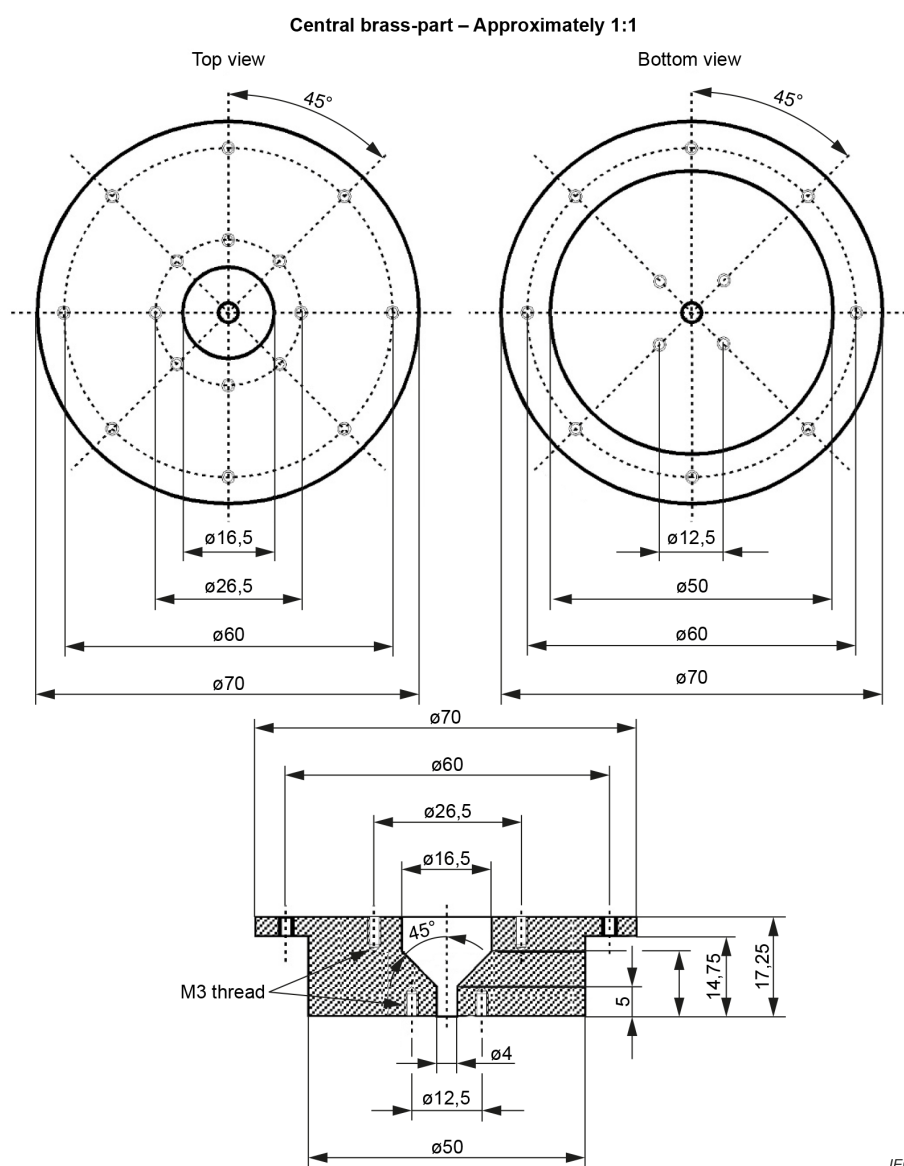
Annex C (informative)

Example of a calibration target meeting the requirements of Annex B

Figure C.1 to Figure C.5 give construction details of a target which meets the requirements of Annex B. 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 20 dB or larger attenuator directly to the target's output port to avoid multiple reflections.

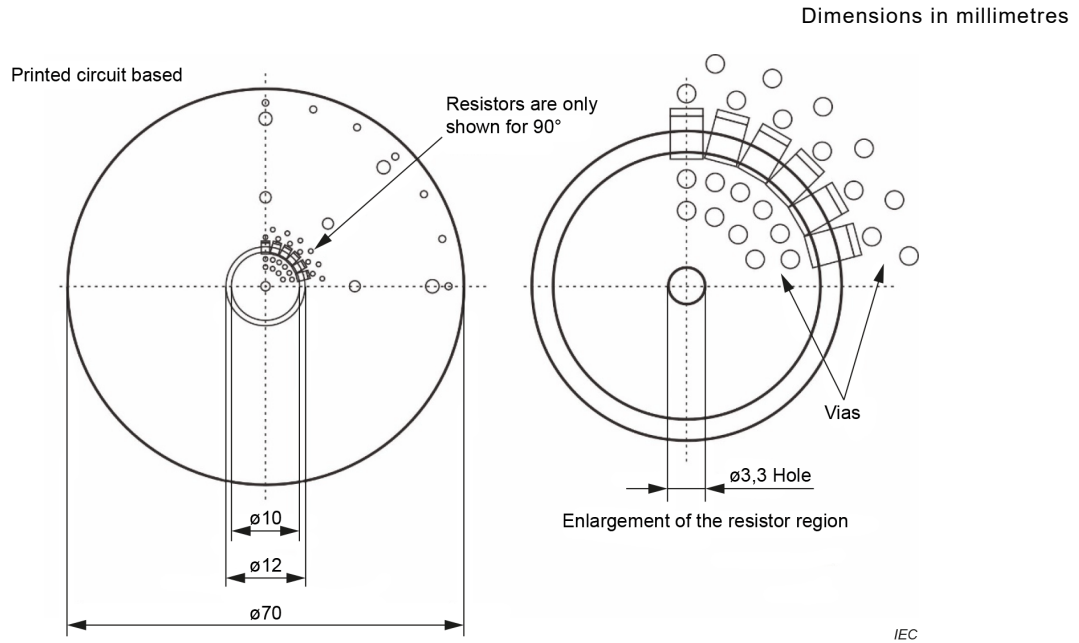
NOTE Figure C.1 to Figure C.5 are examples; therefore no tolerances are specified.

Dimensions in millimeters



IEC

Figure C.1 – Mechanical drawing of a coaxial target showing central brass part

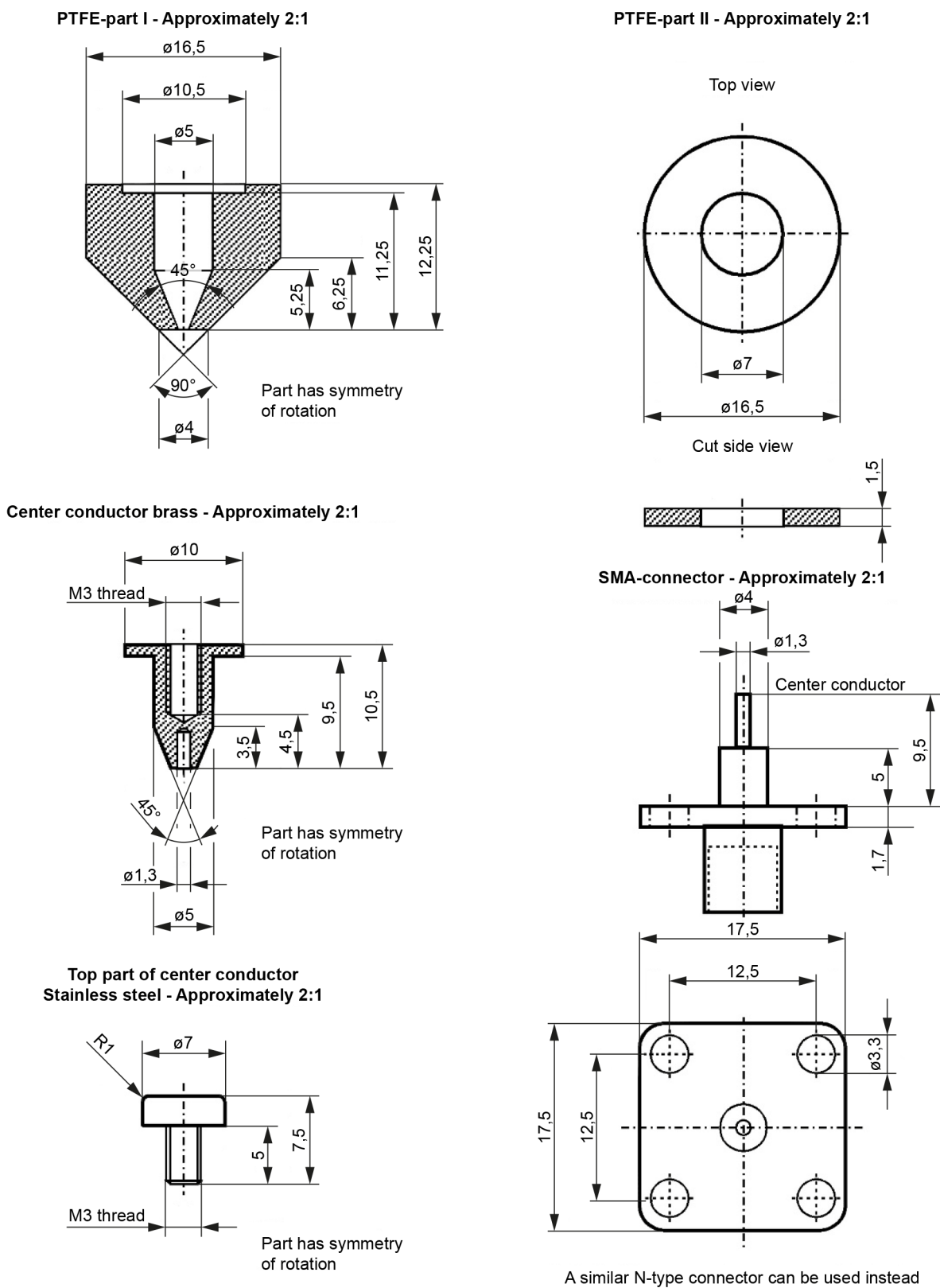


Key

Resistor size	0805
Value	51 Ω
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 printed circuit board. Approximately 25 resistors are necessary

Figure C.2 – Mechanical drawing of a coaxial target showing PCB and resistors

Dimensions in millimetres



IEC

Figure C.3 – Mechanical drawing of a coaxial target showing PTFE part

Dimensions in millimetres

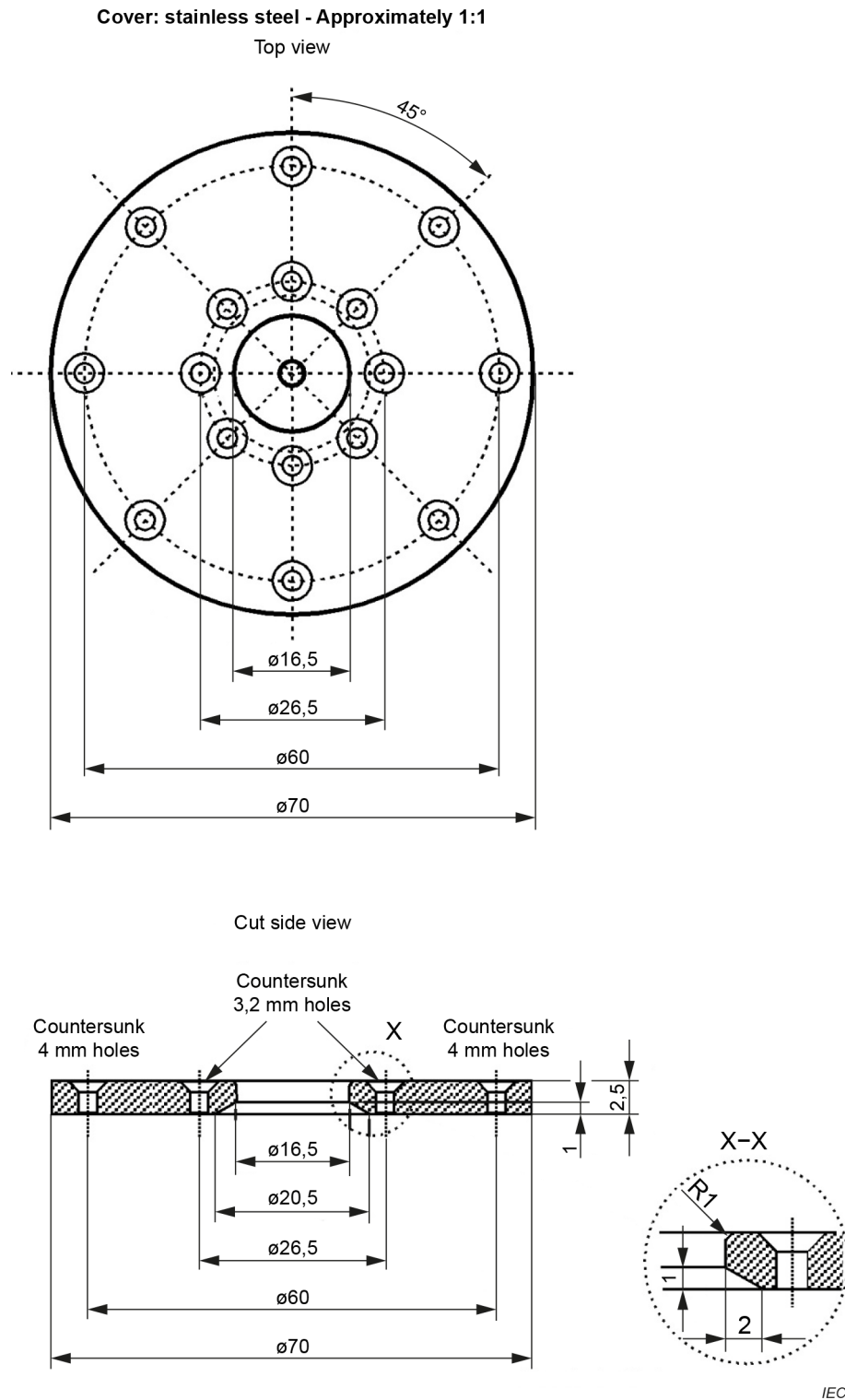
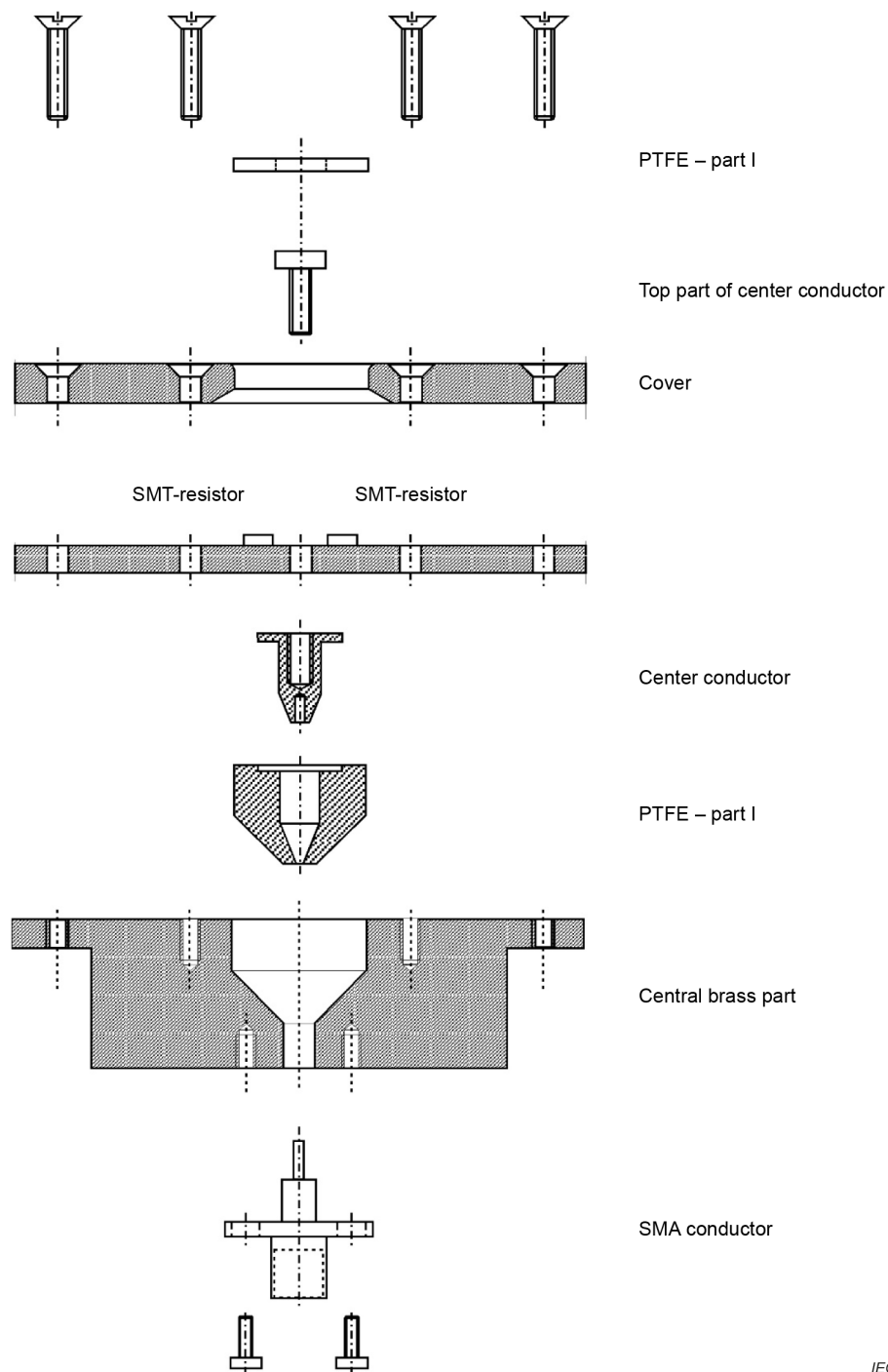


Figure C.4 – Mechanical drawing of a coaxial target showing the cover



IEC

Figure C.5 – Mechanical drawing of a coaxial target showing the mechanical assembly

Annex D (informative)

Radiated fields from human metal discharge and ESD generators

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

D.1.1 General

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

Subclause D.1.2 first reviews the process of a human discharge, and D.1.3 then reviews the process as it occurs with an ESD generator.

D.1.2 Human ESD

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

- a) As the hand-held metal piece approaches a metallic surface of an EUT and prior to the discharge of current, an electrostatic field exists. There is no (or only very little) current flowing and no relevant magnetic field is present.
- b) Once the discharge is initiated between the hand-held metal part and the EUT, the electrostatic field collapses within the gap between the two. Starting from its initial value it collapses to a voltage across the gap of about 25 V to 40 V within 50 ps to 5 ns. The collapse time depends on spark parameters, voltage, etc. The initial collapse of the electric field is the first step in a series of events that causes strong transient electromagnetic fields.
- c) A current starts flowing on the metal part held by the human and on the EUT. The foremost current front expands with the velocity of light and within about 0,8 ns, it has reached the arm of the person. As the current continues to expand further on the EUT and the arm, it will experience reflections and losses due to radiation and resistance, leading to a complex pattern of current density on both the EUT and the person.
- d) As the discharge process continues, the highest frequency components of the current will be attenuated quickly, mainly due to radiation. The current then becomes smoother (i.e. with less high-frequency content) as time increases and finally the body reaches a new electrostatic equilibrium with the EUT. The remaining charge on the body might not be zero, as the spark might extinguish before the body has completely discharged. If the hand and metal object continue to approach the EUT, a second discharge might occur at a lower voltage leading to a sequence of ESDs, each one at a lower voltage, and each one having a faster rise time (partially attributed to the lower voltage).
- e) During each discharge sequence, an observer located on some point of the hand, body or EUT will observe a charge density prior to the discharge, during the discharge phase a fast-changing current and after the discharge a small remaining charge.
- f) From antenna theory it is known that changing charge densities and changing currents will cause radiated fields. In close proximity the fields are dominated by the current and the charge directly, and in larger distances the current and charge time derivative will determine the fields. The transition region between the close proximity fields (near field) and fields seen at a larger distance (far field) is more complex. Measurements and simulations have shown that transient fields of ESD, at least for the most disturbing first nanoseconds, will reach far field conditions at a distance of 10 cm from the spark.
- g) From the above it is clear that the current and charge time derivative are extremely important regarding upset (non-destructive error) of electronic systems.

- h) Note that in a human discharge, the current and charge derivatives are determined by the collapse time of the voltage in the spark. Thus, the current rise time at the discharge determines the high-frequency components.

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

D.1.3 ESD generator

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

- a) The discharge tip of the ESD generator is contacted to a grounded (in most cases) part of the EUT.
- b) Prior to the discharge, a capacitor is charged within the ESD generator. In many designs most of the electrostatic field resulting from the charging process is confined within the ESD generator. As a result, the electrostatic field in the vicinity prior to the discharge is much less than the electrostatic field one would measure at the same point from a human charged with the same voltage.
- c) The discharge is initiated by the closure of a relay internal to the ESD generator. The design of these special relays allows a very good reproducibility of the discharge current; however, because the relay is internal and not at the point at which the ESD generator touches the EUT, the initiation of discharge current flow is quite different from a human discharge.
- d) The voltage collapse times within the relay are very fast, certainly less than 100 ps, which leads to a current wave travelling away from the relay in all directions and on all contacting metal parts and other metal parts in proximity. The current wave will propagate at the velocity of light (in dielectrics at reduced speed). The rise time of this current wave equals the voltage collapse time.
- e) The voltage collapse time is less than 100 ps, but this document requires a current rise time of $(0,8 \pm 0,2)$ ns measured at the point of contact to the target. To achieve this, measures are designed into the ESD generators that increase the rise time from the very low value within the relay to the standardized values at the discharge tip.
- f) The transient fields are caused by all current time derivatives and charge density time derivatives. An important difference between the discharge from a generator and that from a human with metal shall be noted: For a human discharge the current rise time at the spark is the fastest process and it determines the spectrum of the transient fields. However, with an ESD generator in contact mode the high-frequency spectrum is determined by the voltage collapse of the relay, not by the current rise time at the discharge tip.
- g) Since all the changing currents in the generator cause transient fields, there is a contribution of the 100 ps rising currents in the relay to the transient fields from an ESD generator, as well as the contribution from the $(0,8 \pm 0,2)$ ns rising currents at the point of discharge. The transient fields caused by the faster events in the generator are in general unwanted transient fields since they increase the high-frequency content of these radiated fields beyond those developed from an equivalent human-metal discharge having the same current rise time and peak value at the point of discharge.

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

D.2 EUT response to ESD testing

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

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

- discharge into a connector pin causing damage to an IC;
in this example the energy dissipated in the IC, the maximum current or the charge transferred through the IC will most likely determine the damage threshold;
- discharge through a gap in a plastic enclosure allowing a spark to reach an IC;
in this case the ESD test determines the dielectric breakdown strength of the gap through the plastic seam;
- discharge to a chassis causing the system contained in the chassis to become upset.
In this example, it is most likely that the transient fields of the ESD event coupled into traces, wires or directly into ICs of the system, cause voltages or currents that will upset the logical function of the system.

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

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

D.3 Transient fields of ESD reference event

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