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Road vehicles — Test methods for electrical disturbances from electrostatic discharge

Véhicules routiers — Méthodes d'essai des perturbations électriques provenant de décharges électrostatiques

Reference number
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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 32, *Electrical and electronic components and general system aspects*.

This third edition cancels and replaces the second edition (ISO 10605:2008), which has been technically revised. It also incorporates the Amendment ISO 10605:2008/Amd 1 2014 and the Technical Corrigendum ISO 10605:2008/Cor 1:2010.

The main changes are as follows:

— introduction of alternative test set-up with field coupling plane for direct and indirect discharges on component (powered-up test);

— minimum number of discharges changed from 50 to 10 for indirect discharge on component (powered-up test);

— interval between successive single discharges changed from 50 ms to 1 s for indirect discharge on component (powered-up test);

— addition of a ground connection for discharges on DUT pins for component packaging and handling test method (unpowered test);

— optional test set-up and procedure for electronic modules (powered-up test) moved from Annex to main body;

— addition of new Annex G.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The electrostatic discharge, due to former charge build-ups generated, for example, when moving about inside a vehicle or getting out of it, has assumed greater significance with the increase of vehicle electronic modules. Tests simulating the electrostatic discharge of humans, in common use by various industries, were examined and it was determined that they were not fully applicable to the automotive environment. As a consequence, tests tailored to the automotive environment were developed.

Tests that simulate an electrostatic discharge (ESD) into a vehicle electrical system are based on the human ESD model. Sensitive electrical devices can be adversely affected by energy either coupled or radiated from electrostatic discharges.

This document describes ESD tests that are applicable to both automotive electronic modules and vehicles.

Road vehicles — Test methods for electrical disturbances from electrostatic discharge

1 Scope

This document specifies the electrostatic discharge (ESD) test methods necessary to evaluate electronic modules intended for vehicle use. It applies to discharges in the following cases:

— ESD in assembly;

— ESD caused by service staff;

— ESD caused by occupants.

This document describes test procedures for evaluating both electronic modules on the bench and complete vehicles. This document applies to all types of road vehicles regardless of the propulsion system (e.g. spark-ignition engine, diesel engine, electric motor).

The test for electronic modules on the bench described in this document applies to any DUT (powered by an unshielded power system, DUT powered by a shielded power system, self-powered DUT, etc.).

This document does not apply to pyrotechnic modules.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 11452-1, *Road vehicles — Component test methods for electrical disturbances from narrowband radiated electromagnetic energy — Part 1: General principles and terminology*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11452-1 and the following apply.

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
air discharge
test method characterized by bringing the test generator discharge tip close to the *device under test (DUT)* (3.3); the discharge is by arcing on the DUT

3.2
contact discharge
test method characterized by contact of the test generator discharge tip with the *device under test (DUT)* (3.3), where discharge is initiated by the generator discharge switch

3.3
DUT
device under test
single component or combination of components as defined to be tested

3.4
direct discharge
discharge directly on the *device under test (DUT)* (3.3)

3.5
ESD
electrostatic discharge
transfer of electrostatic charge between bodies at different potentials occurring prior to contact or induced by an electrostatic field

3.6
ESD generator
instrument that simulates the *human ESD model* (3.9)

3.7
GP
ground plane
flat conductive *surface* (3.11) whose potential is used as a common reference

Note 1 to entry: The test voltage should also be referenced to the ground plane.

3.8
holding time
interval of time within which the decrease of the test voltage due to leakage, prior to the discharge, is 10 %

3.9
human ESD model
network of passive elements and voltage that characterizes a charged person as a source of an *electrostatic discharge* (3.5) for automotive conditions

3.10
indirect discharge
discharge to a coupling plane near the *device under test (DUT)* (3.3)

Note 1 to entry: Discharge current produces a transient field that might affect the DUT. Indirect discharge simulates discharge by a human being on items near the DUT.

3.11
surface
uninterrupted housing area, gap or opening

EXAMPLE Switches, tip switches, points of contact, air vents, speaker openings.

4 Test conditions

The user shall specify the test severity level(s) for the component and vehicle tests. Suggested test levels are included in Annex C.

Standard test conditions shall be as follows:

— ambient temperature: (25 ± 10) °C;

— relative humidity between 20 % and 60 %.

If other values are agreed to by the users, these values shall be documented in the test report.

5 Test location

Shielded enclosures or even absorber-lined shielded enclosures are allowed but not required.

NOTE ESD testing creates transient fields, which can interfere with sensitive electronic devices or receivers, even at a distance of a few meters. It is advisable that this be considered when choosing a test location.

6 Test apparatus and instrumentation

6.1 ESD generator

The ESD generator characteristics shall be as specified in Table 1.

Table 1 — General ESD generator parameters

Parameter	Characteristic
Output voltage range contact discharge mode	2 kV to 15 kV, or as required in the test plan [a]
Output voltage range air discharge mode	2 kV to 25 kV, or as required in the test plan [a]
Output voltage accuracy	≤ 5 %
Output polarity	Positive and negative
Rise time of short circuit current in contact discharge mode (10 % to 90 %)	0,7 ns to 1,0 ns
Holding time	≥ 5 s
Storage capacitances[b]	150 pF, 330 pF
Discharge resistances[b]	330 Ω, 2 000 Ω

[a] See examples in Annex C.

[b] Storage capacitance and discharge resistance are nominal values, ESD generator shall meet discharge current specifications in 6.3.

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 discharge return cable, unintended current can 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.

The tip voltage should be checked continuously by the generator internal tip voltage supervision.

For contact discharge a grounded discharge resistor with 1 MΩ ±20 % resistance from tip to ground is recommended and prevents pre-pulse-voltage occurrence which can lead to non-reproducible test results; proper fixing of resistor shall not change the current shape.

In cases where a 2 m length of the discharge return cable is insufficient (e.g. for tall DUTs), 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).

The ESD generator protective earth terminal shall be terminated to the facility protective earth.

Guidance on automatic operated ESD testing can be found in Annex G.

6.2 Discharge tips

6.2.1 Contact discharge tip

The discharge tip for contact mode ESD is shown in Figure 1. The tip is typically made of stainless steel. For contact discharge to pins the discharge tip shape can be varied. The diameter of the tip shall be 12 ± 1 mm. Springs for safe contact and a bending of not more than 90° are possible. The current shape with modified tip shall comply with the given specification. The angle “alpha” shall be between 25° and 40°.

Dimensions in millimetres

Key

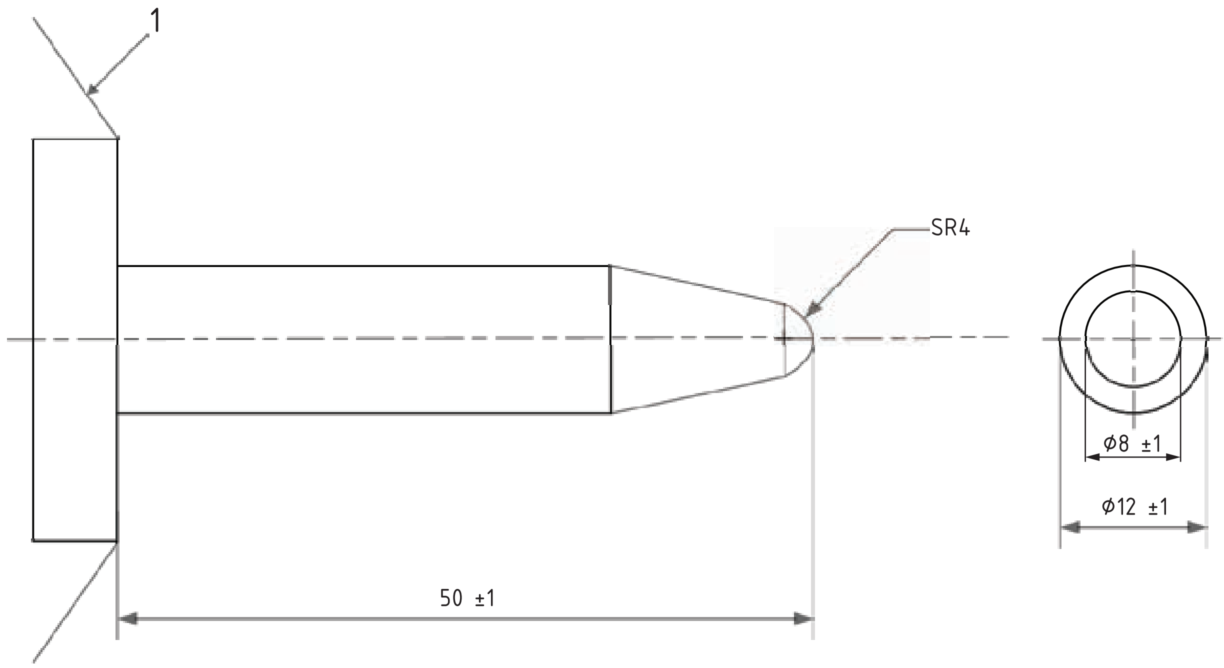
1 sharp point

Figure 1 — Contact discharge tip of the ESD generator

6.2.2 Air discharge tip

The discharge tip for air discharge mode ESD is shown in Figure 2.

Dimensions in millimetres



Key

1 body of simulator

NOTE For air discharge at test voltages higher than 15 kV, a larger tip (e.g. 20 mm to 30 mm diameter) can be used to avoid pre-discharge.

Figure 2 — Air discharge tip of the ESD generator

6.3 Discharge current specifications

6.3.1 Contact discharge mode current specifications

The contact discharge mode currents shall be verified according to Annex A. The contact discharge mode waveform parameters for each discharge network shall be within the value ranges specified in Table 2.

Table 2 — Contact discharge mode current specifications

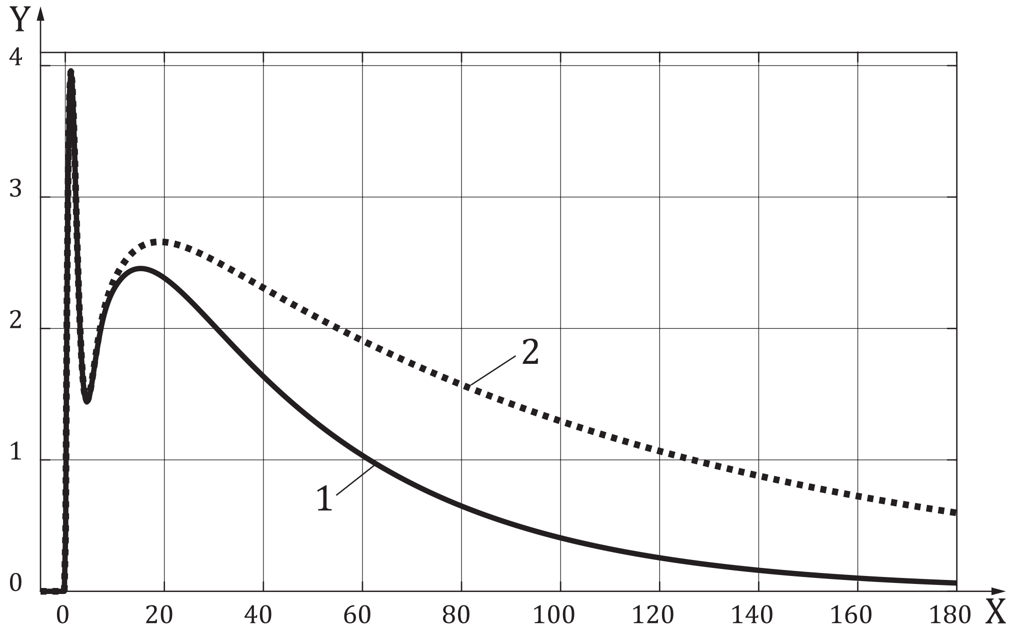
Nominal capacitance/ resistance values	**Peak current/ test voltage** A/kV	**Tolerance** %	**Current at t_1/ test voltage** A/kV	**Tolerance** %	**Current at t_2/ test voltage** A/kV	**Tolerance** %
150 pF / 330 Ω	3,75	±10	2 (at t_1 = 30 ns)	±30	1 (at t_2 = 60 ns)	±30
330 pF / 330 Ω	3,75	±10	2 (at t_1 = 65 ns)	±30	1 (at t_2 = 130 ns)	±30
150 pF / 2 000 Ω	3,75	$^{+30}_{0}$	0,275 (at t_1 = 180 ns)	±30	0,15 (at t_2 = 360 ns)	±50
330 pF / 2 000 Ω	3,75	$^{+30}_{0}$	0,275 (at t_1 = 400 ns)	±30	0,15 (at t_2 = 800 ns)	±50

NOTE 1 The peak current level is taken from the measurement system without any data interpolation.

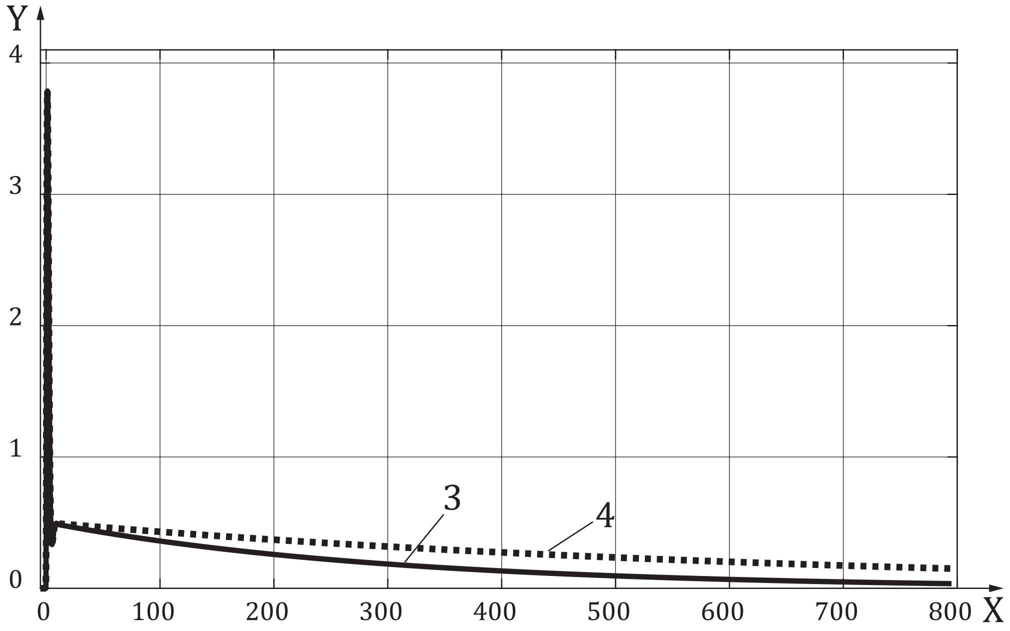
NOTE 2 The target used with this measurement system fulfils the requirements of Clauses A.1 and A.2. An example is defined in Annex B.

The measurement times (30 ns, 60 ns, 65 ns, 130 ns, 180 ns, 360 ns, 400 ns and 800 ns) are derived from the resistance-capacitive (RC) time constant − 40 % (current t_1) and +20 % (current t_2), to define two values on the falling slope of the current pulse in accordance with IEC 61000-4-2.

Examples of calculated contact discharge waveforms in accordance with the specifications in Table 2 are given in Figures 3 a) and 3 b).



a) Calculated contact discharge waveform of ESD generator (for 150 pF / 330 pF, 330 Ω and 1 kV)



Key

X time [ns]

Y current [A]

1 150 pF, 330 Ω

2 330 pF, 330 Ω

3 150 pF, 2 kΩ

4 330 pF, 2 kΩ

b) Calculated contact discharge waveform of ESD generator (for 150 pF/330 pF, 2 kΩ and 1 kV)

Figure 3 — Calculated contact discharge waveform of ESD generator

6.3.2 Air discharge mode current specifications

Information on possible air discharge generator verification procedures is given in Annex E.

6.4 Ground plane

The ground plane (GP) shall be metallic sheets (e.g. copper, brass or aluminium) and have a minimum thickness of 0,25 mm.

NOTE If aluminium is used, care is taken that oxidation does not prevent a good ground connection.

The minimum width of the GP shall be 800 mm, or the width of the entire underneath of the test setup [DUT and associated equipment (e.g. harness including supply lines, load simulator located on the test bench and AN(s)), excluding battery and/or power supply] plus 200 mm, whichever is the larger.

The minimum length of the GP shall be 1 600 mm or the length of the entire underneath of the test setup [DUT and associated equipment (e.g. harness including supply lines, load simulator located on the test bench and AN(s)), excluding battery and/or power supply] plus 200 mm, whichever is the larger.

In case of very large DUT, the above GP dimensions/shape can be adapted by using a GP extension.

Connection between an already existing GP and a GP extension should have a DC resistance lower or equal to 2,5 mΩ.

6.5 Field coupling plane

Details of the construction of the field coupling plane can be found in Annex F.

6.6 Insulating block

Insulating blocks, if used, shall be constructed of clean non-hygroscopic material. The relative permittivity should range between 1 and 5 (e.g. polyethylene). The blocks shall be (50 +/- 5) mm in height and extend beyond the test setup by at least 20 mm on all sides.

6.7 Dissipative mat

Dissipative support from a material which has a surface resistivity between 10^7 Ω per square and 10^9 Ω per square with a height between 2 mm and 3 mm.

6.8 Uncertainty (informative)

Refer to IEC 61000-4-2:2008, Annex E.

7 Discharge modes

7.1 General

Discharges can be applied by two discharge modes: contact and air. See Annex D for guidance on air versus contact discharge modes.

7.2 Contact discharge mode

In the case of contact discharges, the discharge tip (see Figure 1) shall touch a conducting point on the DUT 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 generator penetrates the coating so as to make contact with the conducting substrate.

7.3 Air discharge mode

In air discharge mode, the discharge tip is charged to the test voltage and then brought with the demanded speed of approach to the DUT, applying the discharge through an arc that happens when the tip approaches close enough to the DUT to break down the dielectric material between the tip and test point.

The speed of approach of the discharge tip is a critical factor in the rise time and amplitude of the injected current during an air discharge. Because the approach speed is not trivial to measure, in practice the ESD generator should approach the DUT as quickly as possible (e.g. between 0,1 m/s and 0,5 m/s) until the discharge occurs or the discharge tip touches the discharge point without causing mechanical damage to the DUT or generator.

Where painted surfaces cover a conducting substrate or dielectric surfaces are used as boxes, the following procedure is used. If the coating is declared to be an insulating coating for the dielectric surfaces, then the surface is tested as an insulating surface using the air discharge mode.

8 Component immunity test method (powered-up test)

8.1 General

These tests consist of direct and indirect types of application of discharges to the DUT, as follows:

— direct type discharges (contact or air discharge mode) are applied directly to the DUT and to the remote parts that are accessible by the vehicle users, e.g. surfaces of switches, diagnostic connectors, buttons (see 8.3).

— indirect type discharges (contact discharge mode) simulate discharges that occur to other conductive objects in the vicinity of the DUT and are applied through an intervening metal, such as to GP (see 8.4).

For direct and indirect discharge testing of electronic modules, the ESD generator shall be configured with the 330 pF or 150 pF capacitor, depending on the DUT location in the vehicle (see 10.1), and the 330 Ω resistor. If the DUT location is not specified, the 330 pF capacitor shall be used.

Conductive surfaces shall be tested using contact discharge mode. For contact discharge, use the contact discharge tip (see Figure 1). Air discharge may also be applied to conductive surfaces, if required in the test plan.

Non-conductive surfaces shall be tested using air discharge mode. For air discharge, use the air discharge tip (see Figure 2).

Before applying any discharges to the DUT, verify that the ESD generator discharge verification procedure, as specified in Annex A, has been performed within the time period established by the laboratory or the customer.

8.2 Test plan

Prior to performing the test, generate a test plan, including the following:

— the detailed test set-up;

— test points;

— electronic module mode of operation;

— any special instructions and changes from the standard test.

8.3 Test procedure for direct discharges

8.3.1 General

Discharges shall be applied to all specified test points with the equipment operating in normal modes. Product response may be affected by the polarity of the discharge. Both polarities of discharge shall be used during testing to determine their effect on the DUT.

8.3.2 Test set-up

Two alternative test setups can be used:

— test setup with GP only;

— test setup with GP and field coupling plane.

The test set-up to be used shall be defined in the test plan.

8.3.2.1 Test set-up with GP only

Place the DUT on the GP (see Figure 4). Chassis-mounted DUTs shall be placed on and directly connected to the GP. DUTs that are not chassis-mounted shall be placed with an insulating block between the DUT and the GP (see 6.5).

For testing, the DUT shall be connected to all peripheral devices (e.g. load simulator, AN(s), power supply, battery) necessary for functional testing. The test harness shall be 1 700 $\left(^{+300}_{\ 0}\right)$ mm long (or as agreed upon the test plan).

If vehicle intent peripheral devices are not available for testing, substitute peripheral devices and test discharge points shall be addressed in the test plan.

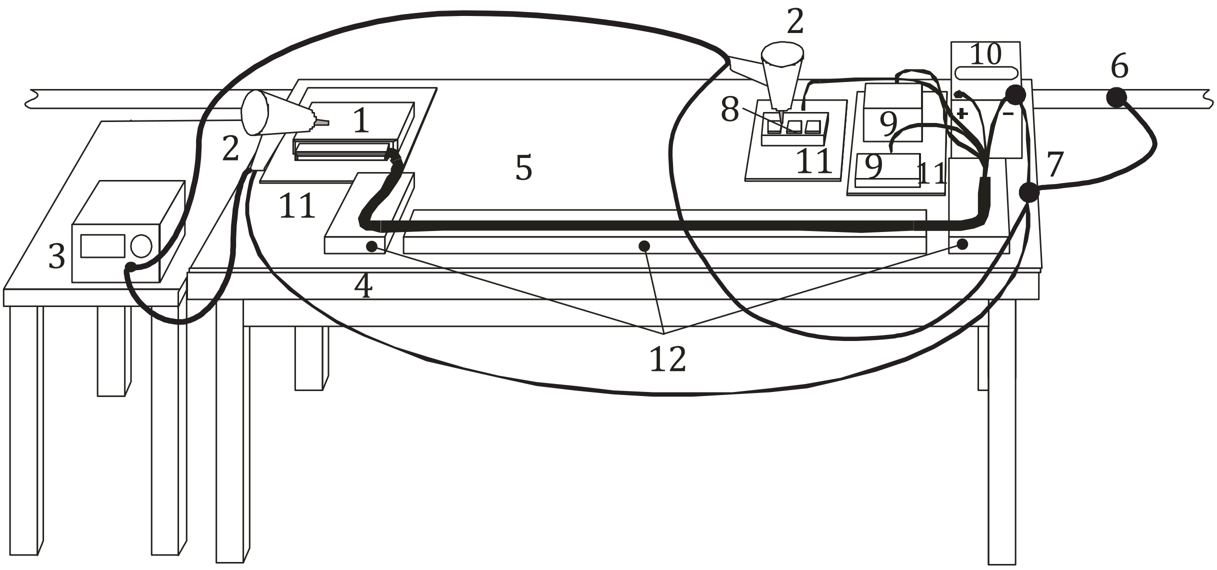
All components on the test table shall be a minimum distance of 200 mm from each other. The lines shall be laid in such a way that they run parallel to the GP edges and the plane and, like all components, they shall be a distance of 100 mm ± 10 mm away from the GP edges. The lines should be bundled and shall be secured on an insulating block, in accordance with 6.5. The wiring type is defined by the actual system application and requirement.

Unless otherwise specified, the load simulator and remotely accessible part of DUT shall be placed on an insulating block.

The supply battery shall be on the test table, with the negative terminal of the battery directly connected to the GP. The explosion hazard of the battery shall be taken into account and appropriate protective measures taken.

The ESD test bench (test surface) shall be a minimum of 100 mm from other conductive structures, such as the surfaces of a shielded room.

The same generator discharge return cable to the GP shall be used for verification and testing. While the discharge is being applied, the discharge return cable of the generator shall be kept at least 200 mm away from the DUT and all cables connected to the DUT (to reduce coupling from this cable which might affect the test results).



Key

1 DUT
2 ESD generator
3 ESD generator main unit
4 non-conductive table
5 GP
6 facility protective earth
7 GP connection
8 remotely accessible parts of the DUT
9 load simulator
10 battery
11 insulating blocks (for non-chassis mounted DUT)
12 insulating blocks

Figure 4 — Test set-up example for testing powered DUT immunity to direct ESD with GP only

8.3.2.2 Test set-up with GP and field coupling plane

Place and connect chassis mounted DUTs on the field coupling plane. DUTs that are not chassis-mounted shall be placed with a dissipative mat between the DUT and the field coupling plane.

For testing, the DUT shall be connected to all peripheral devices necessary for functional testing. The test harness(es) (LV, HV, etc.) shall have a length of $1\ 700\left(\begin{smallmatrix}+300\\0\end{smallmatrix}\right)$ mm and placed directly on the field coupling strip. The harness(es) shall exit the DUT harness support 10 mm from the edge of the discharge island most distant from the DUT. The ground reference for the DUT wiring harness and load box is at point 10 shown in Figure 5.

The field coupling plane shall be large enough so as to extend beyond the DUT on all sides by at least 10 mm.

The ground connection (wiring) of the DUT shall be connected according to the intended grounding configuration in the vehicle (for local ground, directly connected to the field coupling plane (key 12) and for remote ground connected to ground reference point (key 10) via the wiring harness(es), in Figure 5).

The battery ground shall be electrically connected to the ground reference point.

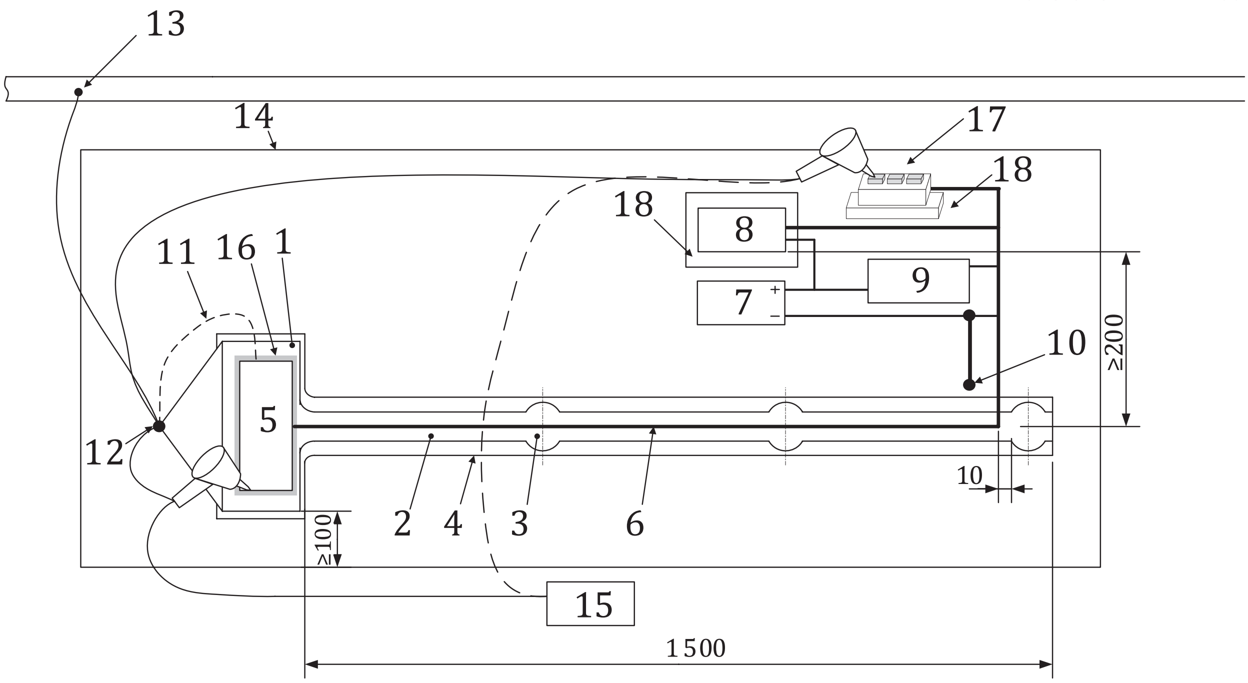
All of the switches, displays, sensors, actuators, etc. required to operate the DUT shall be part of the test configuration. Wherever possible, production intent parts and wiring shall be used.

Unless otherwise specified, the load simulator and remotely accessible part of DUT shall be placed on an insulating block.

Any peripheral devices shall be separated from the field coupling strip by at least 200 mm.

If vehicle intent peripheral devices are not available for testing, substitute peripheral devices and test discharge points shall be addressed in the test plan.

Dimensions in millimetres



Key

1 field coupling plane
2 field coupling strip
3 discharge island
4 DUT and wiring harness(es) isolation block
5 DUT
6 DUT wiring harness(es)
7 battery
8 load simulator
9 artificial network (AN) (if required in the test plan)
10 ground reference point
11 DUT local ground (if required)
12 coupling fixture ground reference point
13 facility protective earth
14 GP
15 ESD generator main unit
16 dissipative mat (for the non-chassis mounted DUT)
17 remotely accessible parts of the DUT
18 insulating block

NOTE The tolerance of dimensions is ±5 %.

Figure 5 — Test set-up example for testing powered DUT immunity to direct ESD with GP and field coupling plane

8.3.3 Test method

The discharges shall be applied to all accessible points on the DUT that can be touched during normal operation (surfaces, tip switches, switches, connectors, antennas, displays etc., as well as the diagnostic plug with pins). Ungrounded conductive surfaces shall be tested for subsequent voltage breakdown at the desired test voltage. The individual discharge points shall be specified in the test plan.

DUTs that are accessible to occupants inside the vehicle shall be tested using an ESD simulator with a discharge network of 330 pF and 330 Ω; otherwise, use a discharge network of 150 pF and 330 Ω. Refer to Clause C.4 for discharge probe and test level information.

For direct discharge, the ESD generator's discharge tip is held perpendicular to the surface of the DUT when possible; if not possible, an angle of at least 45° to the surface of the DUT is preferred.

All test points shall be tested with the required test voltage steps and both polarities. Suggested test levels are given in Clause C.4.

For each polarity and test voltage, at least three contact discharges to conductive points on the DUT, only as defined in the test plan, shall be carried out at each of the specified discharge points. In this process, the ESD simulator with the contact discharge tip shall be positioned on the device and then discharged.

For each polarity and test voltage (see Annex C), at least three air discharges shall be carried out at each of the specified discharge points. In this process, the ESD simulator with the air discharge tip shall be moved towards the discharge point in the way described in 7.3.

The time interval between successive single discharges shall be as long as necessary in order to allow charges that were built up due to the tests to dissipate, but not less than 1 s, in order to ensure that the charges are removed before each new discharge

The methods described below can be applied.

— Between two individual discharges, the charge applied shall be removed via a grounded discharge resistor with 1 MΩ ±20 % resistance by touching the discharge point and the housing. Alternatively, a duration of at least 2 s can be allowed to pass between two discharges.

— If the time interval is lengthened between two successive discharges, the build-up charge vanishes due to the natural charge decay.

— Air-ionizers may be used to speed up the “natural” discharging process of the DUT to its environment. The ionizer shall be turned off when applying an air discharge test.

The test voltages (in accordance with Annex C) shall be increased, using at least two values, up to the maximum test level.

NOTE Some products have the tendency to exhibit susceptibility responses when exposed to specific test voltages, but not necessarily at other test voltage levels.

The performance of the DUT shall be monitored and recorded according to the test plan.

8.4 Test procedure for indirect discharges

8.4.1 General

Discharges to objects placed or installed near the DUT are simulated by applying contact discharges of the ESD generator to a GP or to a field coupling plane.

8.4.2 Test set-up

Two alternative test setups can be used:

— test setup with GP only;

— test setup with GP and field coupling plane.

The test set-up to be used shall be defined in the test plan.

8.4.2.1 Test set-up with GP only

Place the DUT on the GP (see Figure 6). Chassis-mounted DUTs shall be placed on and directly connected to the GP. DUTs that are not chassis-mounted shall be placed with an insulating blocks between the DUT and the GP (see 6.5).

The DUT shall be positioned on the GP such that its closest surface is 100 mm ± 10 mm from the edge of the GP receiving the discharge. The DUT may need to be repositioned during the test, when applying

ESD to the edge of the GP, in order to maintain this 100 mm ± 10 mm spacing between the DUT edge and the edge of the GP.

For testing, the DUT shall be connected to all peripheral devices necessary for functional testing. The test harness shall be 1 700 $\left(\begin{smallmatrix}+300\\0\end{smallmatrix}\right)$ mm long (or as agreed upon the test plan).

If vehicle intent peripheral devices are not available for testing, substitute peripheral devices and test discharge points shall be addressed in the test plan.

All components on the test table shall be a minimum distance of 200 mm from each other. The lines shall be laid in such a way that they run parallel to the GP edges and the plane and, like all components, they shall be a distance of 100 mm ± 10 mm away from the GP edges. The lines should be bundled and shall be secured on an insulating block, in accordance with 6.5. The wiring type is defined by the actual system application and requirement.

Unless otherwise specified, the load simulator and remotely accessible part of DUT shall be placed on an insulating block.

The supply battery shall be on the test table, with the negative terminal of the battery directly connected to the GP. The explosion hazard of the battery shall be taken into account and appropriate protective measures taken.

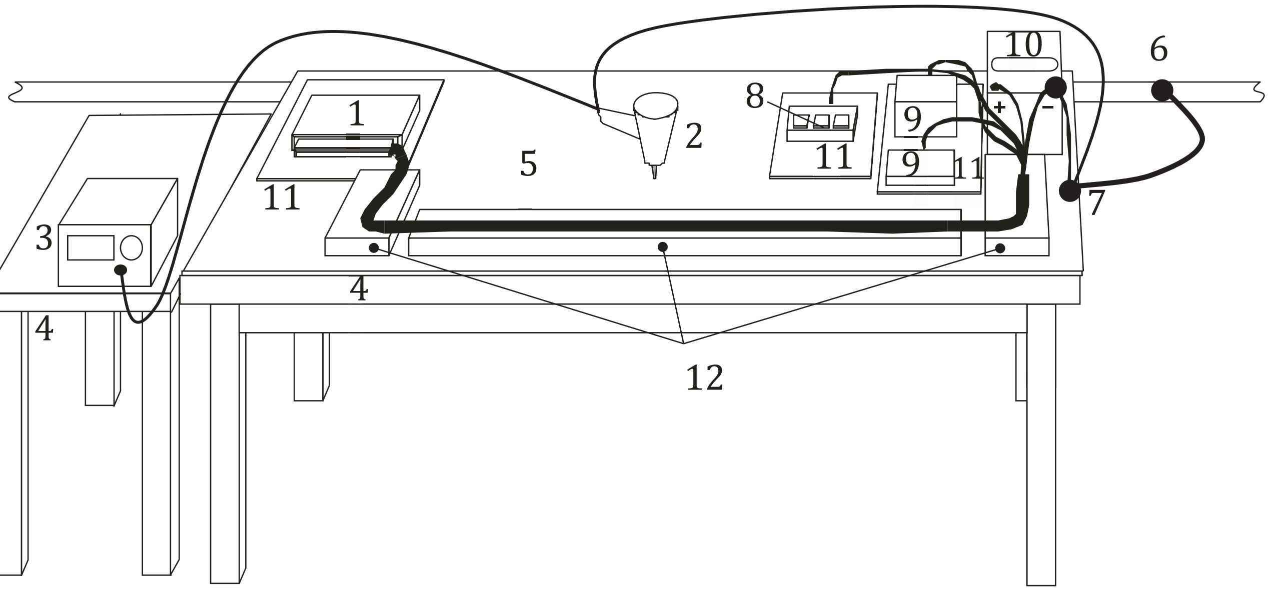
For indirect discharge, the discharge return cable of the ESD generator shall be connected to the GP (as defined in the test plan), as shown in Figure 6. The ESD test bench (test surface) shall be a minimum of 100 mm from other conductive structures, such as the surfaces of a shielded room.

The same generator discharge return cable to the GP shall be used for verification and testing. While the discharge is being applied, the discharge return cable of the generator shall be kept at least 200 mm away from the DUT and all cables connected to the DUT (to reduce coupling from this cable which might affect the test results).

Contact discharges shall be applied to:

— the GP at points around the cable harness with a distance of 100 mm ± 10 mm;

— the edges of the GP.



Key

1	DUT	7	GP connection
2	ESD generator	8	remotely accessible parts of the DUT
3	ESD generator main unit	9	load simulator
4	non-conductive table	10	battery
5	GP	11	insulating block, (for non-chassis mounted DUT)
6	facility protective earth	12	insulating blocks

Figure 6 — Test set-up example for testing powered DUT immunity to indirect ESD with GP only

8.4.2.2 Test set-up with GP and field coupling plane

The DUT shall be placed on the field coupling plane (see Figure 7). Place and connect chassis-mounted electronic modules directly on the field coupling plane.

For testing, the DUT shall be connected to all peripheral devices necessary for functional testing. The test harness(es) (LV, HV, etc.) shall have a length of 1 700 $\left(\begin{smallmatrix}+300\\0\end{smallmatrix}\right)$ mm and placed directly on the field coupling strip.

The harness(es) shall exit the DUT harness(es) support 10 mm ± 1 mm from the edge of the discharge island most distant from the DUT. The ground reference for the DUT wiring harness(es) and load box is at point 10 shown in Figure 7.

The DUT coupling plane shall be large enough so as to extend beyond the DUT on all sides by at least 10 mm.

The ground connection (wiring) of the DUT shall be connected according to the intended grounding configuration in the vehicle (for local ground, directly connect to coupling plane ground reference point (key 12) and for remote ground connect to ground reference point (key 10) via the wiring harness(es), in Figure 7).

If the case of the DUT is conductive and is grounded in the vehicle application, it shall be grounded to the field coupling plane or at point 12 in Figure 7.

The battery ground shall be electrically connected to the GP at point 10 shown in Figure 7.

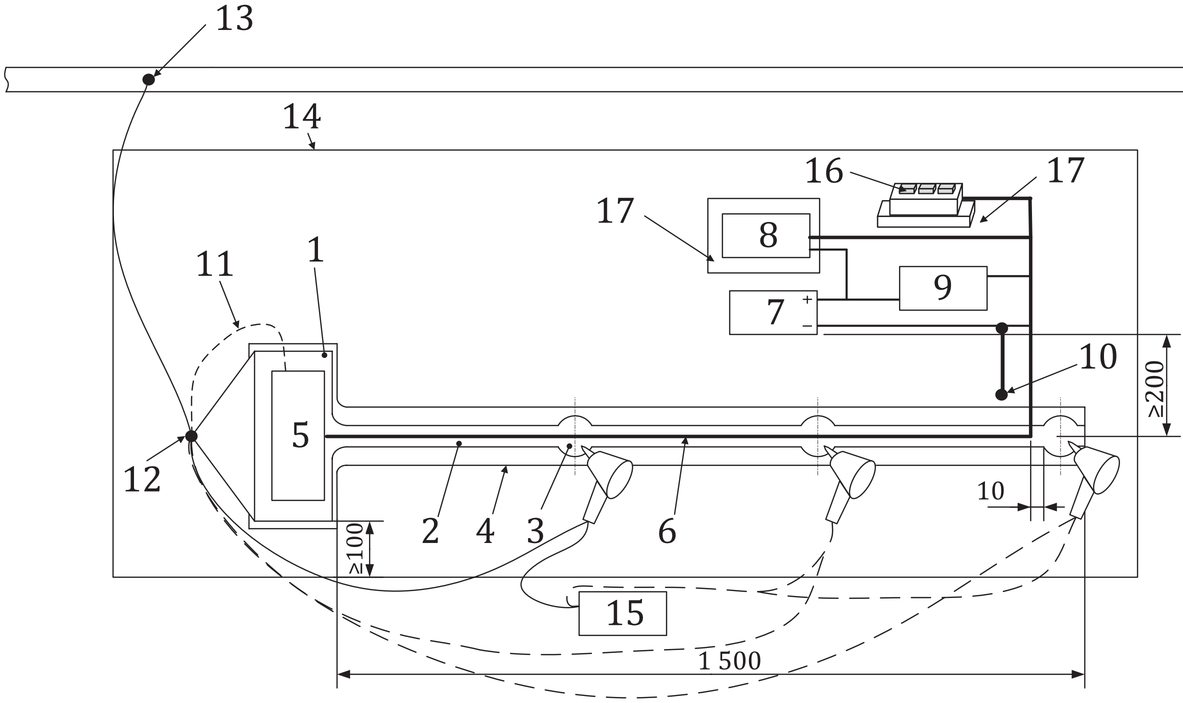
All of the switches, displays, sensors, actuators, etc. required to operate the DUT shall be part of the test configuration. Wherever possible, production intent parts and wiring shall be used.

Unless otherwise specified, the load simulator and remotely accessible part of DUT shall be placed on an insulating block.

Any peripheral devices shall be separated from the field coupling strip by at least 200 mm.

If vehicle intent peripheral devices are not available for testing, substitute peripheral devices and test discharge points shall be addressed in the test plan.

Dimensions in millimetres



Key

1 field coupling plane
2 field coupling strip
3 discharge island
4 DUT and wiring harness(es) isolation block
5 DUT
6 DUT wiring harness(es)
7 battery
8 load simulator
9 artificial network (AN) (if required in the test plan)
10 ground reference point
11 DUT local ground (if required)
12 coupling plane ground reference point
13 facility protective earth
14 GP
15 ESD generator main unit
16 remotely accessible parts of the DUT
17 insulating block

NOTE The tolerance of dimensions is ±5 %.

Figure 7 — Test set-up example for testing powered DUT immunity to indirect ESD with GP and field coupling plane

8.4.3 Test method

Unless otherwise specified, the ESD simulator shall have a discharge network of 330 pF and 330 Ω and the contact discharge tip shall be used.

Discharges should be applied:

— to the GP (if using Test set-up with GP only);

— to the centre of the free area not covered by the wiring harness(es) at each of the three specified discharge islands (if using Test set-up with GP and field coupling plane).

For each polarity and test voltage, at least 10 contact discharges shall be applied either to each discharge point on the GP (see 8.4.2.1) or each discharge islands.

The time intervals between successive single discharges shall be 1 s or longer.

Unless otherwise specified in the test plan, for DUT with multiple harness(es) branches (i.e. separate connectors), the branches shall be tested separately and as a combined bundle.

Do not discharge directly to the harness(es). If there are more than 40 lines in the harness(es) bundle, the harness(es) bundle shall be flipped over (180°) and the indirect coupled test repeated.

For discharges to coupling planes (i.e. indirect discharges), the discharge tip is in the same plane as the GP while making contact with the edge of the plane. No discharge is made to the flat surface of the GP.

NOTE 1 In specific cases (e.g., dedicated software analysis) discharges with an increased repetition rate can be applied.

The test voltages, shall be increased, using at least two values, up to the maximum test level.

NOTE 2 Some products have the tendency to exhibit susceptibility responses when exposed to specific test voltages, but not necessarily at other test voltage levels.

9 Component packaging and handling test method (unpowered test)

9.1 General

The test shall subject the DUT to simulated discharges from humans during the assembly process or in the service case. Testing shall consist of direct application of discharges to the DUT.

Before applying any discharges to the DUT, verify that the ESD generator discharge verification procedure, as specified in Annex A, has been performed within the time period established by the laboratory or the customer.

For the packaging and handling test, the ESD generator shall be configured with the 150 pF capacitor and the resistor value specified in the test plan.

9.2 Test plan

Prior to performing the test, generate a test plan, including the following:

— the detailed test set-up;

— test points;

— electronic module mode of operation;

— any special instructions and changes from the standard test.

9.3 Test procedure

9.3.1 General

The test shall be performed by direct contact discharge to all pins and contacts (LV connectors, HV connectors, etc.), and/or air discharge mode on all surfaces and points that can be touched during the assembly process or in the service case.

Apply the ESD at (as a minimum) each connector pin, case, button, switch, display, case screw and case opening of the DUT that is accessible during handling. For this procedure, recessed connector pins are considered accessible during handling.

To access recessed connector pins, an insulated solid wire with a cross-section between 0,5 mm^2 and 2 mm^2 and a maximum length of 25 mm shall be used.

Discharge to pins of a connector with closely-spaced pins may be difficult. In this case, it is possible to use insulated solid wire with a cross-section between 0,5 mm^2 and 2 mm^2, and a maximum length of 25 mm, as for recessed pins.

Discharges shall be applied to all specified test points in the test plan. Product response may be affected by the polarity of the discharge. Both polarities of discharge shall be used during testing to determine their effect on the DUT.

9.3.2 Test set-up

The test set-up for testing of packaging and handling sensitivity is shown in Figure 8. The DUT shall be tested without peripheral devices, as delivered by the supplier.

Unless otherwise specified, the DUT shall be placed on a dissipative mat located on the GP (see Figure 8). It shall be ensured that the mat projects beyond the DUT by at least 50 mm on all sides.

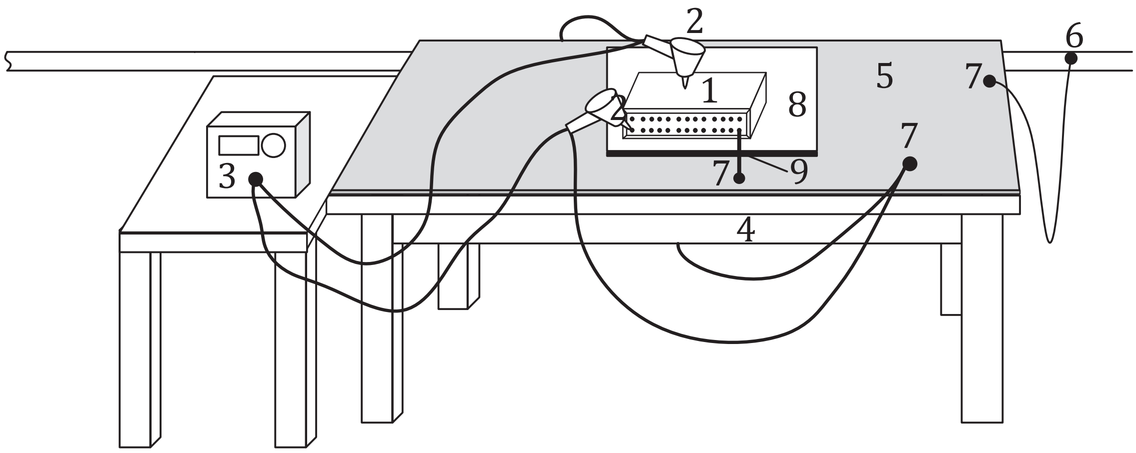
Place and connect chassis-mounted electronic modules directly on the GP, when applicable.

A ground connection copper wire shall be added, only for testing of the pins, between the DUT ground pin and the GP with a maximum length of 200 mm and a minimum cross section area of 0,5 mm^2 (or as agreed upon the test plan). In case of several, not galvanically connected ground pins, a separate wire for each ground pin shall be used.

For direct discharge (contact discharge mode and/or air discharge mode), the discharge return cable of the ESD generator shall be connected to the GP, as shown in Figure 8.

The ESD test bench (test surface) shall be a minimum of 100 mm from other conductive structures, such as the surfaces of a shielded room.

The same generator discharge return cable to the GP shall be used for verification. The discharge return cable of the generator should be positioned at least 200 mm away from the DUT while the discharge is being applied. The discharge return cable shall also be kept at least 200 mm away from the DUT.



Key

1	DUT	6	facility protective earth
2	ESD generator	7	ground point (on GP)
3	ESD generator main unit	8	dissipative mat (unless otherwise specified)
4	non-conductive table	9	ground connection wire - only for direct discharge pin testing
5	GP		

Figure 8 — Test set-up example for packaging and handling sensitivity classification

9.3.3 Test method

For direct discharge, the ESD generator's discharge tip is held perpendicular to the surface of the DUT when possible; if not possible, an angle of at least 45° to the surface of the DUT is preferred.

At least 3 discharges shall be applied to all direct discharge test points for each specified test voltage and polarity (see Annex C). The time interval between successive single discharges shall be as long as necessary in order to allow charges that were built up due to the tests to dissipate, but not less than 1 s, in order to ensure that the charges are removed before each new discharge. The methods described below can be applied.

— Charge build-up can be eliminated by briefly connecting a grounded discharge resistor with 1 MΩ ±20 % resistance in the following sequence: (1) between the discharge location and ground, and (2) between the ground point of the DUT and ground. If there is evidence that the wire does not have any impact on the test result, it can remain connected to the DUT.

— If the time interval is lengthened between two successive discharges, the build-up charge vanishes due to the natural charge decay.

— Air-ionizers may be used to speed up the "natural" discharging process of the DUT to its environment. The ionizer shall be turned off when applying an air discharge test.

The test voltages, shall be increased, using at least two values, up to the maximum test level.

NOTE Some products have the tendency to exhibit susceptibility responses when exposed to specific test voltages, but not necessarily at other test voltage levels.

Once complete testing has been performed, the DUT shall pass complete function testing successfully. There shall be no permanent damage. In addition, the effectiveness of the EMC protective circuits (e.g. input capacitors ensuring electromagnetic interference immunity and emission, respectively) should be tested after ESD exposure, in accordance with Annex C.

10 Vehicle test method

10.1 General

Choose a generator capacitance of 330 pF for areas that can easily be accessed only from the inside of the vehicle and resistance of 330 Ω or 2 kΩ. The maximum test voltage can be limited in this case to 15 kV. Choose a capacitance of 150 pF for points that can easily be touched only from the outside of the vehicle and resistance of 330 Ω or 2 kΩ. In this case, the maximum test voltage is 25 kV. Areas that can be touched both from the outside and inside shall be tested with both generator capacitance values and 15 kV and 25 kV maximum test voltage, respectively.

Before applying any discharges to the DUT, verify that the ESD generator discharge verification procedure, as specified in Annex A, has been performed within the time period established by the laboratory or the customer.

Conductive surfaces shall be tested using contact discharge mode. For contact discharge, use the contact discharge tip (see Figure 1). Air discharge may also be applied to conductive surfaces, if required in the test plan.

Non-conductive surfaces shall be tested using air discharge mode. For air discharge, use the air discharge tip (see Figure 2).

10.2 Test plan

Prior to performing the test, generate a test plan, including the following:

— test points;

— electronic module mode of operation;

— vehicle modes of operation (e.g. drive, idle, cruise);

— any special instructions and changes from the standard test.

10.3 Test procedure

10.3.1 General

Testing shall consist of contact and/or air discharge mode application.

Discharges shall be applied to all specified test points with the vehicle operating as defined in the test plan. Product response may be affected by the polarity of the discharge. Both polarities of discharge shall be used during testing to determine their effect on the DUT.

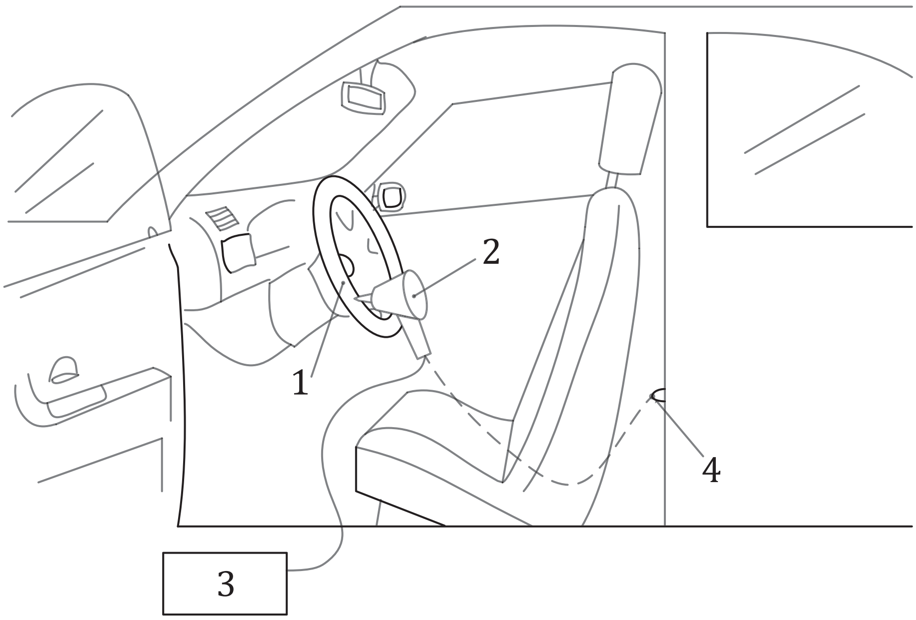
10.3.2 Test set-up

For areas accessible only from the inside of the vehicle, the ESD generator ground connection shall be connected directly to the grounded metallic part of the body (e.g. seat railing, door latch). Figure 9 a) provides an example of test set-up for an internal point.

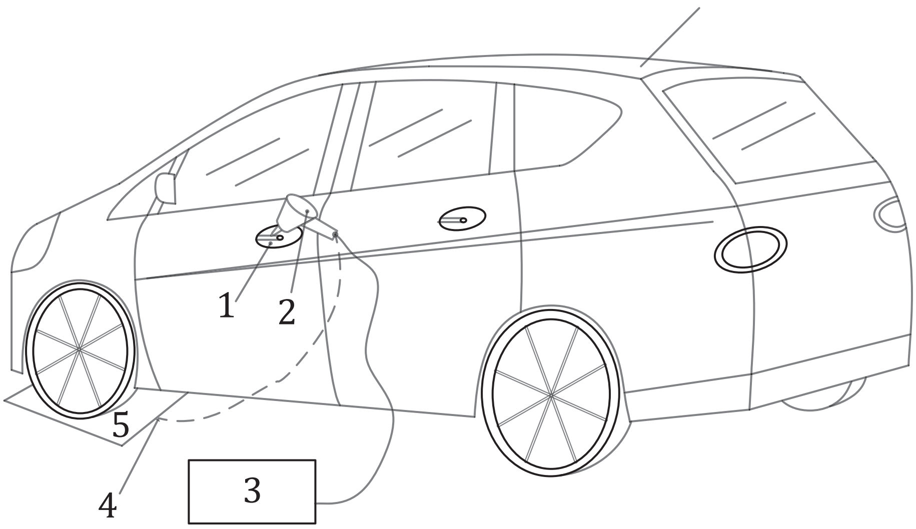
For areas accessible from the outside of the vehicle, the ESD generator ground connection can be connected directly to the nearest metallic part of the body, or directly to a metal plate placed under the wheel closest to the application point (as defined in the test plan). Figure 9 b) provides an example of test set-up for an external point.

The metal plate placed under the wheel (see Figure 9 b) shall have dimensions with at least 100 mm extension in regard to the projected surface of the tyre.

In a standard test sequence, the engine of the vehicle shall be running in drive or idle mode. If the test sequence involves tests of systems (e.g. cruise control) at road speeds using a dynamometer, specify the speed in the test plan.



a) internal point



b) external point

Key

1 DUT
2 ESD generator
3 ESD generator main unit
4 ESD generator ground connection
5 metal plate

Figure 9 — Example of vehicle ESD test setup (internal and external point)

10.3.3 Test method

For direct discharge, the ESD generator's discharge tip is held perpendicular to the surface of the DUT when possible; if not possible, an angle of at least 45° to the surface of the DUT is preferred.

At least 3 discharges shall be applied to all direct discharge test points for each specified test voltage and polarity (see Annex C). The time interval between successive single discharges shall be as long as necessary in order to allow charges that were built up due to the tests to dissipate, but not less than 1 s, in order to ensure that the charges are removed before each new discharge. The methods described below can be applied.

— Charge build-up can be eliminated by briefly connecting a grounded discharge resistor with 1 MΩ ±20 % resistance in the following sequence: (1) between the discharge location and ground, and (2) between the ground point of the DUT and ground. If there is evidence that the wire does not have any impact on the test result, it can remain connected to the DUT.

— If the time interval is lengthened between two successive discharges, the build-up charge vanishes due to the natural charge decay.

— Air-ionizers may be used to speed up the "natural" discharging process of the DUT to its environment. The ionizer shall be turned off when applying an air discharge test.

The test voltages, shall be increased, using at least two values, up to the maximum test level.

NOTE Some products have the tendency to exhibit susceptibility responses when exposed to specific test voltages, but not necessarily at other test voltage levels.

Once complete testing has been performed, the DUT shall pass complete function testing successfully. There shall be no permanent damage. In addition, the effectiveness of the EMC protective circuits (e.g. input capacitors ensuring electromagnetic interference immunity and emission, respectively) should be tested after ESD exposure, in accordance with Annex C.

Testing is performed on and in the vehicle by applying air discharges or contact discharge (as described in the test plan) on all areas that can be reached by the person using the vehicle (e.g. tip switches, switches, displays, surfaces, steering lock, controls, antennas).

11 Test report

As required in the test plan, the test report shall be submitted detailing information regarding the test equipment (in particular discharge network values), test levels, test area, systems tested, discharge points, environmental conditions, grounding conditions, DUT operating mode, DUT monitoring conditions, system interactions and any other relevant information regarding the test.

Annex A
(normative)

Current target specification and verification of ESD generator

A.1 Current target specification — Input impedance

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

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

NOTE 2 Annex B provides a description of an example for the current target.

A.2 Verification of ESD generator

A.2.1 General

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

The ESD generators shall meet all specifications at any specified repetition rate used for compliance testing independent of guidance / fixation (robot, stand or manual handling).

A.2.2 Test equipment required for ESD generator verification

The following equipment is required for calibrating ESD generators:

— oscilloscope with at least 1 GHz analogue bandwidth;

— current target;

— high-voltage meter capable of measuring voltages of at least 25 kV with at least 5 % accuracy; it may be necessary to use an electrostatic voltmeter to avoid loading the output voltage;

— reference plane at least 1,2 m × 1,2 m, with the coaxial current target mounted such that there is a distance of at least 0,6 m from the target to any edge of the plane;

— attenuator(s), as required.

A.2.3 Procedure for contact mode generator verification

Prior to verifying the discharge current, the amplitude of the ESD generator's test voltage should be determined using a high-voltage meter, at the tip. The accuracy of the test voltage measurement shall be as specified in Table 1.

The verification of discharge tip output voltage should consider electrical structure of ESD generator (e.g. electrical circuit structure) and specification (e.g. input impedance and input stray capacitance) of high-voltage meter for correct measuring.

The following environmental conditions at the time verification is performed shall be recorded:

— temperature;

— relative humidity.

These conditions should be within the limits specified in Clause 4.

The current target shall be mounted at the centre of the vertical verification plane of at least 1,2 m × 1,2 m (see Figure A.1). The connection for the ESD generator discharge return cable to the verification plane shall be made directly below the target, at a distance of 0,5 m below the target. The discharge return cable shall be pulled backwards at the middle of the cable, forming an isosceles triangle. The discharge return cable shall not lie on the floor during verification.

The measurement discharge current procedure is shown in Table A.1. The following parameters shall be measured, or obtained from measured values, in order to verify whether or not the current waveform of an ESD generator is within specifications:

— I_p, the peak value of the discharge current, in A,

— I_1, the value of the current at t_1, in A (from Table 2),

— I_2, the value of the current at t_2, in A (from Table 2),

— t_r, the rise time of the current, in ns.

The average value of a parameter X_x is indicated by $\bar{X}_x$

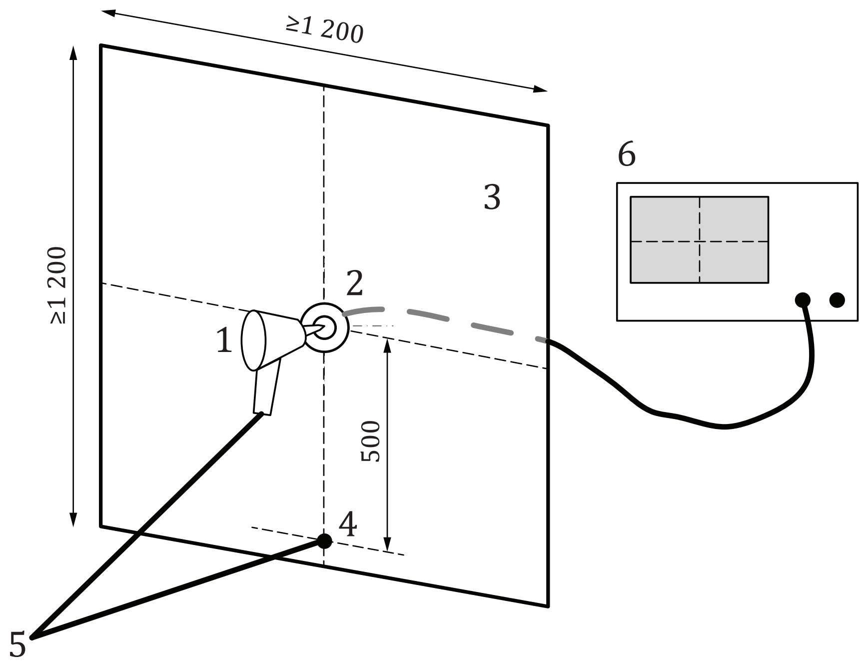
EXAMPLE $\bar{I}_p$ signifies the average of the peak current values.

Table A.1 — Contact discharge current waveform verification procedure

Step	**Resistance**				**Explanation**
	330 Ω		2 kΩ		
	Capacitance		**Capacitance**		
	150 pF	330 pF	150 pF	330 pF	
Discharge the ESD generator at a given test voltage 10 times, store each result.					Multiple measurements are taken 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_1, I_2 and t_r on each waveform.					The parameters have to be checked at each test level.

Step	Resistance				Explanation
	330 Ω		2 kΩ		
	Capacitance		**Capacitance**		
	150 pF	330 pF	150 pF	330 pF	
Calculate the averages $\overline{I}_p$, $\overline{I}_1$, $\overline{I}_2$ and $\overline{t}_r$ of the measured I_p, I_1, I_2 and t_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.
Check: current at t_1/test voltage (A/kV).	Check if $\overline{I}_1 = 2 \pm 30\ \%$	Check if $\overline{I}_1 = 2 \pm 30\ \%$	Check if $\overline{I}_1 = 0{,}275 \pm 30\ \%$	Check if $\overline{I}_1 = 0{,}275 \pm 30\ \%$	Again, compliance of the ESD generator is verified on the average of the parameter.
Check: current at t_2/test voltage (A/kV).	Check if $\overline{I}_2 = 1 \pm 30\ \%$	Check if $\overline{I}_2 = 1 \pm 30\ \%$	Check if $\overline{I}_2 = 0{,}15 \pm 50\ \%$	Check if $\overline{I}_2 = 0{,}15 \pm 50\ \%$	Again, compliance of the ESD generator is verified on the average of the parameter.
Check: peak current/test voltage (A/kV).	Check if $\overline{I}_p = 3{,}75 \pm 10\ \%$		Check if $\overline{I}_p = 3{,}75^{+30}_{\ 0}\ \%$		Again, compliance of the ESD generator is verified on the average of the parameter.
Check rise time.	Check if $0{,}7\ ns \leq \overline{t}_r \leq 1\ ns$				

Dimensions in millimetres



Key

1 ESD generator perpendicular to vertical verification plane
2 current target
3 vertical verification plane
4 ground point
5 discharge return cable pulled backwards at its midpoint
6 oscilloscope (a shielded enclosure for the oscilloscope and connecting cables may be used but not mandatory)

Figure A.1 — Typical arrangement for verification of ESD generator performance

The shielded enclosure, with a vertical ground reference plane of at least 1,2 m × 1,2 m in which the target is mounted in order 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 verification results. When the oscilloscope is set to a trigger level that is ≤ 10 % compared to the resulting peak output 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 verification system can be declared sufficiently immune and no shielded enclosure is needed.

Annex B
(informative)

Standard target drawings and target verification method

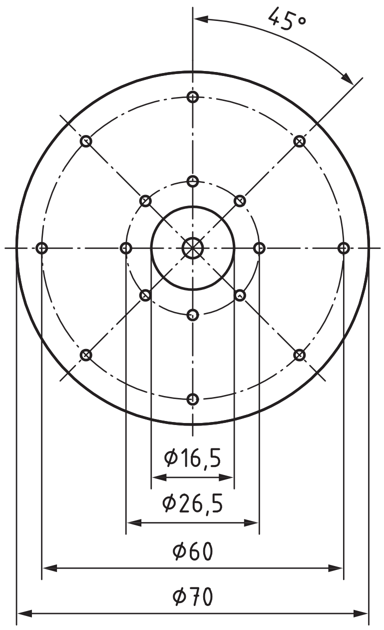
B.1 Standard target description

Figures B.1 to B.5 illustrate a method or design for a target that meets the requirements of Annex A.

NOTE This target is different from the one defined in the first edition of this document.

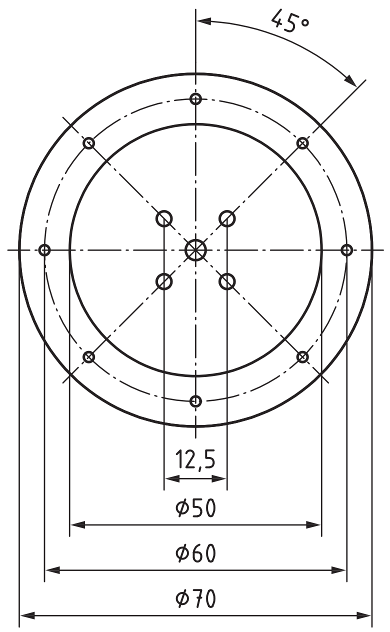
This target is designed to give a flat insertion loss if 1 m of RG 400 cable is used. It is suggested to connect an attenuator of at least 6 dB directly to the output port of the target in order to avoid multiple reflections. The target does not need to be identical to the one illustrated in Figures B.1 to B.5.

Dimensions in millimetres

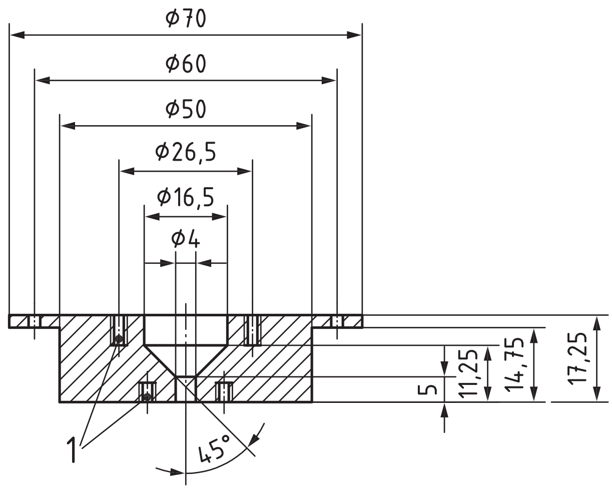


a) Top view

Dimensions in millimetres



b) Bottom view



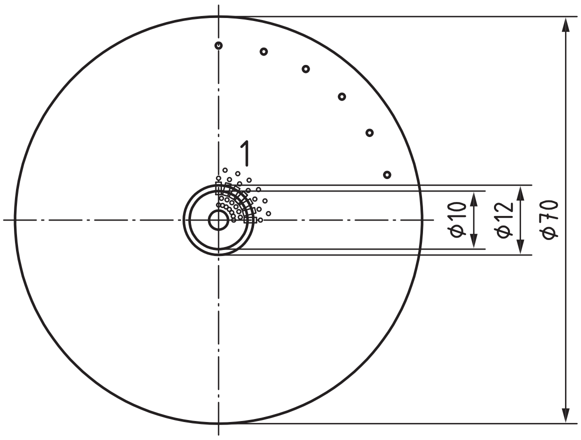
Key

1 threaded holes

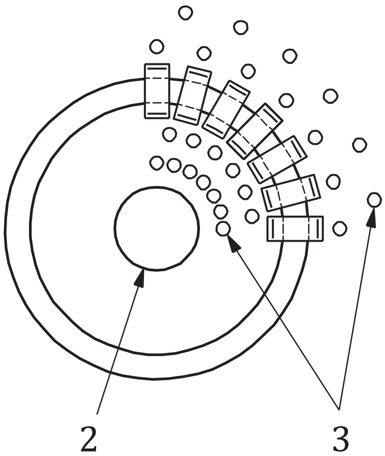
c) Cut side view

Figure B.1 — Mechanical drawing of a current target — Central brass part

Dimensions in millimetres



a) Printed circuit board



b) Enlargement of the resistor region

Key

1 resistor region consisting of approximately 25 resistors (shown only for 90°):

— resistor size: 0805

— resistor value: 51 Ω

— placement: touching, exactly symmetric (use a template)

— material: 0,5 mm FR4, gold plated

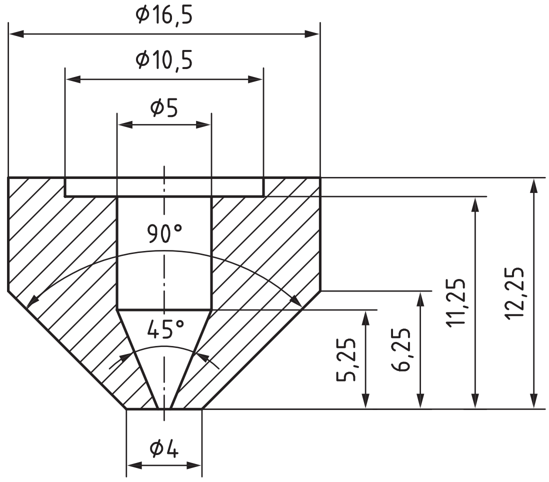
— vias: two rings of vias on each side of the resistors plus one ring close to the outer edge of the PCB

2 3,3 mm diameter hole

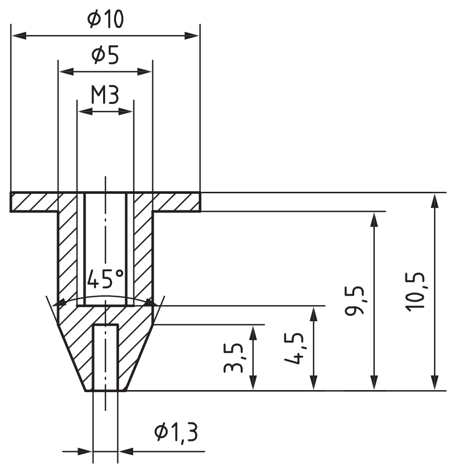
3 vias

Figure B.2 — Mechanical drawing of a current target — Printed circuit board

Dimensions in millimetres

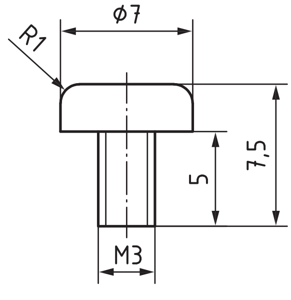


a) Polyfluor plastics (PTFE) part I

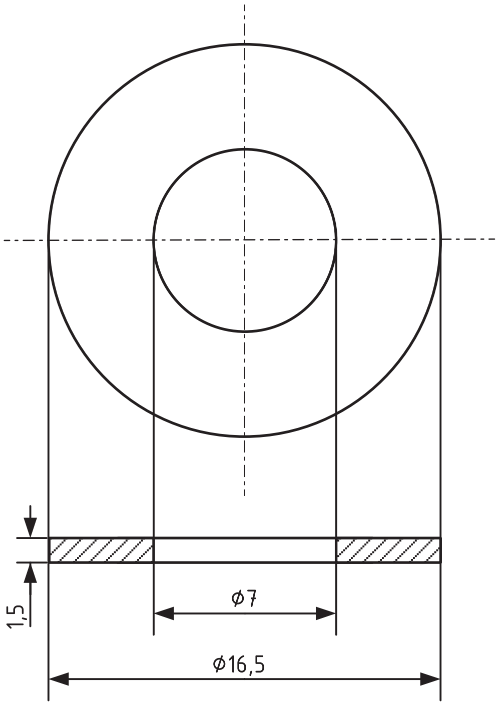


b) Centre conductor, brass

Dimensions in millimetres

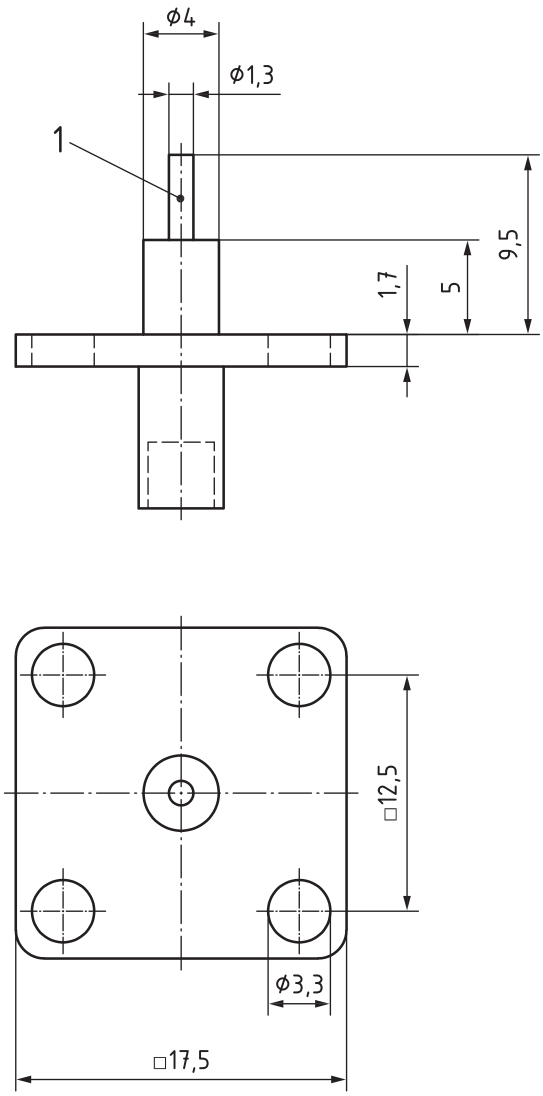


c) Top part of centre conductor, stainless steel



d) PTFE part II

Dimensions in millimetres



e) Sub miniature version A — Coaxial RF (SMA) connector

Key

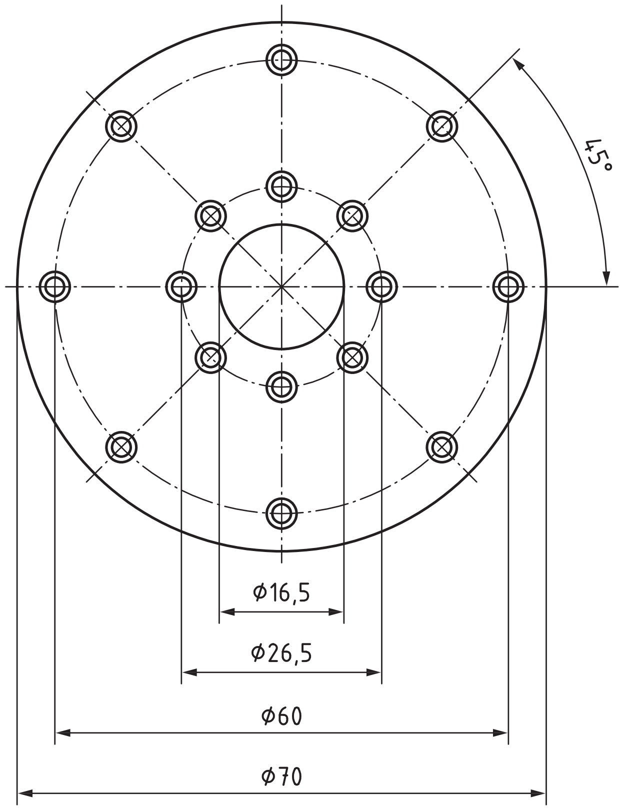
1 centre conductor

NOTE 1 A similar N-type connector can be used instead.

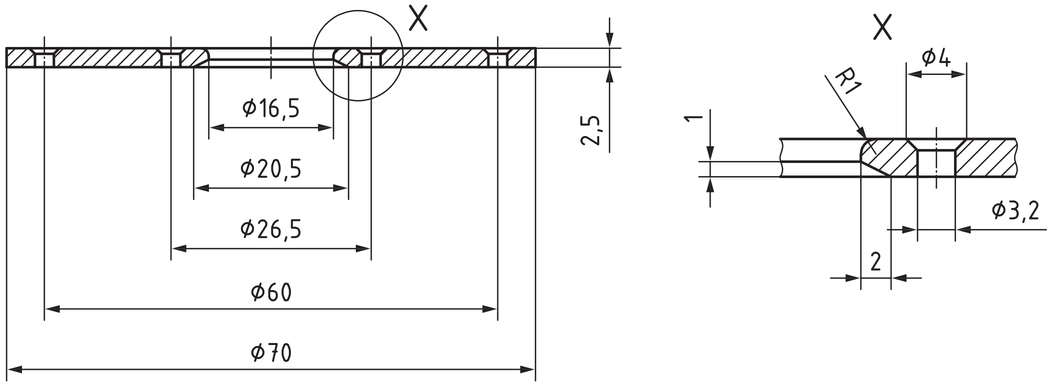
NOTE 2 In subfigures a) to c) the parts have symmetry of rotation.

Figure B.3 — Mechanical drawing of a current target

Dimensions in millimetres

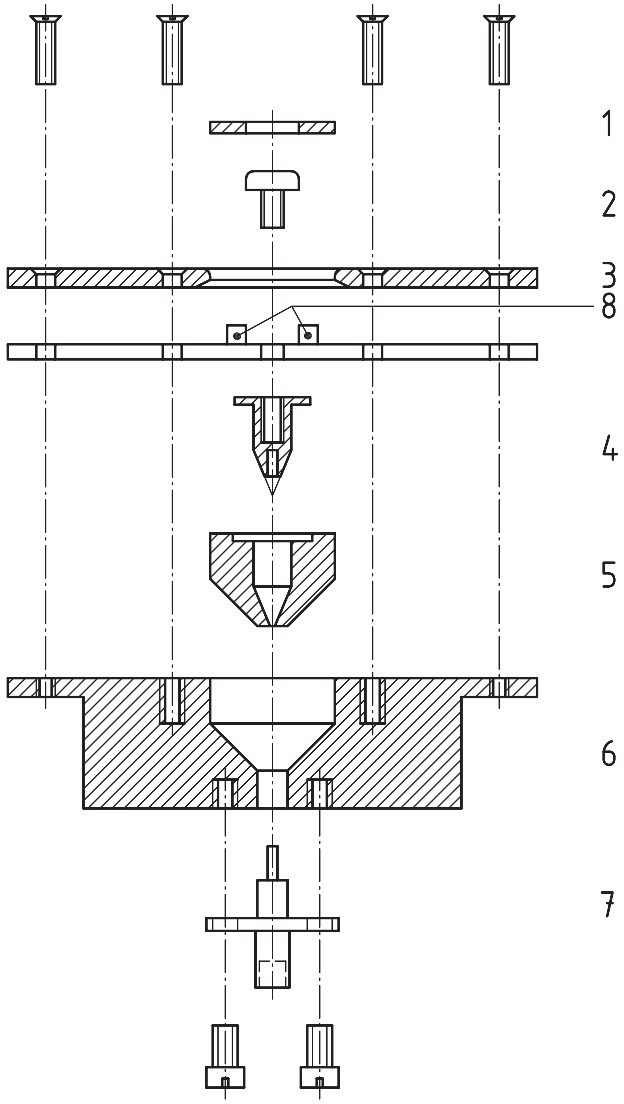


a) Top view



b) Cut side view

Figure B.4 — Mechanical drawing of a current target — Cover, stainless steel



Key

1 PTFE part II
2 top part of centre conductor
3 cover
4 centre conductor
5 PTFE part I
6 central brass part
7 SMA connector
8 SMT resistors

Figure B.5 — Mechanical drawing of a current target

B.2 Current target specification

B.2.1 Current target specification — Insertion loss

Instead of specifying the insertion loss of the 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 only this chain and the oscilloscope need to be characterized, instead of each element individually.

The variation of the insertion loss of the target-attenuator-cable chain shall be less than ±0,5 dB between d.c. and 1 GHz.

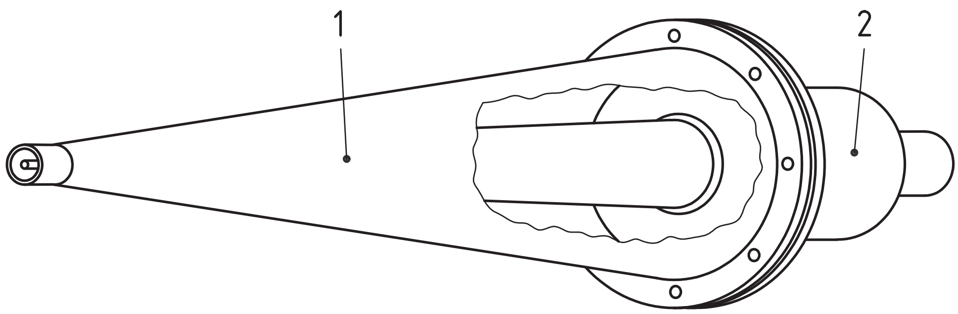
NOTE 1 If the variation limits of the insertion loss are exceeded, then by means of complex Fast Fourier transform (FFT) and inverse FFT, this response can be compensated for. However, this is not recommended.

NOTE 2 Different verification 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.

B.2.2 Target adapter line

The target adapter line shown in Figure B.6 may be used to connect 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 B.7) 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 relative permittivity of the material that fills the target adapter line (typically air). The target adapter line shall maintain 50 Ω ± 2 % within a 1 GHz bandwidth. The return loss of two target adapter lines placed face-to-face shall be greater than 30 dB up to 1 GHz. The insertion loss of the two target adapter lines placed face to face shall be less than ± 0,3 dB from d.c. to 1 GHz.

NOTE Interfacing with other connectors fulfilling the impedance and loss demands is possible.

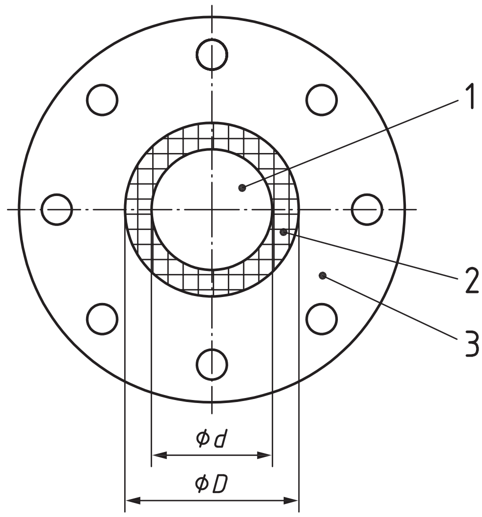


Key

1 conical adapter line

2 ESD current target

Figure B.6 — Target adapter line attached to current target



Key

1 inner electrode

2 resistive gap

3 ground

d outer diameter of the inner discharge tip

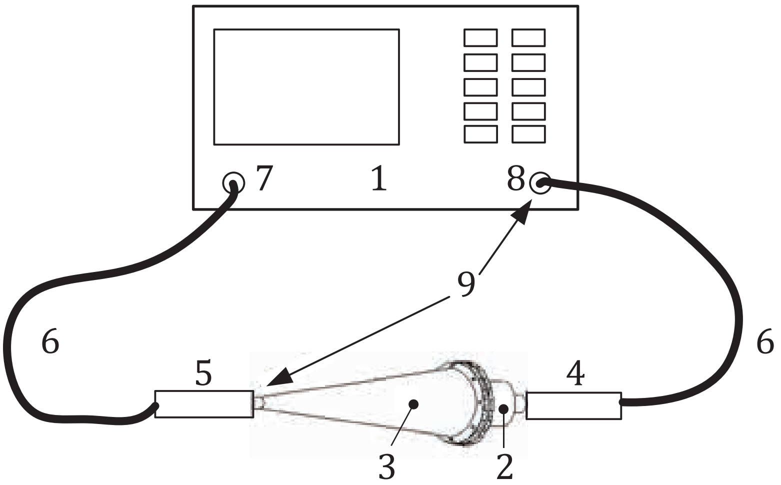
D inner diameter of the outer discharge tip

Figure B.7 — 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 by comparing a through connection to the chain (see Figure B.8). 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.



Key

1 network analyser
2 ESD current target
3 50 Ω conical adapter line
4 attenuator A
5 attenuator B
6 coaxial cable (between attenuator A and network analyser and between attenuator B and network analyser)
7 network analyser output connector
8 network analyser input connector
9 calibrate the network analyser at these points

NOTE The ESD current target, attenuator A and the coaxial cable are the target-attenuator-cable chain, which is verified using this set-up.

Figure B.8 — Network analyser measurement of the insertion loss of a current target-attenuator-cable chain

The measurement procedure for the insertion loss is to calibrate the network analyser at the verification points shown in Figure B.8.

If no network analyser is used, the procedure is modified accordingly:

— connect a target adapter line to the target-attenuator-cable chain and insert it as shown in Figure B.8;

— measure the insertion loss.

The variation of the insertion loss of the target-attenuator-cable chain shall be less than ±0,5 dB, between d.c. and 1 GHz.

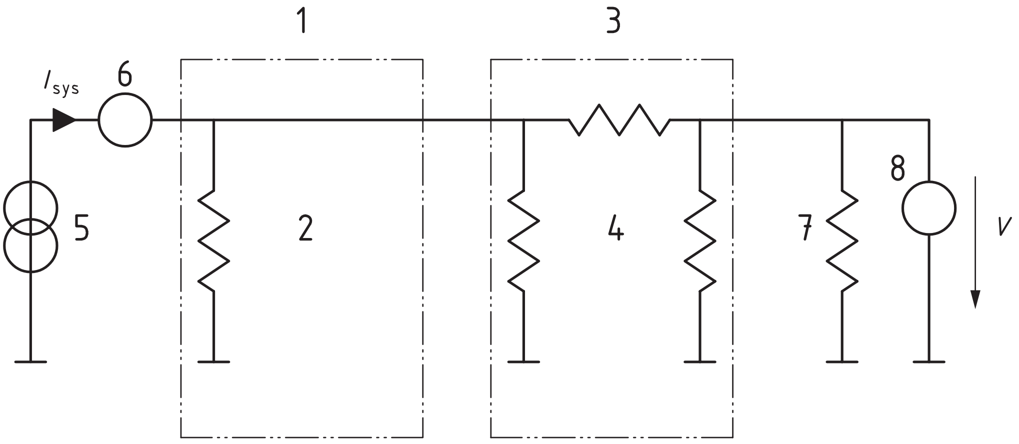
NOTE 1 Instead of d.c., the lowest frequency available with the network analyser is used. The DC characteristics are measured separately.

NOTE 2 Different verification 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 can 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.

B.2.4 Determining the DC transfer resistance of a target-attenuator-cable chain

The DC transfer resistance 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. placed at the end of the cable instead of the oscilloscope). The circuit diagram is illustrated in Figure B.9.

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 DC system transfer resistance Z_{sys}.



Key

1 target
2 example of internal circuit of a current target (other circuits are possible)
3 attenuator
4 internal circuit of an attenuator
5 DC current source
6 ammeter
7 50 Ω load
8 digital voltmeter (DVM)

Figure B.9 — Circuit diagram to determine the DC system transfer resistance

The DC system transfer resistance of the target-attenuator-cable chain may be determined by the method below.

— Inject 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 shall be known within ±1 %. Larger currents may be used if they do not thermally stress the target beyond its specifications. Measure the test voltage V across the precision 50 Ω load.

— Calculate the transfer impedance according to Formula (B.1):

$$Z_{sys} = \frac{V}{I_{sys}} \quad (B.1)$$

NOTE To verify that thermal voltages do not influence the result, the measurement can be done with positive and negative current. A check is made that the two results are within 0,5 % of each other.

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

Annex C
(informative)

Function performance status classification (FPSC)

C.1 General

This annex provides a general method for defining the acceptable performance of electrical/electronic functions of automotive electrical systems during and after ESD immunity testing. This method is based on the following considerations:

b) a DUT/vehicle can include one or several functions (e.g. an electronic unit can manage front wiping, courtesy lighting and low beam lighting);

c) a function can have one or several operating modes (e.g. low beam ON, low beam OFF, courtesy lighting ON, courtesy lighting OFF);

d) an operating mode can have several statuses (I, II, III, IV) (e.g. in low beam ON operating mode, the status II can be associated to low beam OFF during disturbance application with automatic recovery of low beam after disturbance suppression).

The functional performance status classification is applicable to each function.

C.2 FPSC approach

The approach is based on the following principles:

a) functional performance status classification is applicable to each individual function; hence, a vehicle will have many functions and a DUT is likely to include several functions (e.g. an electronic unit can manage front wiping, courtesy lighting and low beam lighting);

b) a function can be a simple on-off operation or it can be complex, like data communication on a data bus.

It has to be emphasized that, as described in this document, components or systems shall only be tested under the conditions that represent the simulated automotive electromagnetic environments to which the devices would actually be subjected. This will help to ensure a technically and economically optimized design for potentially susceptible components and systems.

It should also be noted that this annex is not intended to be a product specification and cannot function as one. It should be used in conjunction with a specific test procedure in this document. Therefore, no specific values for the test signal severity level are included in this annex since they should be determined by the vehicle manufacturers and component suppliers. Nevertheless, using the concepts described in this annex and by careful application and agreement between manufacturer and supplier, this annex can be used to describe the functional status requirements for a specific device. This can then, in fact, be a statement of how a particular device can be expected to perform under the influence of the specified test signals.

C.3 Essential elements of FPSC

C.3.1 General

There are two elements, outlined in C.3.2 and C.3.3, required to describe an FPSC.

C.3.2 Function performance status

This element defines the expected performance objectives for the function of the DUT subjected to the test conditions. The four function performance statuses of the function (expected behaviour of the function observed during testing) are listed below.

NOTE 1 This element is applicable to every single individual function of a DUT and describes the operational status of the defined function during and after a test.

NOTE 2 The minimum functional status is given in each test. An additional test requirement can be agreed between supplier and vehicle manufacturer.

a) **Status I:** The function performs as designed, during and after the test.

b) **Status II:** The function does not perform as designed during the test, but returns automatically to normal operation after the test.

c) **Status III:** The function does not perform as designed during the test and does not return to normal operation without a simple driver/passenger intervention, such as turning off/on the DUT, or cycling the ignition switch after the disturbance is removed.

d) **Status IV:** The function does not perform as designed during or after the test and cannot be returned to proper operation without more extensive intervention, such as disconnecting and reconnecting the battery or power feed. The function shall not have sustained any permanent damage as a result of the testing.

C.3.3 Test signal severity level

This element defines the specification of test signal severity level (test severity level) of essential signal parameters. The test signal severity level is the stress level applied to the DUT for any given test method. The test signal severity levels should be determined by the vehicle manufacturer and supplier depending on the required operational characteristics of the function.

C.4 FPSC approach example

C.4.1 General example of FPSC application

Figure C.1 demonstrates the relationship between the test signal severity levels and their corresponding function performance status classification.

Comments listed in Figure C.1 can be interpreted as follows:

a) the function should be nominal event No. 1 (Status I) up to severity level L_1;

b) unexpected event No. 2 is allowed above test severity level L_1;

c) unexpected event No. 3 is allowed above test severity level L_2.

Users may group functions into categories to allow the use of different test levels.

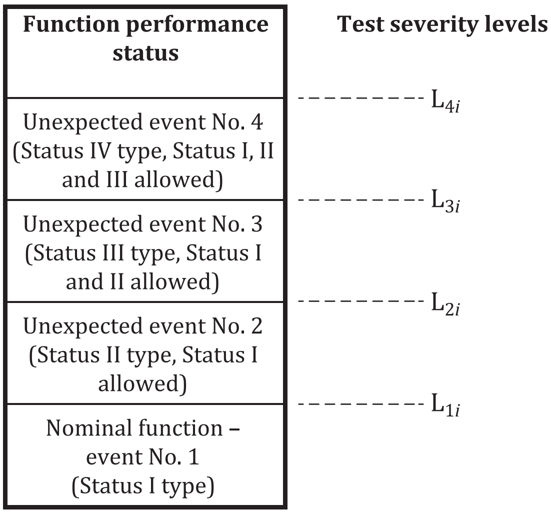


Figure C.1 — Illustration of function performance status classification

C.4.2 Suggested test severity levels

Tables C.1 to C.9 provide examples of test severity levels.

Table C.1 — Component test — Example severity levels for direct contact discharge

Test severity level	Category 1	Category 2	Category 3
L_{4i}	±8 kV	±8 kV	±15 kV
L_{3i}	±6 kV	±8 kV	±8 kV
L_{2i}	±4 kV	±4 kV	±6 kV
L_{1i}	±2 kV	±2 kV	±4 kV

Table C.2 — Component test — Example severity levels for direct air discharge

Test severity level	Category 1	Category 2	Category 3
L_{4i}	±15 kV	±15 kV	±25 kV
L_{3i}	±8 kV	±8 kV	±15 kV
L_{2i}	±4 kV	±6 kV	±8 kV
L_{1i}	±2 kV	±4 kV	±6 kV

Table C.3 — Component test — Example severity levels for indirect contact discharge

Test severity level	Category 1	Category 2	Category 3
L_{4i}	±8 kV	±15 kV	±20 kV
L_{3i}	±6 kV	±8 kV	±15 kV
L_{2i}	±4 kV	±4 kV	±8 kV
L_{1i}	±2 kV	±2 kV	±4 kV

Table C.4 — Component test — Packaging and handling — Example severity levels for direct contact discharge (connector pins)

	Category 1	Category 2	Category 3
Full function after test	±1 kV	±2 kV	±4 kV

Table C.5 — Component test — Packaging and handling — Example severity levels for direct air discharge

	Category 1	Category 2	Category 3
Full function after test	±8 kV	±15 kV	±25 kV

Table C.6 — Vehicle test — Example severity levels for contact discharge (test points accessible only from inside vehicle)

Test severity level	Category 1	Category 2	Category 3
L_{4i}	±6 kV	±8 kV	±8 kV
L_{3i}	±4 kV	±4 kV	±6 kV
L_{2i}	±2 kV	±2 kV	±2 kV
L_{1i}	not applicable	not applicable	not applicable

Table C.7 — Vehicle test — Example severity levels for air discharge (test points accessible only from inside vehicle)

Test severity level	Category 1	Category 2	Category 3
L_{4i}	±8 kV	±15 kV	±15 kV
L_{3i}	±6 kV	±8 kV	±8 kV
L_{2i}	±4 kV	±4 kV	±6 kV
L_{1i}	±2 kV	±2 kV	±4 kV

Table C.8 — Vehicle test — Example severity levels for contact discharge (test points accessible only from outside vehicle)

Test severity level	Category 1	Category 2	Category 3
L_{4i}	±6 kV	±8 kV	±8 kV
L_{3i}	±4 kV	±6 kV	±6 kV
L_{2i}	±2 kV	±2 kV	±4 kV
L_{1i}	not applicable	not applicable	±2 kV

Table C.9 — Vehicle test — Example severity levels for air discharge (test points accessible only from outside vehicle)

Test severity level	Category 1	Category 2	Category 3
L_{4i}	±15 kV	±15 kV	±25 kV
L_{3i}	±8 kV	±8 kV	±15 kV
L_{2i}	±4 kV	±6 kV	±8 kV
L_{1i}	±2 kV	±4 kV	±6 kV

Annex D
(informative)

Test method guidance — Generator resistor value and air or contact discharge

D.1 Resistor value selection

Testing with 2 kΩ resistor represents the discharge of a human body directly through the skin. Testing with 330 Ω resistor represents the discharge of a human body through a metallic part (e.g. tool, key, ring). A test with a 330 Ω resistor is more severe than testing with 2 kΩ.

Selection of the discharge resistance to be used for the test should be specified in the test plan.

D.2 Test method selection

The particular test method (air or contact) selected as appropriate for DUT evaluation should be determined by first establishing an intended result for the information that will be gained from the ESD test. Clauses D.3 to D.5 provide an overview of the two approaches, in conjunction with the advantages and disadvantages of each approach.

D.3 Air discharge

D.3.1 General

The air discharge method virtually replicates ESD, as it would occur in the actual environment. In effect, this means that the impulse current waveforms delivered to the DUT are allowed (and expected) to vary significantly from pulse to pulse.

D.3.2 Air discharge advantages

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

D.3.3 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 pulses to a DUT in order to fully (adequately) evaluate and understand the responses of the DUT and their probabilities of occurrence. Apart from the disadvantage of test time, the DUT may respond inconsistently to the ESD excitations. This produces serious repeatability problems in the test results, requiring further ESD tests to ultimately determine the performance profile of the DUT.

D.4 Contact discharge

D.4.1 General

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 that the impulse current waveforms delivered to the DUT will remain relatively consistent from pulse to pulse.

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 DUT surfaces, provided that the DUT surfaces are not fully nonconductive in construction.

D.4.2 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 a more consistent and repeatable DUT 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 impulses applied to the DUT at a relatively fast pulse repetition rate (if it is guaranteed that the charge built up in the meantime between two discharges can vanish). In practice, the use of the contact discharge method permits the evaluation of DUT susceptibility to ESD to be made in a manner that significantly conserves test time.

D.4.3 Contact discharge disadvantages

The major disadvantage of the contact discharge method is that it requires a surface conductivity at the point of test application. In addition, contact discharge testing may not provide an estimate of DUT response to actual-use voltages, since the random variations in the ESD waveform that exist 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.

D.5 DUT surfaces

D.5.1 General

The choice of test method may be made partly on the basis of whether the surfaces of the DUT are conductive or non-conductive.

D.5.2 Conductive surfaces

Conductive surfaces and coupling planes may be subjected to either the air or the contact discharge test method.

Due to better reproducibility, contact mode discharge should be used for conductive surfaces.

D.5.3 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 DUT, 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.

D.5.4 Indirect ESD tests

When performing indirect ESD testing, either the air or the contact method may be used, depending on the compatibility of the test method with the goals established for the simulation, as explained in Clauses D.3 and D.4. For this International Standard, only contact mode discharges are used for indirect ESD testing. The reason for this is that contact discharges are more reproducible and require less time between discharges.

Annex E
(informative)

Rationale for air discharge generator verification

It is possible to characterize the approximate behaviour of the generator in air discharge verification. Achieving results that are predictable and repeatable is subject to the same conditions of an air discharge ESD test, as explained in Clause D.3. One major problem is the approach speed of the charged generator discharge tip towards the uncharged verification target. Even with all other critical parameters (i.e. humidity, temperature and approach speed) held constant, the stochastic nature of the statistical time lag may create large changes in the rise time and peak current. 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 generator.

As the breakdown physics are independent of the generator design, there is no need to verify them. This gives two options for handling the time-dependent arc resistance:

— 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

— choose the parameters such that the arc influences the discharge current in a known manner.

In both cases, it is possible to investigate the electrical and mechanical design of the generator.

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

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

b) If the test 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 generator is discharged against the target at such a low-test voltage, the displayed waveform will be determined by the measurement system (rise time and also the peak value somewhat) and the generator design. Using this method, one would typically discharge the generator at 500 V against the target at fast approach speeds a couple of times and select the waveform that has the fastest rise time (during this discharge, the arc best approached an ideal switch). The obtained waveform can then be compared against a reference discharge waveform, in the knowledge that the displayed rise time may be totally determined by the measurement system, not the generator design.

c) Air discharge can be reproduced very well if the test 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 (possibly as slowly as 20 V/sec) increasing the test 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, for example, 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, no satisfactory verification method has been developed. Therefore, it was decided not to require an air discharge verification. 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 generator discharge tip test voltage) between discharges. This is exactly what happens in realistic air discharge ESD events.

Annex F
(informative)

Description of field coupling fixture for direct and indirect discharge to powered-up DUT

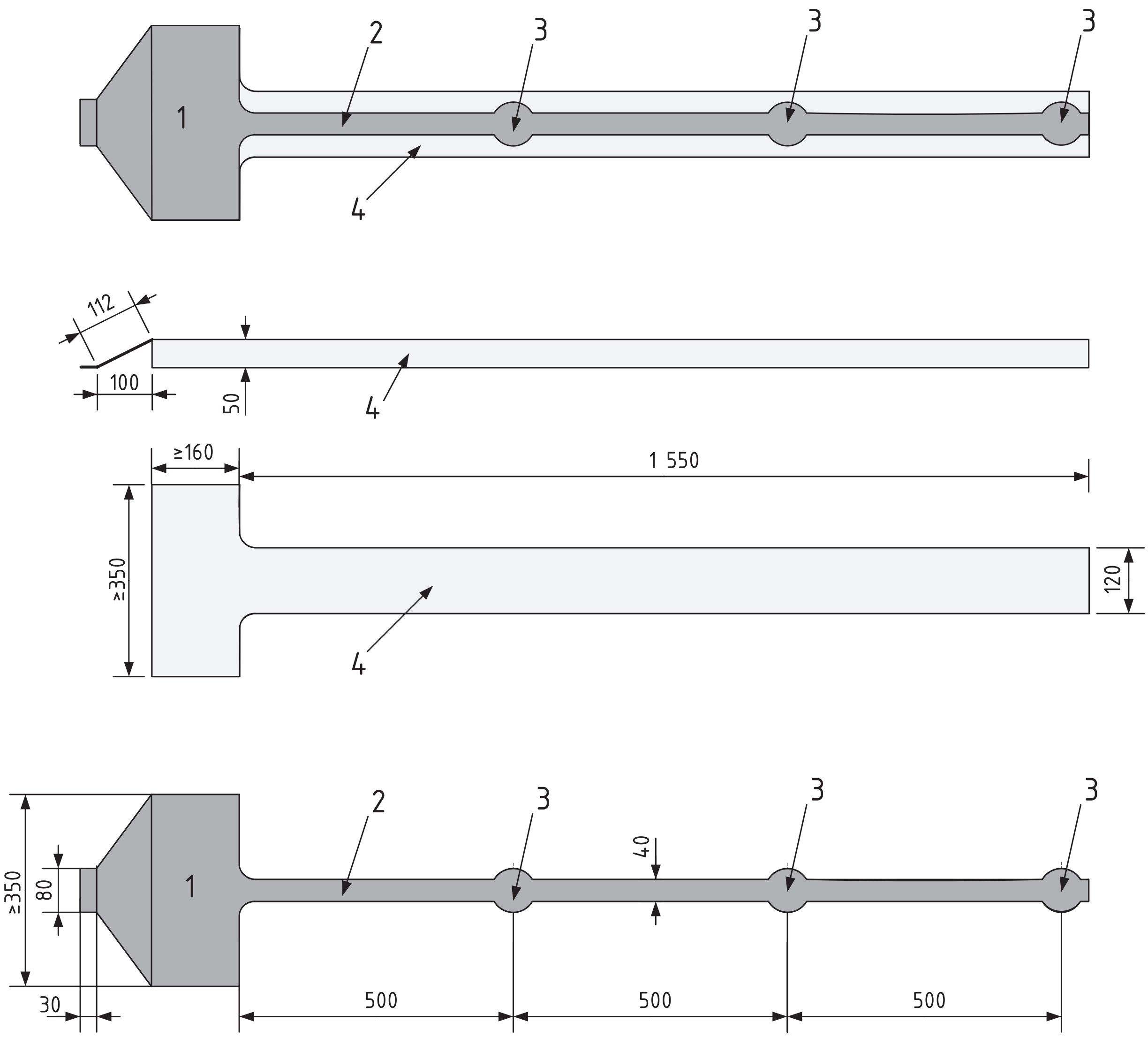
F.1 General

This annex introduces detailed information for the test fixture, to be used for direct and indirect discharge for powered-up DUT.

F.2 Test fixture

For schematic diagrams of the test fixture for this test, refer to Figure F.1.

Dimensions in millimetres



Key

1 field coupling plane at least 10 mm larger than the DUT on all sides, but with 160 mm × 350 mm minimum dimensions to support DUT and the tapered section to connect to the GP

2 field coupling strip (40 mm wide) to support the harness(es)

3 discharge islands — conductively bonded to, or one piece with, the field coupling strip; 80 mm in diameter

4 DUT and wiring harness isolation block: made of nonconductive material, $\varepsilon_r < 2{,}5$; 50 mm high (e.g. foamed polypropylene or Styrofoam)

NOTE The field coupling plane and field coupling strip are made of copper or brass, 0,5 mm to 2 mm thick. The tolerance of dimensions is ±5 %.

Figure F.1 — ESD Powered-up test — Bench top set-up

Annex G
(informative)

Test method guidance – automatic operated ESD testing

G.1 Scope

Manual ESD testing is a monotonous and exhausting work which may cause unwanted variability in test results when performed by human operators. Especially the ESD packaging and handling test on connector pins is a critical activity which requires precision and concentration, difficult to ensure by humans during a longer time. Automatic handling of the ESD-generator with robots can overcome the mentioned problems. Reproducibility can be significantly improved.

The automated operation of the ESD-generator requires modifications of the test environment which may influence the test results. The following chapter gives guidelines for possible modifications to avoid unwanted influence from automated testing setup.

G.2 Discharge tip modifications

The automated operation requires a modification of the discharge tip which allows an adaptation to the requirements of ESD landing pads, the non-elastic handling structure and mechanic adapters. The following modifications are in accordance to this document.

— A pin extension from 9.3.1 can be integrated into the discharge tip, defined in 6.2. The shape of the tip can be modified as long as the tip diameter does not exceed the given maximum value from 6.2.

— A metallic spring contact is permitted as long as the conductivity of tip is not affected.

Discharge current verification with the modified tip and robot discharge unit holder shall meet the requirements of this document.

G.3 Installation for automated operation

The automated operating apparatus (e.g. robot) requires definitions for the positioning and outline of the test environment. The following topics should be fixed for proper test conditions.

— The automated apparatus (e.g. robot) can be either positioned close to or on the test table.

— DUT can be fixed on the table using dielectric holders.

— Material of the test table to provide mechanical stability when robot is fixed on the test bench.

— Modified orientation of DUT and grounded extender to meet requirement for ESD landing pads close to the table.

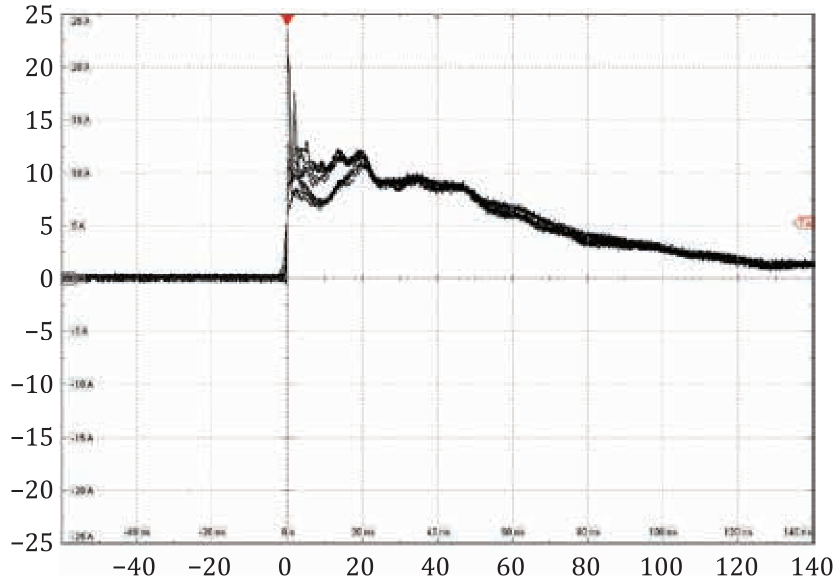
G.4 Examples of air discharge waveform with automatic operated ESD testing

Spike discharge currents may occur by human operated ESD testing depending on the approach speed of the tip, the approach angle of the tip to the surface of DUT, and whether the tip contacts the DUT or not. On the other hand, automatic operated testing may guarantee reproducible discharge currents compared to the human operated testing by controlling the conditions that could impact on discharge current waveform.

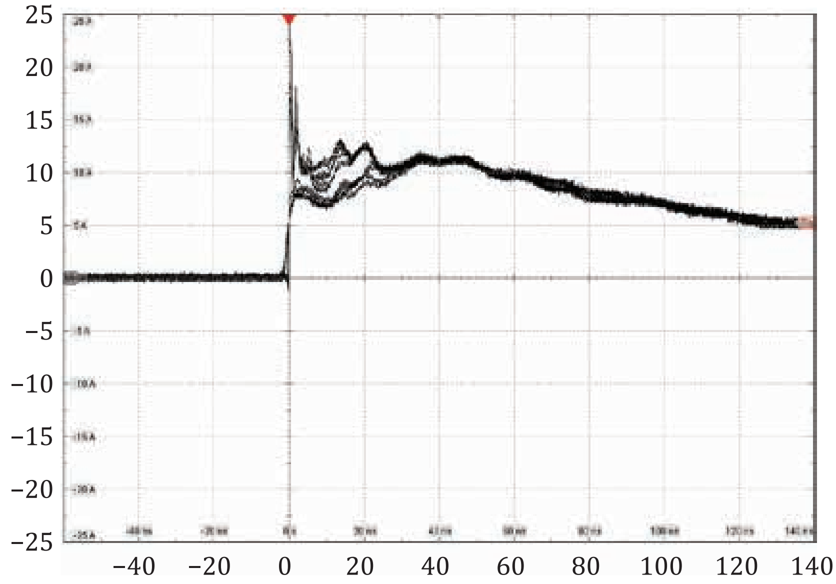
Figure G.1 and Figure G.2 are the measured example pictures of air discharge current waveforms when the tip approaches the target quickly enough (e.g. operating speed is 0,5 m/s and deceleration is -1,2 m/s^2) for the human operated and automatic operated testing respectively.

The discharge current waveforms in Figure G.1 show relatively poor reproducibility in human operated testing, in which the test conditions, such as the speed, are hardly controllable.

The discharge current waveforms in Figure G.2 show relatively good reproducibility in automatic operated testing, in which the test conditions are deemed to be controllable. Note that all the tests were performed with the discharge tip to be held perpendicular to the current target.

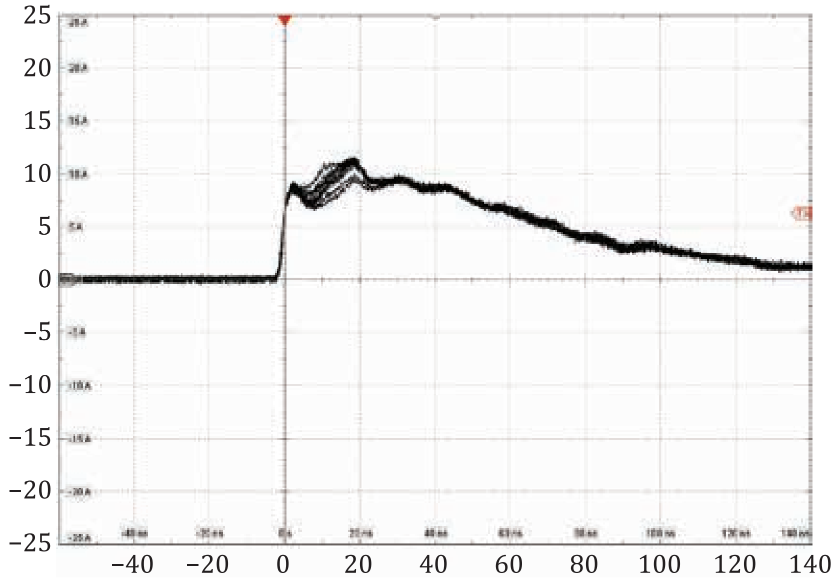


a) Discharge current with 150 pF, 330 Ω

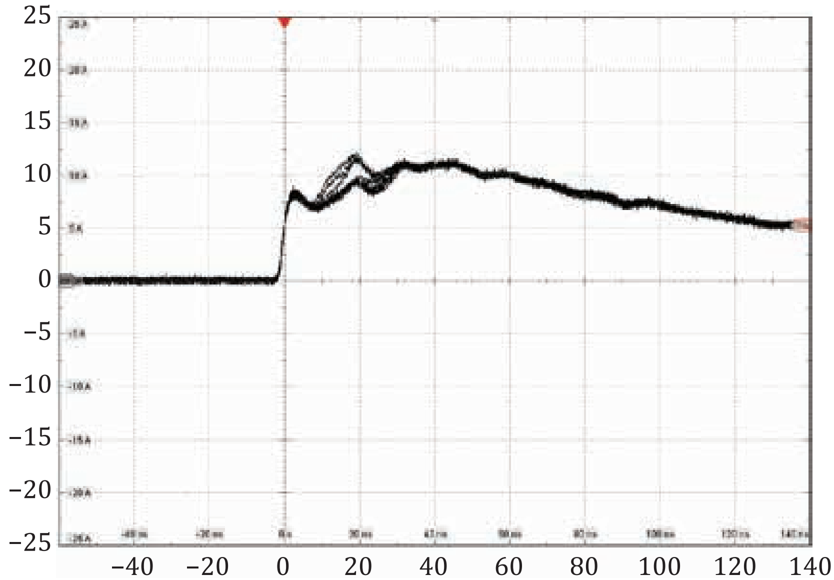


b) Discharge current with 330 pF, 330 Ω

Figure G.1 — Examples of + 5 kV air discharge current waveform by human operated testing



a) Discharge current with 150 pF, 330 Ω



b) Discharge current with 330 pF, 330 Ω

Figure G.2 — Examples of + 5 kV air discharge current waveform by automatic operated testing

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