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Road vehicles — Component test methods for electrical disturbances from narrowband radiated electromagnetic energy —

Part 4:
Harness excitation methods

Véhicules routiers — Méthodes d'essai d'un équipement soumis à des perturbations électriques par rayonnement d'énergie électromagnétique en bande étroite —

Partie 4: Méthodes d'excitation des faisceaux

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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 fifth edition cancels and replaces the fourth edition (ISO 11452-4:2011), which has been technically revised. The main changes compared to the previous edition are as follows:

— extension of the frequency range for BCI test method down to 100 kHz;

— introduction to reference to additional artificial networks (HV-AN, AMN, AAN) for DUT powered by a shielded power system;

— precisions for ground plane dimensions;

— addition of test set-up descriptions and Figures for DUT powered by a shielded power system;

— precisions for DUT with multiple connectors; and

— suppression of Annex C relative to artificial networks which are now defined in ISO 11452-1.

A list of all parts in the ISO 11452 series can be found on the ISO website.

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.

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Road vehicles — Component test methods for electrical disturbances from narrowband radiated electromagnetic energy —

Part 4:
Harness excitation methods

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1 Scope

This document specifies harness excitation test methods and procedures for determining the immunity of electronic components of passenger cars and commercial vehicles regardless of the propulsion system (e.g. spark-ignition engine, diesel engine, electric motor).

The bulk current injection (BCI) test method is based on current injection into the wiring harness using a current probe as a transformer where the harness forms the secondary winding.

The tubular wave coupler (TWC) test method is based on a wave coupling into the wiring harness using the directional coupler principle. The TWC test method was developed for immunity testing of automotive components with respect to radiated disturbances in the GHz ranges (GSM bands, UMTS, ISM 2,4 GHz). It is best suited to small (with respect to wavelength) and shielded device under test (DUT), since in these cases the dominating coupling mechanism is via the harness.

The electromagnetic disturbances considered in this document are limited to continuous narrowband electromagnetic fields.

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 11452-1:2015, *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 apply.

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

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

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

4 Test conditions

The applicable frequency ranges of the BCI and the TWC test methods are direct functions of the transducer characteristics (current probe or tubular wave coupler). More than one type of transducer may be required.

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To test automotive electronic systems, the typical applicable frequency range:

— of the BCI test method is 100 kHz to 400 MHz,

— of the TWC test method is 400 MHz to 3 GHz.

The users shall specify the test severity level(s) over the frequency range. Suggested test levels are included in Annex D.

Standard test conditions are given in ISO 11452-1 for the following:

— test temperature;

— supply voltage;

— modulation;

— dwell time;

— frequency step sizes;

— definition of test severity levels;

— test signal quality.

5 Test location

The tests shall be performed in a shielded enclosure.

6 Test instrumentation

6.1 BCI test method

6.1.1 General

BCI is a method of carrying out immunity tests by inducing disturbance signals directly into the wiring harness by means of a current injection probe. The injection probe is a current transformer through which the wiring harnesses of the device under test (DUT) are passed. Immunity tests are carried out by varying the test severity level and frequency of the induced disturbance.

The following equipment is used:

— ground plane;

— current injection probe(s);

— current measurement probe(s);

— artificial networks (AN), high voltage artificial networks (HV-AN), artificial mains networks (AMN), and asymmetric artificial networks (AAN);

— radio frequency (RF) generator with internal or external modulation capability;

— power amplifier;

— power measuring instrumentation to measure the forward and reverse power;

— current measurement equipment.

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6.1.2 Injection probe

An injection probe or set of probes capable of operating over the test frequency range is required to couple the test signal to the DUT. The probe(s) shall be capable of withstanding the necessary input power for the maximum test level over the test frequency range regardless of the test set-up loading.

Saturation of the injection probe by test level and by DUT current should be taken into consideration.

6.1.3 Current measurement probe

The current measurement probe or set of probes shall be capable of operating over the test frequency range.

6.1.4 Stimulation and monitoring of the DUT

The DUT shall be operated as required in the test plan by actuators which have a minimum effect on the electromagnetic characteristics, for example plastic blocks on the push-buttons, pneumatic actuators with plastic tubes.

Connections to equipment monitoring electromagnetic interference reactions of the DUT may be accomplished by using fibre-optics, or high-resistance leads. Other type of leads may be used but require extreme care to minimize interactions. The orientation, length and location of such leads shall be carefully documented to ensure repeatability of test results.

Any electrical connection of monitoring equipment to the DUT may cause malfunctions of the DUT. Extreme care shall be taken to avoid such an effect.

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6.2 TWC test method

6.2.1 General

The approach of this test method is an equivalent coupling to a plane wave coupling into a wiring harness of automotive components. To realize this, a short 50 Ω coaxial line configuration with open ends, an inner tube-shaped conductor and matched terminations are used to generate a transverse electromagnetic (TEM) wave inside. The wiring harness leads through the inner conductor of the wave coupler. This leads to two disturbing components for the DUT: a TEM wave component coupled via the cable, and a radiated component, caused by the scattering field from the primary TEM wave in the connecting cable between the coupler and the DUT.

The following equipment is used:

— ground plane;

— tubular wave coupler;

— artificial networks (AN), high voltage artificial networks (HV-AN), artificial mains networks (AMN), and asymmetric artificial networks (AAN);

— radio frequency (RF) generator with internal or external modulation capability;

— power amplifier;

— power measuring instrumentation to measure the forward and reverse power.

6.2.2 Tubular wave coupler

A tubular wave coupler is used to couple the disturbances into the test wiring harness. It shall be capable of coupling the test power over the test frequency range into the wiring harness and shall have a sufficiently high coupling and power rating.

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6.2.3 50 Ω load resistor

A 50 Ω load resistor is used to match the output of the tubular wave coupler. The power rating shall be equal or greater than the applied forward power.

6.2.4 Stimulation and monitoring of the DUT

See 6.1.4.

7 Test set-up for DUT powered by an unshielded power system

7.1 Ground plane

The ground plane shall be made of 0,5 mm thick (minimum) copper, brass or galvanized steel.

The minimum width of the ground plane shall be 1 000 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 ground plane shall be:

— 1 500 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 for the BCI method using the closed-loop method with power limitation,

— 2 000 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 for all other methods defined in this document.

The height of the ground plane (test bench) shall be (900 ± 100) mm above the floor.

The ground plane shall be bonded to the shielded enclosure such that the DC resistance shall not exceed 2,5 mΩ. The distance from the edge of the ground strap to the edge of the next strap shall not be greater than 300 mm. The maximum length to width ratio for the ground straps shall be 7:1.

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7.2 Power supply and AN

Each DUT power supply lead shall be connected to the power supply through an AN.

Power supply is assumed to be negative ground. If the DUT utilizes a positive ground, then the test set-ups shown in the figures need to be adapted accordingly. Power shall be applied to the DUT via 5 µH/50 Ω AN (see ISO 11452-1 for the schematic). The number of ANs required depends on the intended DUT installation in the vehicle.

— For a DUT remotely grounded (vehicle power return line longer than 200 mm), two ANs are required, one for the positive supply line and one for the power return line (see Annex C).

— For a DUT locally grounded (vehicle power return line 200 mm or shorter), one AN is required for the positive supply (see Annex C).

The AN(s) shall be mounted directly on the ground plane. The case or cases of the AN(s) shall be bonded to the ground plane.

The power supply return shall be connected to the ground plane between the power supply and the AN(s).

The measuring port of each AN shall be terminated with a 50 Ω load which is capable of dissipating the coupled RF power.

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The length of the power supply lines between the power supply and the load simulator shall be as short as possible and defined in the test plan. Unless otherwise specified, the power supply lines between the power supply and the load simulator shall be placed directly on the ground plane.

7.3 Location of the DUT

The DUT shall be placed on a non-conductive, low relative permittivity (dielectric constant) material ($\varepsilon_r \leq 1{,}4$), at (50 ± 5) mm above the metallic surface of the table.

The case of the DUT shall not be grounded to the metallic surface of the table unless it is grounded in the actual vehicle.

The face of the DUT shall be located at least 100 mm from the edge of the ground plane.

There should be a distance at least 500 mm between the DUT and any metal part such as the walls of the shielded room, with the exception of the ground plane on which the DUT is placed.

7.4 Location of the test harness

Unless otherwise specified in the test plan, the length of test harness between the DUT and the load simulator shall be:

— $\left(1\,700^{+300}_{0}\right)$ mm for all test methods defined in this document except for the BCI test method using the closed-loop method with power limitation;

— $\left(1\,000^{+200}_{0}\right)$ mm for the BCI test method using the closed-loop method with power limitation.

The wiring type is defined by the actual system application and requirement.

The wiring harness shall be straight:

— over at least 1 400 mm starting at the DUT for all test methods defined in this document except for the BCI test method using the closed-loop method with power limitation;

— over its entire length for the BCI test method using the closed-loop method with power limitation.

The wiring harness should be fixed (position and number of wires).

The wiring harness shall pass through the current injection and current measurement probes or the tubular wave coupler and shall be located parallel to the edge of the ground plane at least at 200 mm from the edge of the ground plane. The length of the wires in the load simulator should be short by comparison with the length of the harness. The wires within the load simulator should be fixed.

NOTE If all wires in the load simulator and the wiring harness have the same lengths, strong resonance effects might occur. This can be avoided by using or adding wires of different lengths in the load simulator.

The test harness (or each branch) shall be placed on a non-conductive, low relative permittivity (dielectric constant) material ($\varepsilon_r \leq 1{,}4$), with a thickness of (50 ± 5) mm.

For DUTs with multiple harness branches, the branches not included in the probe shall be placed at least 100 mm away from the branch included in the probe.

7.5 Location of the load simulator

Unless otherwise specified in the test plan, the load simulator should be placed directly on the ground plane. If the load simulator has a metallic case, this case shall be bonded to the ground plane.

Alternatively, the load simulator may be located adjacent to the ground plane (with the case of the load simulator bonded to the ground plane) or outside of the test chamber, provided the test harness from

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the DUT passes through an RF boundary bonded to the ground plane. The layout of the test harness that is connected to the load simulator shall be defined in the test plan and recorded in the test report.

When the load simulator is located on the ground plane, the DC power supply lines of the load simulator shall be connected through the AN(s).

7.6 Location of the harness excitation

7.6.1 BCI test method

7.6.1.1 Substitution method

The injection probe shall be placed at (150 ± 50) mm from the connector of the DUT. Additional tests at d = (450 ± 50) mm and d = (750 ± 50) mm may be required.

Distances from DUT are measured from the centre/midpoint of probes.

If a current measurement probe is used during the test, it shall be placed at (50 ± 10) mm from the connector of the DUT.

An example of a test configuration is shown in Figure 1.

7.6.1.2 Closed-loop method with power limitation

The injection probe shall be placed at (900 ± 10) mm from the connector of the DUT.

Distance from DUT is measured from the centre/midpoint of the injection probe.

The current measurement probe shall be placed at (50 ± 10) mm from the connector of the DUT.

An example of a test configuration is shown in Figure 2.

7.6.2 TWC test method

The tubular wave coupler shall be placed at (100 ± 10) mm from the DUT and isolated from the ground plane. It shall be connected to the high-frequency equipment at the port, which is closer to the DUT. The 50 Ω load resistor shall be insulated from the ground plane and placed at a minimum distance of 200 mm from the wiring harness and connected to the second port of the TWC.

Figure 3 gives an example for the test set-up.

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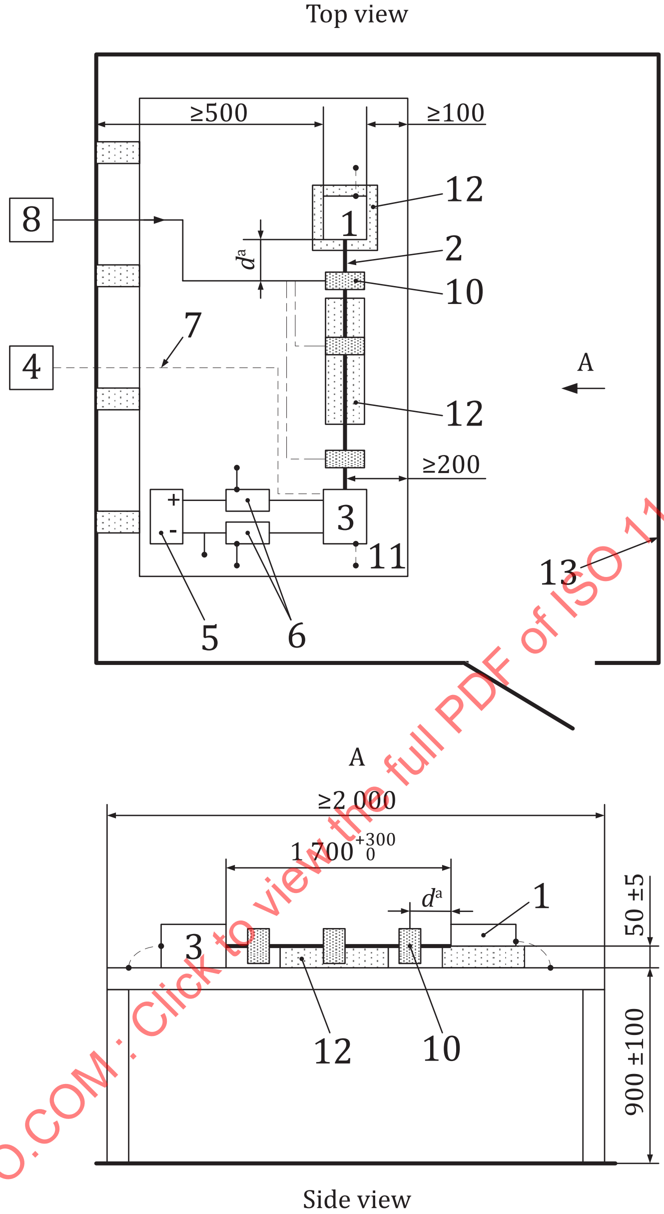
Dimensions in millimetres



Key

1 DUT (grounded locally if required in test plan)

2 test harness

3 load simulator (placement and ground connection according to 7.5)

4 stimulation and monitoring system

5 power supply

6 AN

7 optical fibres

8 high frequency equipment (generator, amplifier and measuring instruments)

9 optional current measurement probe (not shown in this figure, but shown in Figure 2)

10 injection probe (represented at 3 positions)

11 ground plane (bonded to shielded enclosure)

12 low relative permittivity support ($\varepsilon_r \leq 1,4$)

13 shielded enclosure

a See 7.6.1.1.

Figure 1 — BCI configuration — Substitution method

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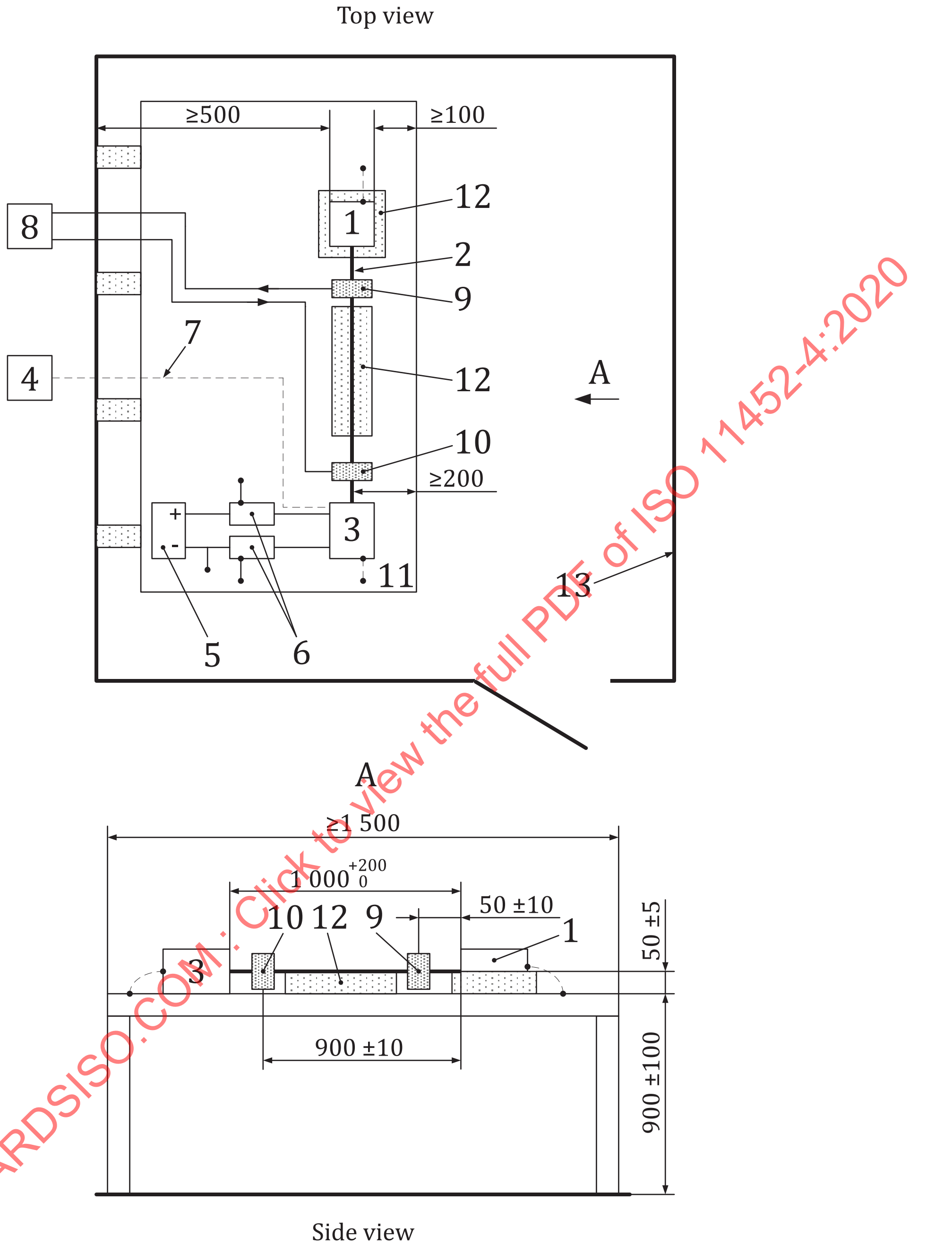
Dimensions in millimetres



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Key

1 DUT (grounded locally if required in test plan)

2 test harness

3 load simulator (placement and ground connection according to 7.5)

4 stimulation and monitoring system

5 power supply

6 AN

7 optical fibres

8 high frequency equipment (generator, amplifier and measuring instruments)

9 current measurement probe

10 injection probe

11 ground plane (bonded-to shielded enclosure)

12 low relative permittivity support ($\varepsilon_r \leq 1{,}4$)

13 shielded enclosure

Figure 2 — BCI configuration — Closed-loop method with power limitation

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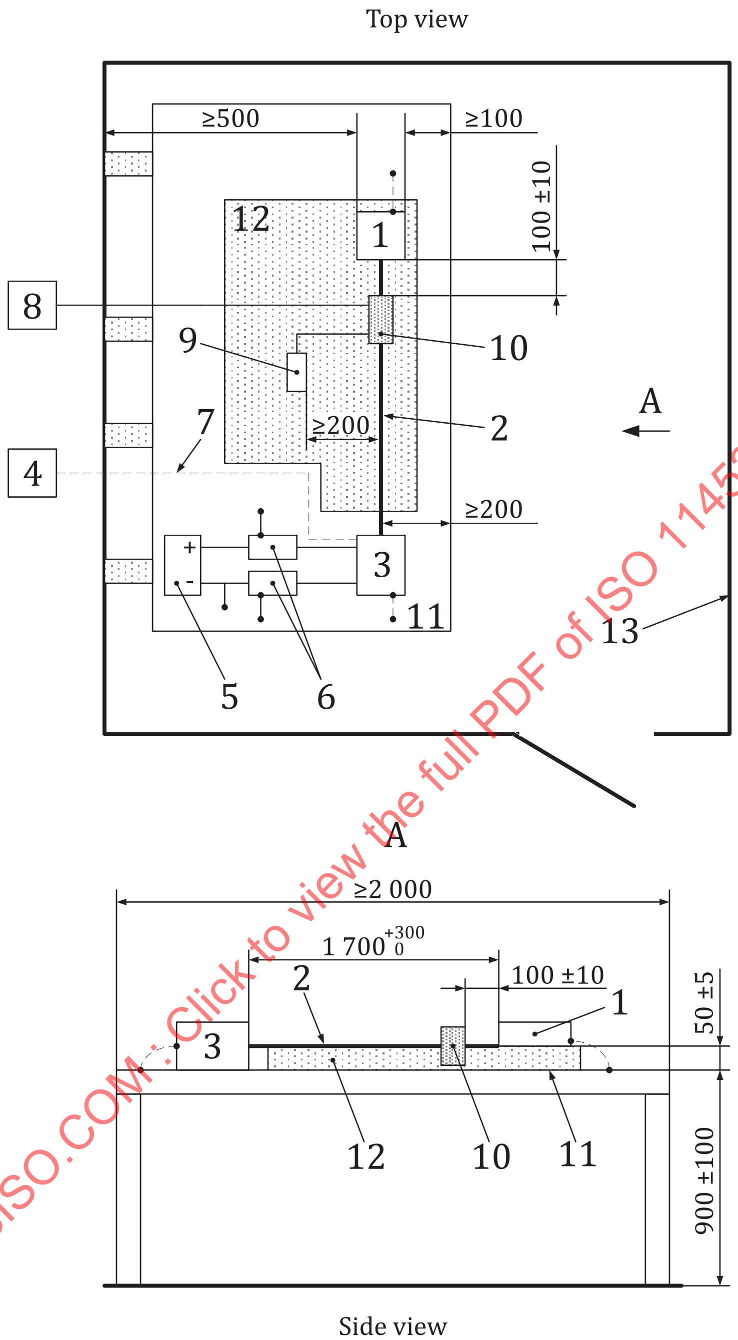
Dimensions in millimetres



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Key

1 DUT (grounded locally if required in test plan)
2 test harness
3 load simulator (placement and ground connection according to 7.5)
4 stimulation and monitoring system
5 power supply
6 AN
7 optical fibres
8 high frequency equipment (generator, amplifier and measuring instruments)
9 50 Ω load
10 tubular wave coupler
11 ground plane (bonded-to shielded enclosure)
12 low relative permittivity support ($\varepsilon_r \leq 1{,}4$)
13 shielded enclosure

Figure 3 — Tubular wave coupler test set-up

8 Test setup for DUT powered by a shielded power system

8.1 Ground plane

The ground plane conditions defined in 7.1 apply.

8.2 Power supply and AN, HV-AN, AMN and AAN

Each DUT power supply lead shall be connected to the power supply through an HV-AN (for DUT with DC HV supply) and/or AMN (for DUT with AC supply).

— DC HV supply shall be applied to the DUT via a 5 µH/50 Ω HV-AN (see ISO 11452-1 for the schematic).

— AC supply shall be applied to the DUT via a 50 µH/50 Ω AMN (see ISO 11452-1 for the schematic).

The HV-AN(s) shall be mounted directly on the ground plane. The case or cases of the HV-AN(s) shall be bonded to the ground plane.

The measuring port of each HV-AN(s) shall be terminated with a 50 Ω load.

The vehicle HV battery should be used; otherwise the external HV power supply shall be connected via feed-through-filtering.

Shielded supply lines for the positive HV DC terminal line (HV+), the negative HV DC terminal line (HV−) and three phase AC lines may be separate coaxial cables or in a common shield depending on the connector system used.

The shielded harnesses used for this test shall be representative of the vehicle application in terms of cable construction and connector termination as defined in the test plan.

Care should be taken when using a power line filter (Key 16) on the HV supply line. This filter will increase the common mode capacitance between HV+ and ground reference or HV- and ground reference and may lead to the generation of extra resonances.

For charger, the AMN(s) shall be mounted on the ground plane. The case or cases of the AMN(s) shall be bonded to the ground plane. The charger PE (protective earth) line shall be bounded to the ground plane and to the AMN(s) PE connection.

For charger/inverter with communication, AAN (see ISO 11452-1 for the schematic) may be inserted in the communication line between the charger/inverter and the communication interface.

The measuring port of each AAN(s) shall be terminated with a 50 Ω load.

The measuring port of each HV-AN(s) / AMN(s) shall be terminated with a 50 Ω load.

8.3 Location of DUT

Unless otherwise specified, the DUT shall be placed directly on the ground plane with the DUT case bonded to the ground plane either directly or via defined impedance.

The face of the DUT shall be located at least 100 mm from the edge of the ground plane.

There should be a distance at least 500 mm between the DUT and any metal part such as the walls of the shielded room, with the exception of the ground straps and of the ground plane on which the DUT is placed.

In case of a charger, the battery charger case shall be bonded to the ground plane.

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8.4 Location of test harness

Unless otherwise specified in the test plan (e.g. use of original vehicle harnesses), the length of harnesses shall be as follows:

— $1\,700^{+300}_{0}$ mm for the HV lines, LV lines and AC lines for all test methods defined in this document except for the BCI test method using the closed-loop method with power limitation,

— $1\,000^{+200}_{0}$ mm for the HV lines, LV lines and AC lines for the BCI test method using the closed-loop method with power limitation,

— less than 1 000 mm for the three phase lines between DUT and electric motor(s).

The HV/LV/AC wiring type is defined by the actual system application and requirement.

The HV/LV/AC wiring harness shall be straight:

— over at least 1 400 mm starting at the DUT for all test methods defined in this document except for the BCI test method using the closed-loop method with power limitation;

— over its entire length for the BCI test method using the closed-loop method with power limitation.

The HV/LV/AC wiring harness should be fixed (position and number of wires).

The long segment of HV lines test harness shall pass through the current injection and current measurement probes or the tubular wave coupler and shall be located parallel to the edge of the ground plane at least at 200 mm from the edge of the ground plane. The long segment of the LV lines test harness shall be located at 100^{+100}_{0} mm from the HV lines test harness (as shown in Figures 4, 5, 6, 8, 9, 10, 12, 13 and 14).

Unless otherwise specified in the test plan, the configuration with the long segment of LV lines test harness passing through the current injection and current measurement probes or the tubular wave coupler with no change of the HV lines test harness and LV lines test harness positions on the test bench shall be tested.

The length of the wires in the load simulator should be short by comparison with the length of the harness. The wires within the load simulator should be fixed.

NOTE If all wires in the load simulator and the wiring harness have the same lengths, strong resonance effects might occur. This can be avoided by using or adding wires of different lengths in the load simulator.

All of the harnesses shall be placed on a non-conductive, low relative permittivity material ($\varepsilon_r \leq 1{,}4$) at (50 ± 5) mm above the ground plane.

The shielded harnesses used for this test shall be representative of the vehicle application in terms of cable construction and connector termination as defined in the test plan. Unless otherwise specified, the shielding of the shielded harnesses shall be bonded to the load simulator case with a 360° connection.

For inverter / charger device, the setup in Figures 7, 11 and 15 are examples for further HV and LV load simulators and supplies attached to the DUT, like for example for testing an on-board charger and its communication links. The distance between the AC power lines and the closest harness (LV or HV) shall be 100^{+100}_{0} mm. Various combinations of the shown setups are possible based on the true application of the HV DUT.

Unless otherwise specified in the test plan, for inverter / charger (see Figures 7, 11 and 15) the configuration with the AC power lines passing through the current injection and current measurement probes or the tubular wave coupler with no change of the HV lines test harness and LV lines test harness positions on the test bench shall be tested.

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For inverter / charger, communication line(s) and AAN(s), if used, shall be defined in the test plan (they are not shown in Figures 7, 11 and 15).

Unless otherwise specified in the test plan, if there are three phases and/or signal lines between the electric motor and the DUT with a length greater or equal to 1 000 mm, the configuration using both HV lines (e.g. the three phases) and the LV signal lines passing simultaneously through the current injection and current measurement probes or the tubular wave coupler shall also be tested. The detailed test configuration shall be defined in the test plan. Examples of setup are shown in Figures 6, 10 and 14.

8.5 Location of load simulator

Unless otherwise specified in the test plan, the load simulator should be placed directly on the ground plane. If the load simulator has a metallic case, this case shall be bonded to the ground plane.

Alternatively, the load simulator may be located adjacent to the ground plane (with the case of the load simulator bonded to the ground plane) or outside of the test chamber, provided the test harness from the DUT passes through an RF boundary bonded to the ground plane. The layout of the test harness that is connected to the load simulator shall be defined in the test plan and recorded in the test report.

When the load simulator is located on the ground plane, the DC power supply lines of the load simulator shall be connected through the AN(s).

Unless otherwise specified, the electric motor shall be mounted on a non-conductive insulating support and its housing bonded to the ground plane. The load machine emulation may be placed outside the shielded room. In case of using a load machine emulation, the test plan shall define the connection conditions between the DUT and the load machine emulation and also the necessary grounding conditions. The load machine emulation will replace the “electric motor”, the “mechanical connection”, the “filtered mechanical bearing” and the “brake or propulsion motor”. The three phase motor supply lines will be fed through a power line filter.

The electric motor may be placed on a separate ground plane. In this case, the test plan shall define the connection configuration between this separate motor ground plane and the DUT ground plane (representing the vehicle grounding configuration).

8.6 Location of the harness excitation

8.6.1 BCI test method

8.6.1.1 Substitution method

The injection probe shall be placed at (150 ± 50) mm from the HV/LV/AC connector of the DUT. Additional tests at d = (450 ± 50) mm and d = (750 ± 50) mm may be required.

If a current measurement probe is used during the test, it shall be placed at (50 ± 10) mm from the HV/LV/AC connector of the DUT.

The probes may need to be elevated above the test bench to meet these requirements.

An example of a test configuration is shown in Figures 4, 5, 6 and 7.

8.6.1.2 Closed-loop method with power limitation

The injection probe shall be placed at (900 ± 10) mm from the HV/LV/AC connector of the DUT.

The current measurement probe shall be placed at (50 ± 10) mm from the HV/LV/AC connector of the DUT.

An example of a test configuration is shown in Figures 8, 9, 10 and 11.

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8.6.2 TWC test method

The tubular wave coupler shall be placed at (100 ± 10) mm from the DUT and isolated from the ground plane. It shall be connected to the RF signal generator and amplifier at the port, which is closer to the DUT. The 50 Ω load resistor shall be insulated from the ground plane and placed at a minimum distance of 200 mm from the closest wiring harness and connected to the second port of the TWC.

Figures 12, 13, 14 and 15 give an example for the test set-up.

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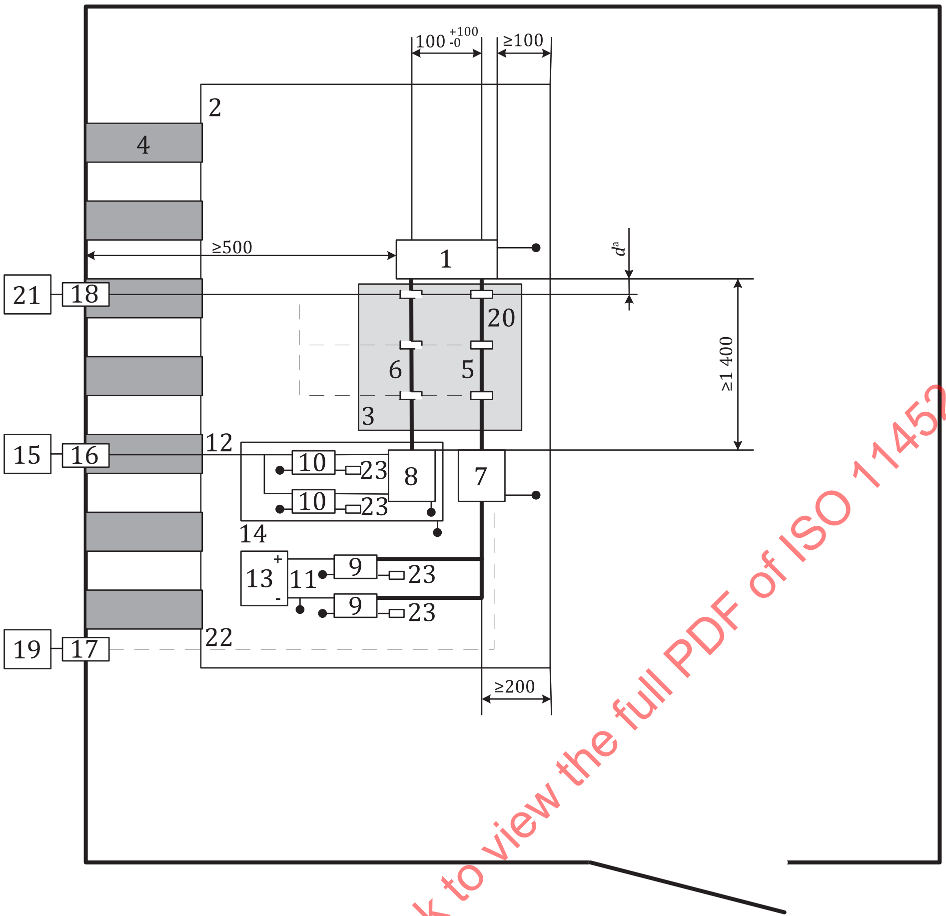
Dimensions in millimetres



Key

1 DUT

2 ground plane

3 low relative permittivity support ($\varepsilon_r \leq 1{,}4$); thickness 50 mm

4 ground straps

5 LV harness

6 HV lines (HV+, HV-)

7 LV load simulator

8 impedance matching network (optional) (see ISO 11452-1)

9 AN

10 HV-AN

11 LV supply lines

12 HV supply lines

13 LV power supply 12 V / 24 V / 48 V (should be placed on the bench)

14 additional shielded box (if necessary)

15 HV power supply (should be shielded if placed inside shielded enclosure)

16 power line filter

17 fibre optic feed through

18 bulk head connector

19 stimulating and monitoring system

20 injection probe

21 high frequency equipment (generator, amplifier and measuring instruments)

22 optical fibre

23 50 Ω load

[a] See 8.6.1.1.

Figure 4 — Example of test set-up – BCI Substitution method – Injection on LV (or HV) lines for DUTs with shielded power supply systems

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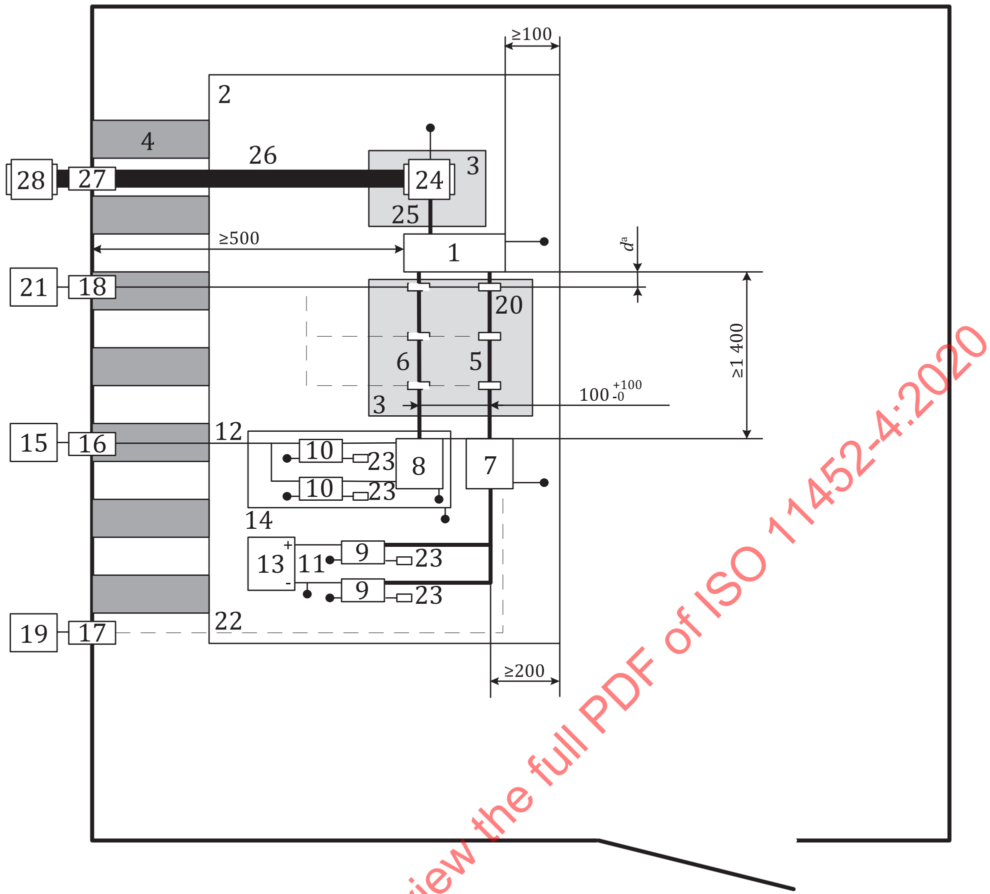
Dimensions in millimetres



Key

1 DUT

2 ground plane

3 low relative permittivity support ($\varepsilon_r \leq 1,4$); thickness 50 mm

4 ground straps

5 LV harness

6 HV lines (HV+, HV-)

7 LV load simulator

8 impedance matching network (optional) (see ISO 11452-1)

9 AN

10 HV-AN

11 LV supply lines

12 HV supply lines

13 LV power supply 12 V / 24 V / 48 V (should be placed on the bench)

14 additional shielded box (if necessary)

15 HV power supply (should be shielded if placed inside shielded enclosure)

16 power line filter

17 fibre optic feed through

18 bulk head connector

19 stimulating and monitoring system

20 injection probe

21 high frequency equipment (generator, amplifier and measuring instruments)

22 optical fibre

23 50 Ω load

24 electric motor

25 three phase motor supply lines

26 mechanical connection (e.g. non-conductive)

27 filtered mechanical bearing (if brake or propulsion motor placed outside the shielded room)

28 brake or propulsion motor (can be placed inside the shielded room)

[a] See 8.6.1.1.

Figure 5 — Example of test set-up – BCI Substitution method – Injection on LV (or HV) lines for DUTs with shielded power supply systems with electric motor attached to the bench

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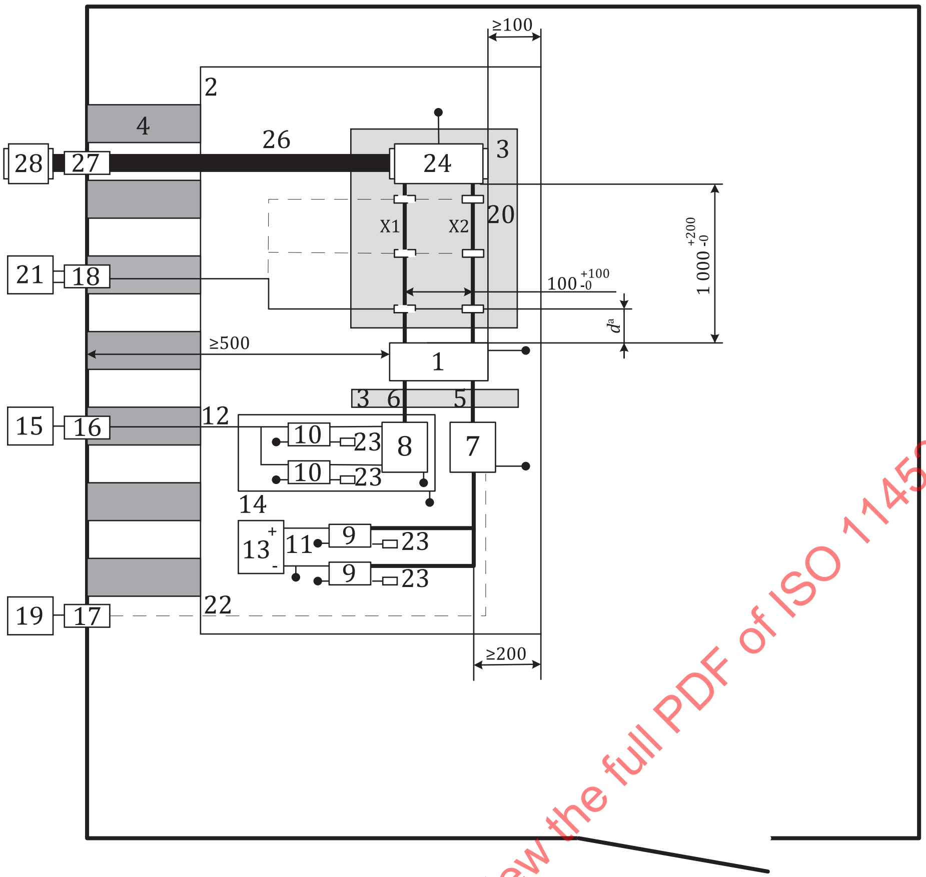
Dimensions in millimetres



Key

1 DUT

2 ground plane

3 low relative permittivity support ($\varepsilon_r \leq 1,4$); thickness 50 mm

4 ground straps

5 LV harness

6 HV lines (HV+, HV-)

7 LV load simulator

8 impedance matching network (optional) (see ISO 11452-1)

9 AN

10 HV-AN

11 LV supply lines

12 HV supply lines

13 LV power supply 12 V / 24 V / 48 V (should be placed on the bench)

14 additional shielded box (if necessary)

15 HV power supply (should be shielded if placed inside shielded enclosure)

16 power line filter

17 fibre optic feed through

18 bulk head connector

19 stimulating and monitoring system

20 injection probe

21 high frequency equipment (generator, amplifier and measuring instruments)

22 optical fibre

23 50 Ω load

24 electric motor

X1 three phase motor supply lines

X2 sensor lines (e.g. resolver, temperature, …)

26 mechanical connection (e.g. non-conductive)

27 filtered mechanical bearing (if brake or propulsion motor placed outside the shielded room)

28 brake or propulsion motor (can be placed inside the shielded room)

[a] See 8.6.1.1.

Figure 6 — Example of test set-up – BCI Substitution method – Injection on electric motor lines for DUTs with shielded power supply systems with electric motor attached to the bench

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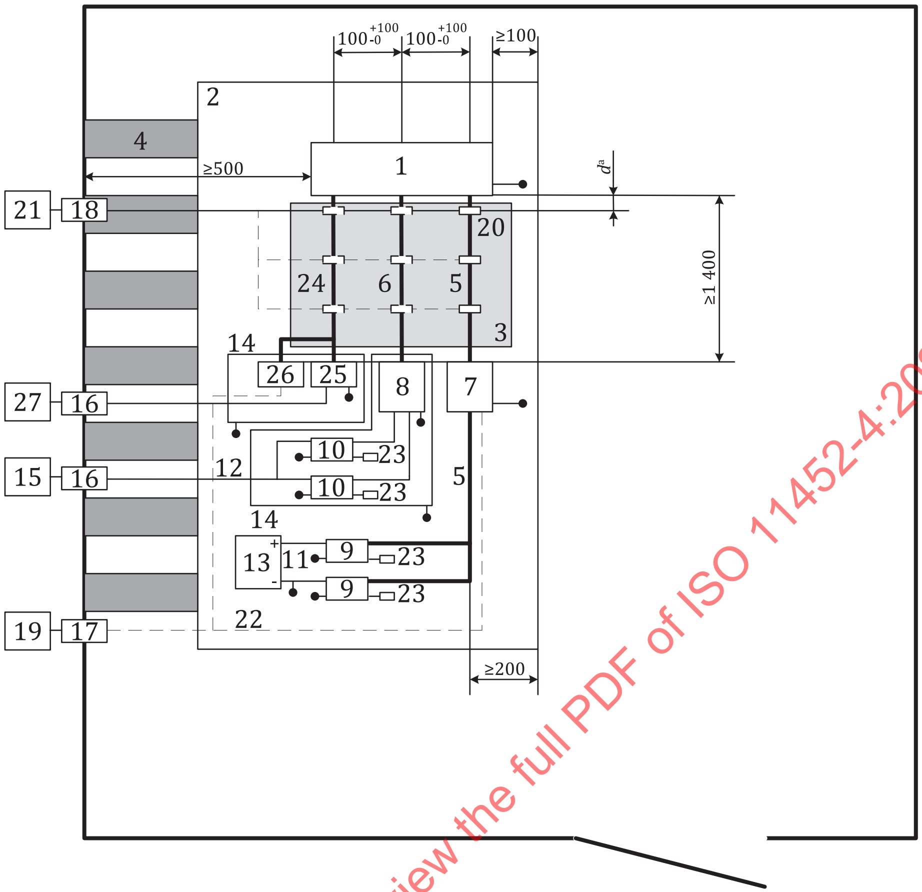
Dimensions in millimetres



Key

1 DUT
2 ground plane
3 low relative permittivity support ($\varepsilon_r \leq 1{,}4$); thickness 50 mm
4 ground straps
5 LV harness
6 HV lines (HV+, HV-)
7 LV load simulator
8 impedance matching network (optional) (see ISO 11452-1)
9 AN
10 HV-AN
11 LV supply lines
12 HV supply lines
13 LV power supply 12 V / 24 V / 48 V (should be placed on the bench)
14 additional shielded box (if necessary)
15 HV power supply (should be shielded if placed inside shielded enclosure)
16 power line filter
17 fibre optic feed through
18 bulk head connector
19 stimulating and monitoring system
20 injection probe
21 high frequency equipment (generator, amplifier and measuring instruments)
22 optical fibre
23 50 Ω load
24 AC lines
25 AMN for AC power mains
26 AC charging load simulator
27 AC power mains

a See 8.6.1.1.

Figure 7 — Example of test set-up – BCI Substitution method – Injection on LV (or HV or AC) lines for DUTs with shielded power supply systems and inverter/charger device

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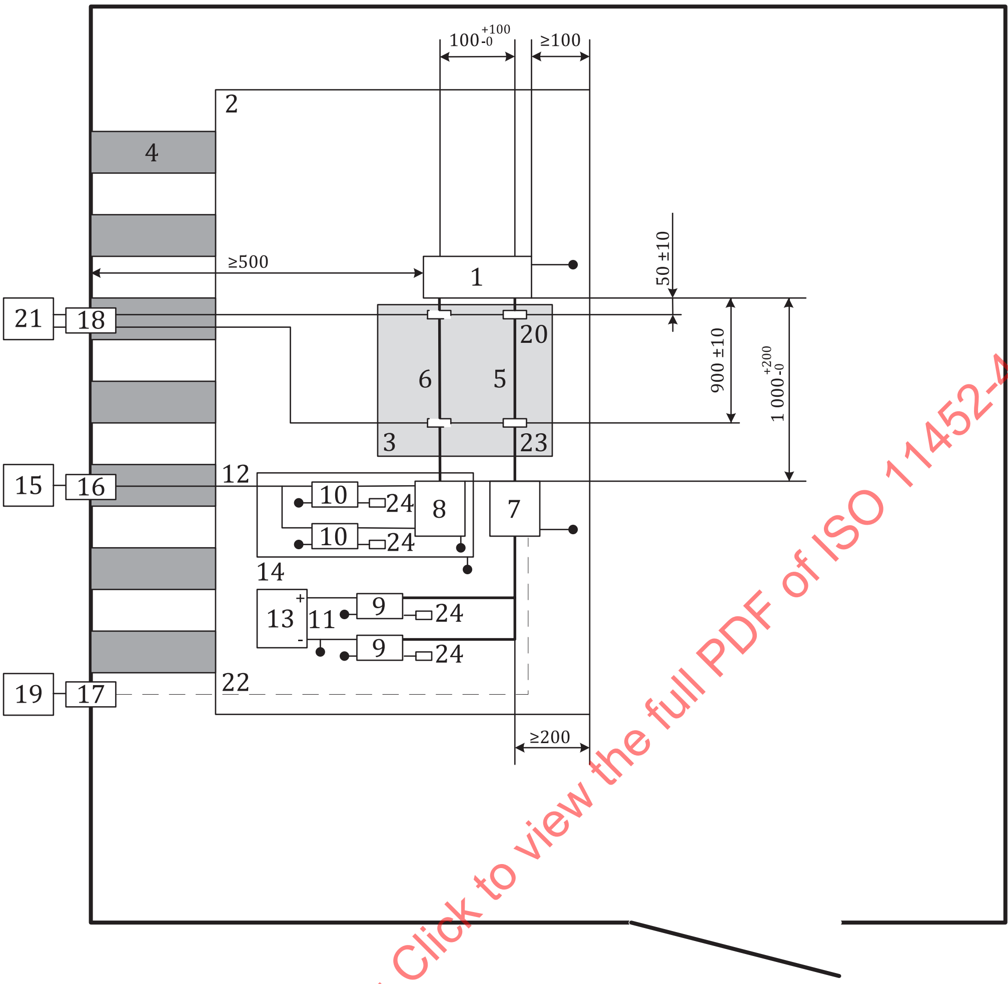
Dimensions in millimetres



Key

1 DUT

2 ground plane

3 low relative permittivity support ($\varepsilon_r \leq 1{,}4$); thickness 50 mm

4 ground straps

5 LV harness

6 HV lines (HV+, HV-)

7 LV load simulator

8 impedance matching network (optional) (see ISO 11452-1)

9 AN

10 HV-AN

11 LV supply lines

12 HV supply lines

13 LV power supply 12 V / 24 V / 48 V (should be placed on the bench)

14 additional shielded box (if necessary)

15 HV power supply (should be shielded if placed inside shielded enclosure)

16 power line filter

17 fibre optic feed through

18 bulk head connector

19 stimulating and monitoring system

20 measuring probe

21 high frequency equipment (generator, amplifier and measuring instruments)

22 optical fibre

23 injection probe

24 50 Ω load

Figure 8 — Example of test set-up –BCI Closed-loop method – Injection on LV (or HV) lines for DUTs with shielded power supply systems

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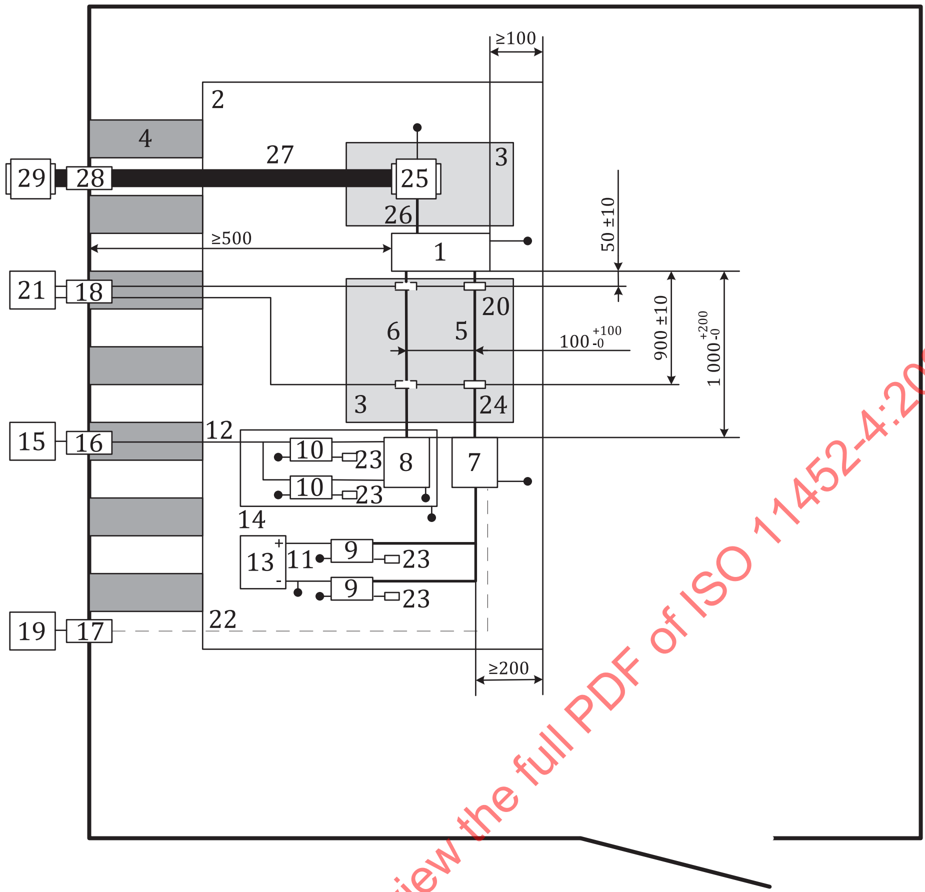
Dimensions in millimetres



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Key

1 DUT
2 ground plane
3 low relative permittivity support ($\varepsilon_r \le 1{,}4$); thickness 50 mm
4 ground straps
5 LV harness
6 HV lines (HV+, HV-)
7 LV load simulator
8 impedance matching network (optional) (see ISO 11452-1)
9 AN
10 HV-AN
11 LV supply lines
12 HV supply lines
13 LV power supply 12 V / 24 V / 48 V (should be placed on the bench)
14 additional shielded box (if necessary)
15 HV power supply (should be shielded if placed inside shielded enclosure)
16 power line filter
17 fibre optic feed through
18 bulk head connector
19 stimulating and monitoring system
20 measuring probe
21 high frequency equipment (generator, amplifier and measuring instruments)
22 optical fibre
23 50 Ω load
24 injection probe
25 electric motor
26 three phase motor supply lines
27 mechanical connection (e.g. non conductive)
28 filtered mechanical bearing (if brake or propulsion motor placed outside the shielded room)
29 brake or propulsion motor (can be placed inside the shielded room)

Figure 9 — Example of test set-up – BCI Closed-loop method – Injection on LV (or HV) lines for DUTs with shielded power supply systems with electric motor attached to the bench

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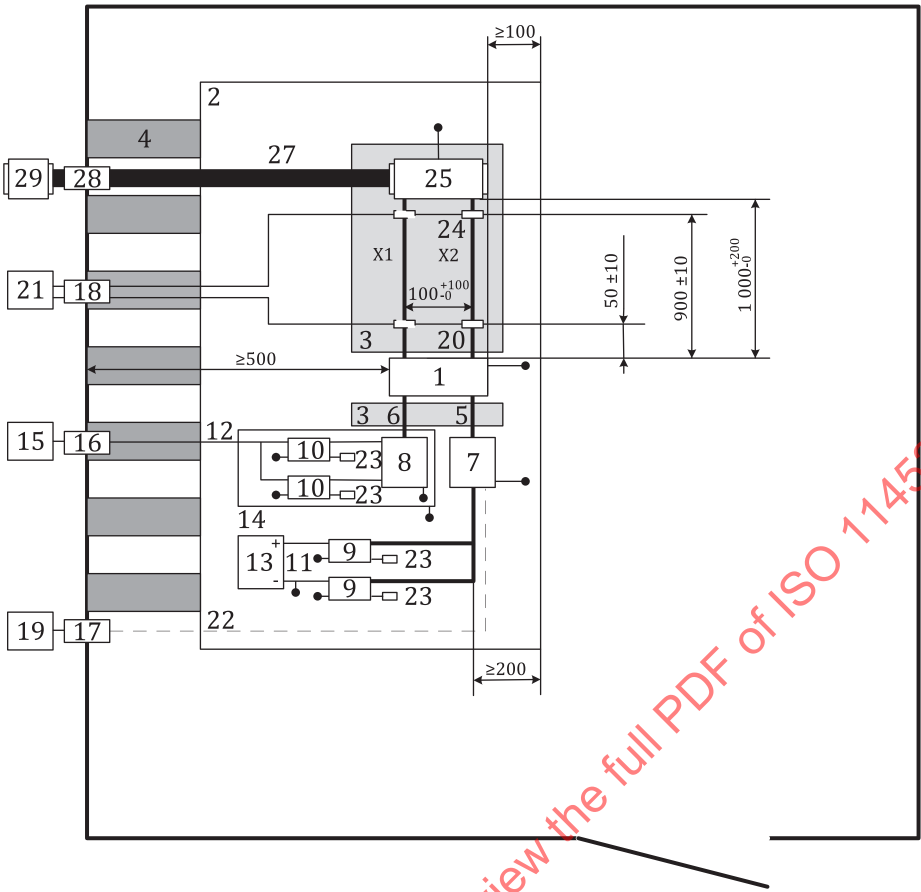
Dimensions in millimetres



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Key

1	DUT	16	power line filter
2	ground plane	17	fibre optic feed through
3	low relative permittivity support ($\varepsilon_r \leq 1,4$); thickness 50 mm	18	bulk head connector
4	ground straps	19	stimulating and monitoring system
5	LV harness	20	measuring probe
6	HV lines (HV+, HV-)	21	high frequency equipment (generator, amplifier and measuring instruments)
7	LV load simulator	22	optical fibre
8	impedance matching network (optional) (see ISO 11452-1)	23	50 Ω load
9	AN	24	injection probe
10	HV-AN	25	electric motor
11	LV supply lines	X1	three phase motor supply lines
12	HV supply lines	X2	sensor lines (e.g. resolver, temperature, ...)
13	LV power supply 12 V / 24 V / 48 V (should be placed on the bench)	27	mechanical connection (e.g. non conductive)
14	additional shielded box (if necessary)	28	filtered mechanical bearing (if brake or propulsion motor placed outside the shielded room)
15	HV power supply (should be shielded if placed inside shielded enclosure)	29	brake or propulsion motor (can be placed inside the shielded room)

Figure 10 — Example of test set-up – BCI Closed-loop method – Injection on electric motor lines for DUTs with shielded power supply systems with electric motor attached to the bench

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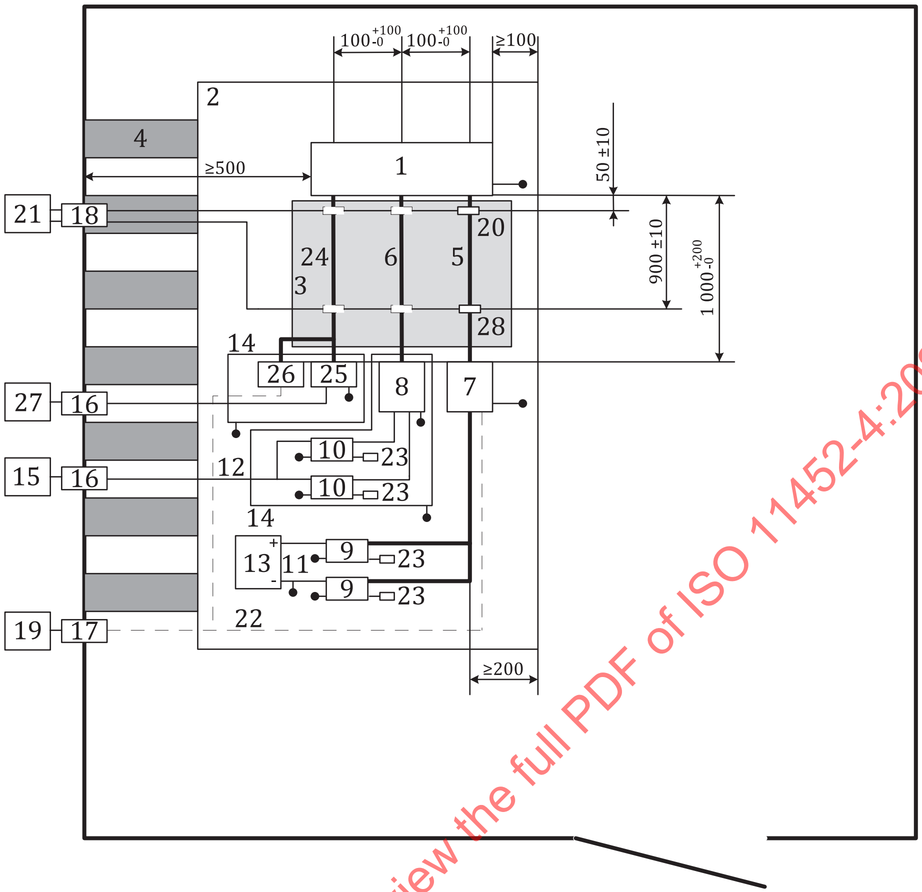
Dimensions in millimetres



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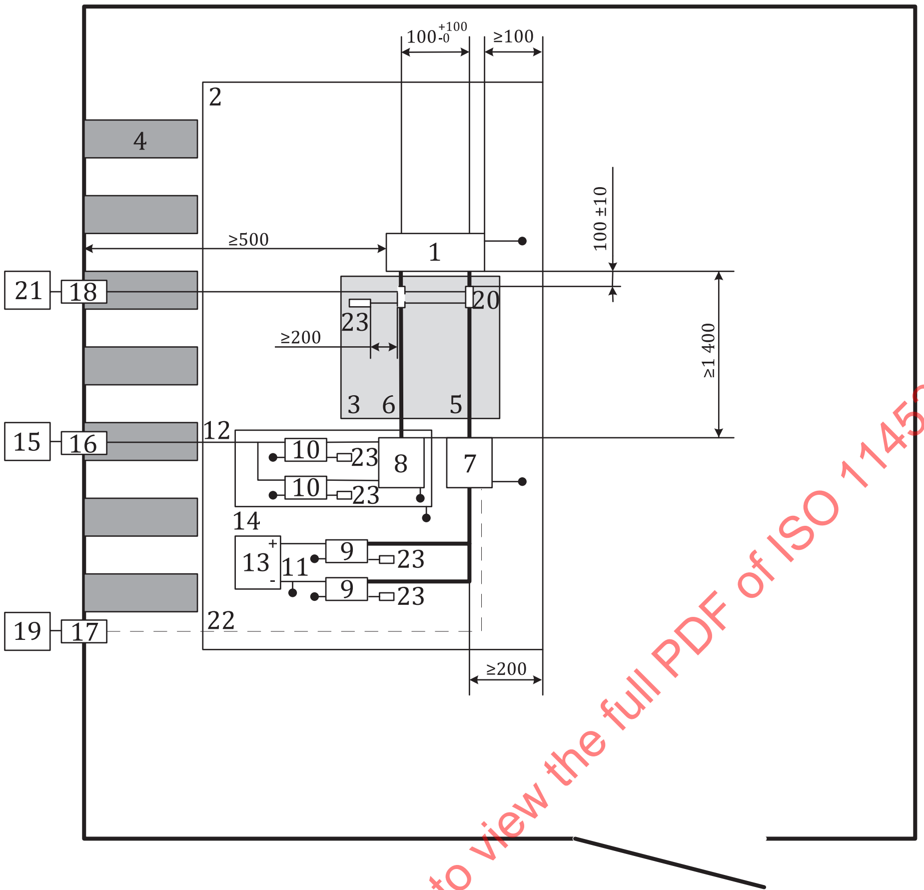
Key

1	DUT
2	ground plane
3	low relative permittivity support ($\varepsilon_r \leq 1,4$); thickness 50 mm
4	ground straps
5	LV harness
6	HV lines (HV+, HV-)
7	LV load simulator
8	impedance matching network (optional) (see ISO 11452-1)
9	AN
10	HV-AN
11	LV supply lines
12	HV supply lines
13	LV power supply 12 V / 24 V / 48 V (should be placed on the bench)
14	additional shielded box (if necessary)
15	HV power supply (should be shielded if placed inside shielded enclosure)
16	power line filter
17	fibre optic feed through
18	bulk head connector
19	stimulating and monitoring system
20	measuring probe
21	high frequency equipment (generator, amplifier and measuring instruments)
22	optical fibre
23	50 Ω load
24	AC lines
25	AMN for AC power mains
26	AC charging load simulator
27	AC power mains
28	injection probe

Figure 11 — Example of test set-up – BCI Closed-loop method – Injection on LV (or HV or AC) lines for DUTs with shielded power supply systems and inverter/charger device

Dimensions in millimetres



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Key

1 DUT

2 ground plane

3 low relative permittivity support ($\varepsilon_r \leq 1,4$); thickness 50 mm

4 ground straps

5 LV harness

6 HV lines (HV+, HV-)

7 LV load simulator

8 impedance matching network (optional) (see ISO 11452-1)

9 AN

10 HV-AN

11 LV supply lines

12 HV supply lines

13 LV power supply 12 V / 24 V / 48 V (should be placed on the bench)

14 additional shielded box (if necessary)

15 HV power supply (should be shielded if placed inside shielded enclosure)

16 power line filter

17 fibre optic feed through

18 bulk head connector

19 stimulating and monitoring system

20 TWC

21 high frequency equipment (generator, amplifier and measuring instruments)

22 optical fibre

23 50 Ω load

Figure 12 — Example of test set-up – TWC method - Injection on LV (or HV) lines for DUTs with shielded power supply systems

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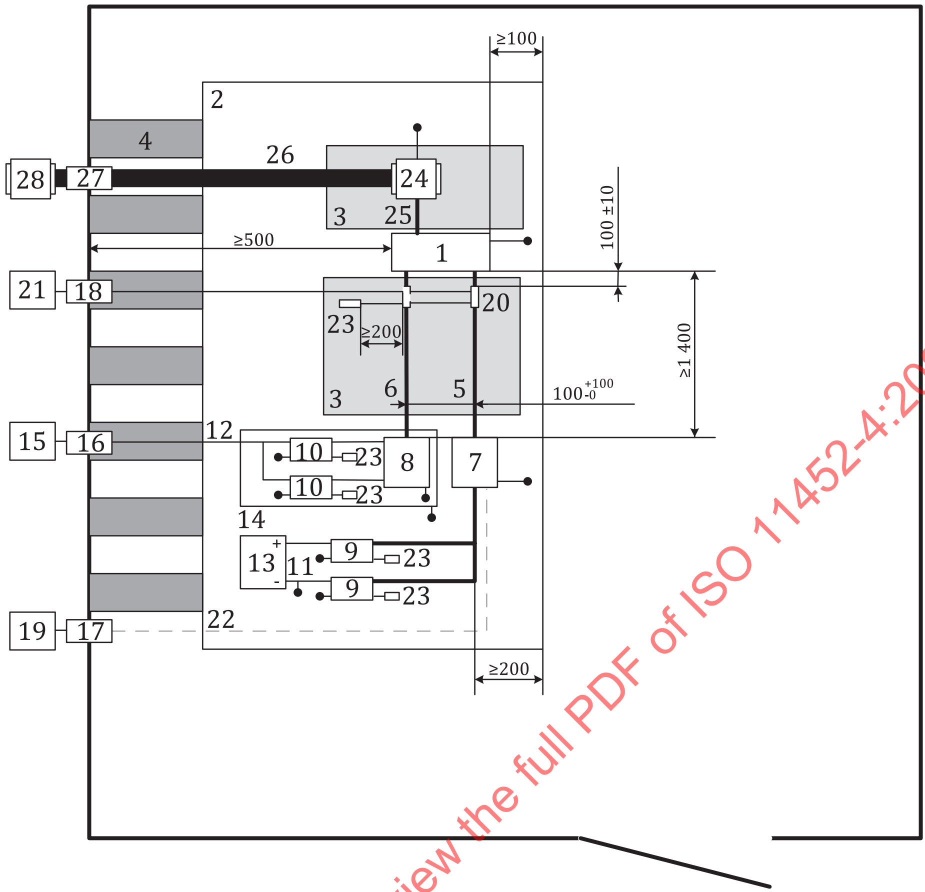
Dimensions in millimetres



Key

1 DUT

2 ground plane

3 low relative permittivity support ($\varepsilon_r \leq 1{,}4$); thickness 50 mm

4 ground straps

5 LV harness

6 HV lines (HV+, HV-)

7 LV load simulator

8 impedance matching network (optional) (see ISO 11452-1)

9 AN

10 HV-AN

11 LV supply lines

12 HV supply lines

13 LV power supply 12 V / 24 V / 48 V (should be placed on the bench)

14 additional shielded box (if necessary)

15 HV power supply (should be shielded if placed inside shielded enclosure)

16 power line filter

17 fibre optic feed through

18 bulk head connector

19 stimulating and monitoring system

20 TWC

21 high frequency equipment (generator and amplifier)

22 optical fibre

23 50 Ω load

24 electric motor

25 three phase motor supply lines

26 mechanical connection (e.g. non conductive)

27 filtered mechanical bearing (if brake or propulsion motor placed outside the shielded room)

28 brake or propulsion motor (can be placed inside the shielded room)

[a] See 8.6.1.1.

Figure 13 — Example of test set-up – TWC method – Injection on LV (or HV) lines for DUTs with shielded power supply systems with electric motor attached to the bench

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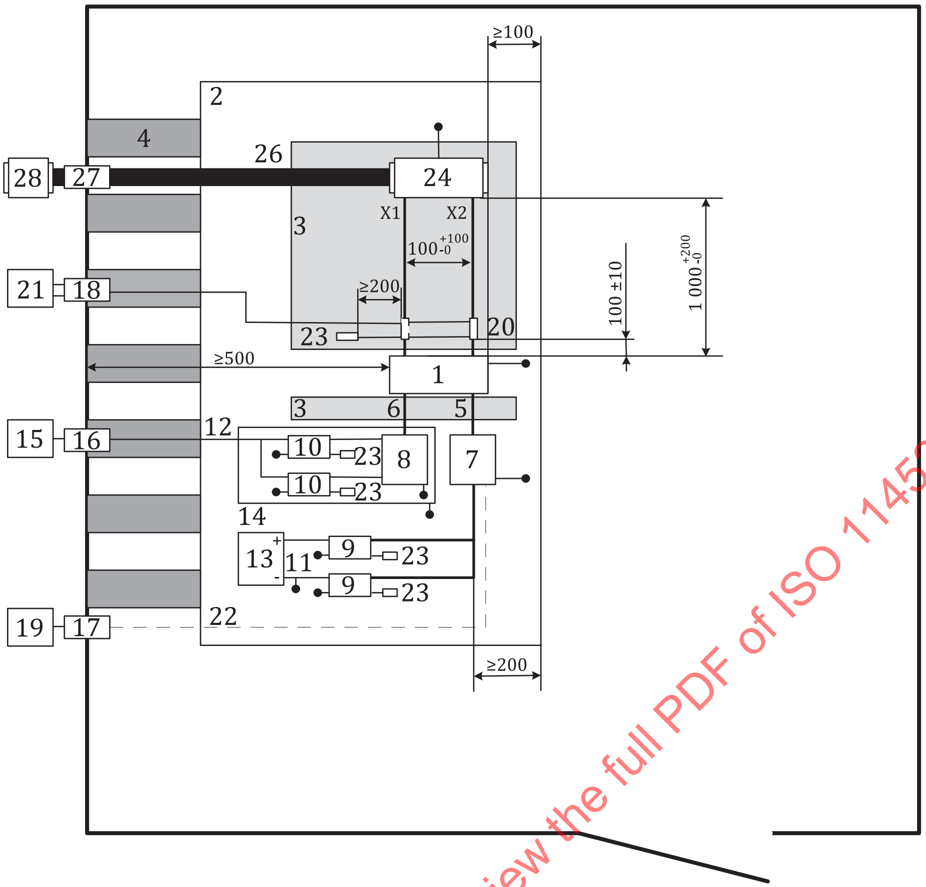
Dimensions in millimetres



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Key

1 DUT

2 ground plane

3 low relative permittivity support ($\varepsilon_r \leq 1{,}4$); thickness 50 mm

4 ground straps

5 LV harness

6 HV lines (HV+, HV-)

7 LV load simulator

8 impedance matching network (optional) (see ISO 11452-1)

9 AN

10 HV-AN

11 LV supply lines

12 HV supply lines

13 LV power supply 12 V / 24 V / 48 V (should be placed on the bench)

14 additional shielded box (if necessary)

15 HV power supply (should be shielded if placed inside shielded enclosure)

16 power line filter

17 fibre optic feed through

18 bulk head connector

19 stimulating and monitoring system

20 TWC

21 high frequency equipment (generator and amplifier)

22 optical fibre

23 50 Ω load

24 electric motor

X1 three phase motor supply lines

X2 sensor lines (e.g. resolver, temperature, ...)

26 mechanical connection (e.g. non conductive)

27 filtered mechanical bearing (if brake or propulsion motor placed outside the shielded room)

28 brake or propulsion motor (can be placed inside the shielded room)

[a] See 8.6.1.1.

Figure 14 — Example of test set-up – TWC method – Injection on electric motor lines for DUTs with shielded power supply systems with electric motor attached to the bench

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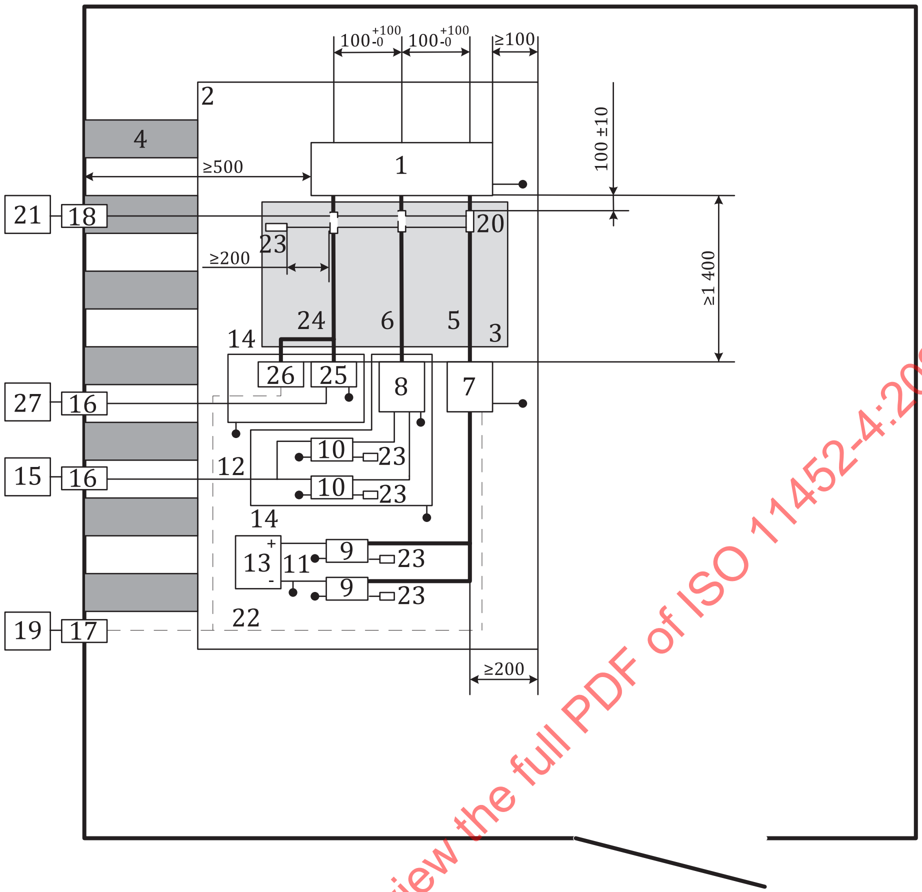
Dimensions in millimetres



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Key

1 DUT

2 ground plane

3 low relative permittivity support ($\varepsilon_r \leq 1,4$); thickness 50 mm

4 ground straps

5 LV harness

6 HV lines (HV+, HV-)

7 LV load simulator

8 impedance matching network (optional) (see ISO 11452-1)

9 AN

10 HV-AN

11 LV supply lines

12 HV supply lines

13 LV power supply 12 V / 24 V / 48 V (should be placed on the bench)

14 additional shielded box (if necessary)

15 HV power supply (should be shielded if placed inside shielded enclosure)

16 power line filter

17 fibre optic feed through

18 bulk head connector

19 stimulating and monitoring system

20 TWC

21 high frequency equipment (generator, and amplifier)

22 optical fibre

23 50 Ω load

24 AC lines

25 AMN for AC power mains

26 AC charging load simulator

27 AC power mains

Figure 15 — Example of test set-up – TWC method – Injection on LV (or HV or AC) lines for DUTs with shielded power supply systems and inverter/charger device

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9 Test procedure

9.1 General

The general arrangement of the disturbance source and connecting harnesses represents a standardized test condition. Any deviations from the standard test harness length shall be agreed upon prior to testing and recorded in the test report.

The DUT shall be made to operate under typical loading and other conditions as in the vehicle. These operating conditions shall be clearly defined in the test plan to ensure that supplier and customer are performing identical tests.

9.2 Test plan

Prior to performing the tests, a test plan shall be generated which shall include the following:

— test set-up;

— test method;

— frequency range;

— DUT mode of operation;

— DUT acceptance criteria;

— test severity levels;

— DUT monitoring conditions;

— injection and measurement probes locations;

— injection conditions for wiring with multiple connectors and/or multiple branches;

— test report content;

— details on load simulator;

— detailed configuration for test on three phases and/or signal lines between the electric motor and DUT;

— any special instructions and changes from the standard test;

— detailed configuration of communication line(s) and AAN(s) if used.

Every DUT shall be tested under the most significant operating conditions depending on significance of road safety and usability, that is at least in stand-by mode and in a mode where all the actuators can be excited.

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9.3 Test methods

CAUTION — Hazardous voltages and fields may exist within the test area. Take care to ensure that the requirements for limiting the exposure of humans to RF energy are met.

9.3.1 BCI test method

9.3.1.1 General

Two BCI test methods are specified:

— the substitution method;

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— the closed-loop method with power limitation.

9.3.1.2 Substitution method

9.3.1.2.1 General

The substitution method is based upon the use of forward power as the reference parameter for calibration and test.

This method is performed in two phases:

— calibration (on fixture);

— test of the DUT.

9.3.1.2.2 Calibration

The specific test level (current) shall be calibrated periodically by recording the forward power required to produce a specific current measured on a 50 Ω calibration fixture as defined in Annex A at frequency steps not greater than the maximum frequency step sizes defined in ISO 11452-1.

For smaller incremental test frequency steps, interpolation between calibration frequencies is allowed with a maximum interpolation error of 0,5 dB.

This calibration shall be performed with an unmodulated sinusoidal RF signal.

The values of forward and reverse power recorded in the calibration file should be included in the test report upon request.

The calibration fixture shall be terminated by a 50 Ω (high power) load at one end and by a 50 Ω RF power measuring instrumentation at the other end, protected by a 50 Ω attenuator of adequate power rating as defined in Annex A.

9.3.1.2.3 DUT test

The DUT, harness and all peripheral devices (e.g. load simulator, AN(s), power supply, battery, ...) are installed on the test bench as shown in Figures 1, 4, 5, 6 or 7.

Install the DUT, harness and all peripheral devices (e.g. load simulator, AN(s), power supply, battery, ...) on the test bench in accordance with Clause 7 (for DUT powered by an unshielded power system) or Clause 8 (for DUT powered by a shielded power system).

The test is conducted by subjecting the DUT to the test signal based on the calibrated value as predetermined in the test plan.

When a harness containing several branches is used, the test should be repeated with the injection probe clamped around each branch. Detailed branches configuration to be tested shall be defined in the test plan and recorded in the test report.

When a DUT has multiple connectors, the test should be repeated with the injection probe clamped around each separate connector bundle, if applicable. Detailed connectors configuration to be tested shall be defined in the test plan and recorded in the test report.

A current measurement probe may be optionally mounted between the current injection probe and the DUT (see 7.6.1.1 and 8.6.1.1). It can provide extra useful information during investigative work on the cause of events and the variances in test conditions after system modifications. Care should be taken because the monitoring probe may affect the injected current.

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9.3.1.3 Closed loop method with power limitation

9.3.1.3.1 General

The closed loop method with power limitation is based upon the use of the forward power as the reference parameter for calibration and test.

This method is performed in two phases:

— calibration (on fixture);

— test of the DUT.

The power limit P_{CWl} is determined using a calibration fixture.

The disturbance ($I_{disturbance}$) applied to the DUT is determined using a limit curve versus frequency.

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9.3.1.3.2 Calibration

This procedure determines the power limit applicable for the test with DUT.

The specific test level (current) shall be calibrated prior to the actual testing as defined in Annex A.

Prior to the actual test with DUT, the forward power required to produce a specific current measured on a 50 Ω calibration fixture as defined in Annex A shall be determined for each frequency.

This calibration shall be performed with an unmodulated sinusoidal RF signal.

The values of forward and reverse power recorded in the calibration file should be included in the test report upon request.

The calibration fixture shall be terminated by a 50 Ω (high power) load at one end and by a 50 Ω RF power measuring instrumentation at the other end, protected by a 50 Ω attenuator of adequate power rating as defined in Annex A.

The current test signal level is applied to the fixture and the corresponding forward power (P_{cal}) is recorded.

The power limit is:

$$P_{CWl} = k\, P_{cal}$$

where

P_{CWl}	is the forward power limit;
P_{cal}	is the forward power applied to reach the current test signal level in the fixture;
k	is a factor equal to 4 unless otherwise specified in the test plan.

9.3.1.3.3 DUT test

The DUT, harness and all peripheral devices (e.g. load simulator, AN(s), power supply, battery, ...) are installed on the test bench as shown in Figures 2, 8, 9, 10 or 11.

The test procedure uses a closed loop method with power limitation (P_{CWl}). The procedure used at each frequency is described below.

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The forward power applied to the current injection probe is increased and the injected current (I_{ref}) is measured until:

— the measured current reaches the specified test level, or

— the forward power reaches the power limit (P_{CWL}).

In either case, the achieved current (I_{ref}) and the applied forward power (P_{ref}) are recorded.

When the DUT susceptibility threshold is found, the fault current (I_{fault}) and the forward power applied (P_{fault}) shall be recorded.

When a harness containing several branches is used, the test should be repeated with the injection probe and the current measurement probe clamped around each branch respectively at (900 ± 10) mm and (50 ± 10) mm from the connector of the DUT. Detailed branches configuration to be tested shall be defined in the test plan and described in the test report.

When a DUT has multiple connectors, the test should be repeated with the injection probe and the current measurement probe clamped around each separate connector bundle, if applicable. Detailed connectors configuration to be tested shall be defined in the test plan and described in the test report.

9.3.2 Tubular wave coupler test method

For the tubular wave coupler test method, the substitution method is used. It is based on using forward power as the reference parameter for calibration and testing, which leads to a two-step test method:

— calibration, using a calibration fixture, and

— testing the DUT.

9.3.2.1 Calibration

For calibration, the insertion loss of the used tubular wave coupler in a calibration fixture with a characteristic impedance of 150 Ω shall be measured at frequency steps not greater than the maximum frequency step sizes defined in ISO 11452-1.

For smaller incremental test frequency steps, interpolation between calibration frequencies is allowed with a maximum interpolation error of 0,5 dB.

The calibration fixture shall include a broadband matching network to the 50 Ω impedance of the measuring equipment. The manufacturer of the calibration fixture shall give the correction factor of this matching network with a maximum uncertainty of 1,5 dB.

Since the tubular wave coupler and the calibration fixture are linear systems, the coupler insertion loss should be measured using a network analyser.

The calibration set-up using a network analyser is shown in Figure 16.

The analysing of coupler insertion loss S_{21} using the test power is possible but not necessary. For full power calibration, the maximum power handling capability of the calibration fixture shall be considered.

The network analyser shall be calibrated including all cables connecting the tubular wave coupler and the calibration fixture. Alternatively, the cables shall be appropriately taken into account for the de-embedding, e.g. by full 2-port characterisation of the cables.

The S-parameter S_{21} shall be measured.

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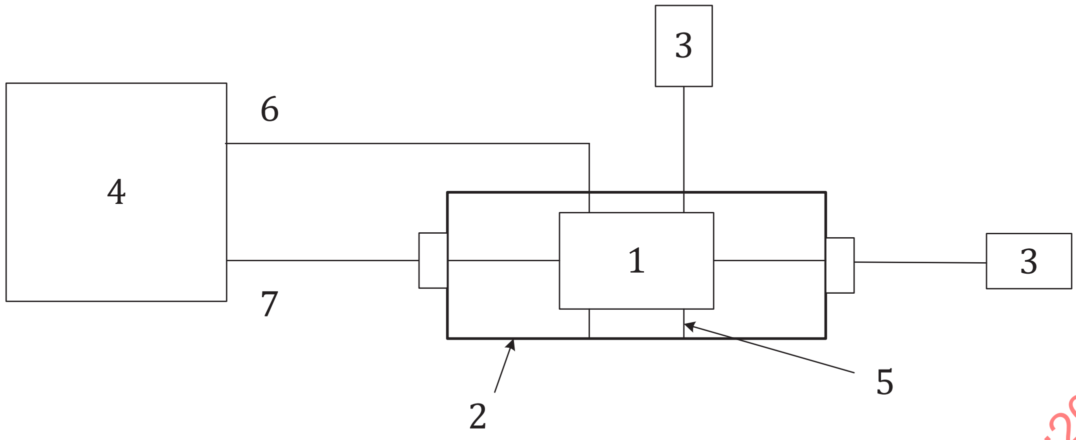

Key

1 tubular wave coupler
2 calibration fixture with internal matching unit to 50 Ω - system
3 50 Ω load resistor, VSWR 1,2:1 maximum
4 network analyser (50 Ω)
5 insulating support
6 coaxial cable (network analyser output)
7 coaxial cable (network analyser input)

Figure 16 — Tubular wave coupler calibration set-up

The insertion loss of the coupler is given by:

$$I_L = - |S_{21}| - F$$

where

I_L is the insertion loss of the tubular wave coupler, in dB;

$|S_{21}|$ is the amplitude of the S_{21} parameter, in dB;

F is the correction factor of the calibration fixture, in dB.

9.3.2.2 DUT test

The DUT, harness and all peripheral devices (e.g. load simulator, AN(s), power supply, battery ...) are installed on the test bench as shown in Figures 3, 12, 13, 14 or 15.

The forward power P_{fr} for DUT testing shall be calculated by:

$$P_{fr} = P_t + I_L$$

where

P_t is the required test power according to the test plan, in dBm;

P_{fr} is the forward power, in dBm;

I_L is the insertion loss of the used tubular wave coupler, in dB.

9.4 Test report

As required in the test plan, a test report shall be submitted detailing information regarding the test equipment, load simulator, test area, systems tested, frequencies, power levels, system interactions and

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any other relevant information regarding the test. Any deviation from the test plan shall be specified in the test report.

For the BCI closed loop method with power limitation, the following additional information shall be included in the test report:

— the values I_{ref}, P_{ref}, I_{fault}, P_{fault}, P_{CWI};

— the test bench transfer impedance (the voltage injected at the plane of the current injection probe divided by the current measured by the current measurement probe). A precise description of test bench transfer impedance measurement or calculation methods is given in Annex B.

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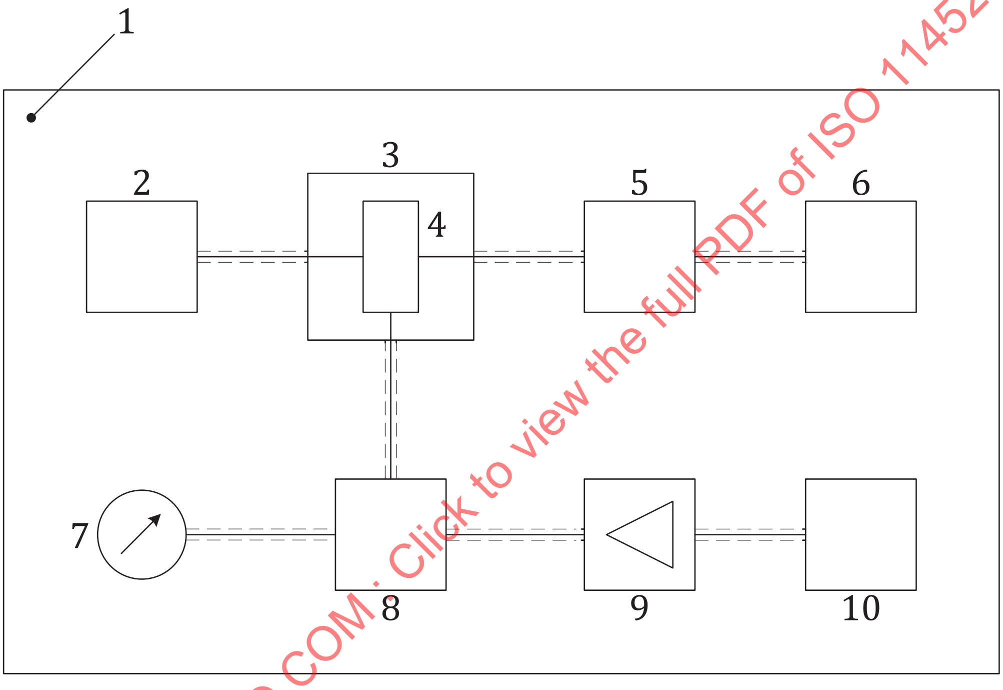
Annex A
(normative)

Calibration configuration (current injection probe calibration)

A calibration fixture is used to determine the injected current. Figure A.1 shows an example of a test equipment configuration for the current injection probe calibration.

Mount the injection probe centred in the calibration fixture (see Figure A.2) and, while sweeping the test frequency range, measure the forward power required to achieve the current at which testing is to be conducted.



Key

1 shielded enclosure
2 50 Ω coaxial load, VSWR 1,2: 1 max
3 calibration fixture
4 injection probe
5 50 Ω attenuator
6 spectrum analyser or equivalent
7 RF power level measuring device (two are required)
8 RF 50 Ω dual directional coupler (with 30 dB minimum decoupling coefficient)
9 broadband amplifier with 50 Ω output impedance
10 RF signal generator

Figure A.1 — Example of current injection probe calibration configuration

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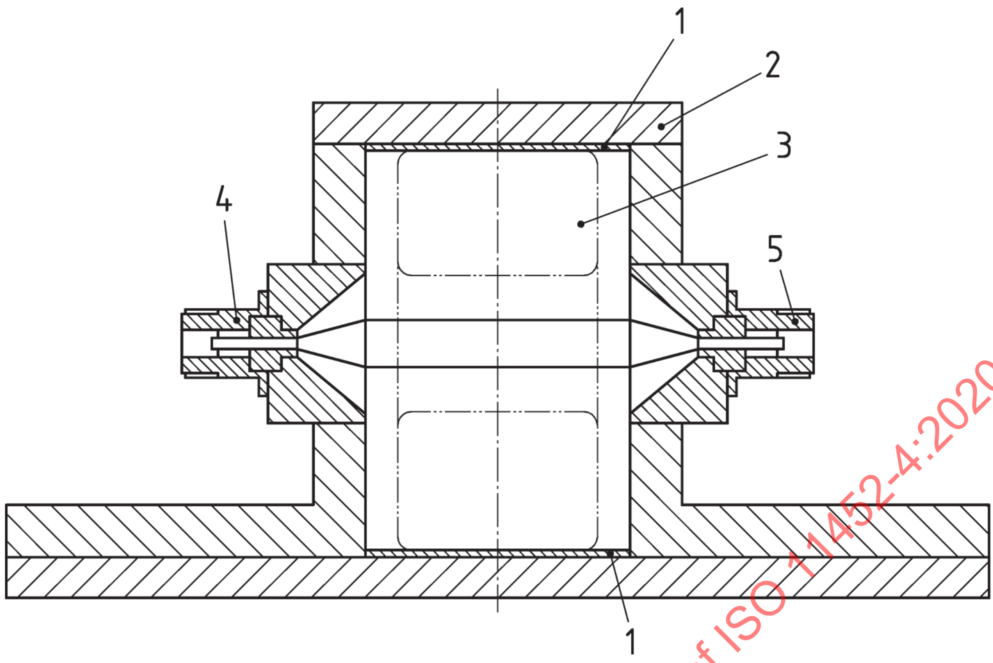

Key

1 insulation

2 removable metal cover

3 current injection probe

4 direct connection to 50 Ω measurement equipment

5 direct connection to 50 Ω load

Figure A.2 — Example of calibration fixture

The physical size of the calibration fixture shall be in accordance with the probe manufacturer's requirements.

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Annex B
(informative)

Test set-up transfer impedance

B.1 General

The test set-up transfer impedance is defined as follows in Formula (B.1):

$$Z_{tr} = \frac{V_{ind}}{I_{ind}} \quad (B.1)$$

where

Z_{tr} is the test set-up transfer impedance;

V_{ind} is the common mode voltage induced in the wiring harness by the current injection probe;

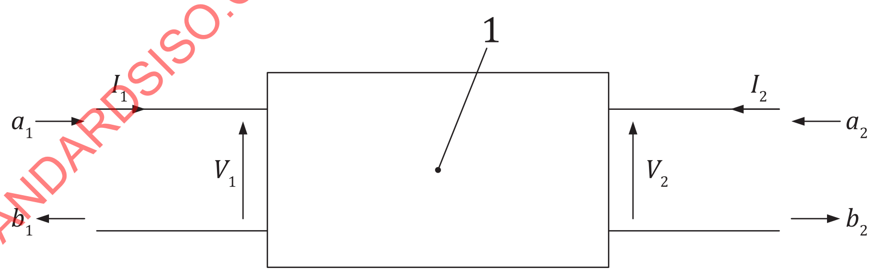
I_{ind} is the common mode current induced at the measurement point.

It is used to characterise the system comprising the wiring harness, the DUT and the loads, independently of the injection and current measurement probes, to make it easier to compare tests carried out in different laboratories or using different test wiring harnesses.

It can be measured using a network analyser as described in B.2 or deduced from the direct power and current measurements during calibration and testing as described in B.3.

B.2 Measuring the transfer impedance using a network analyser

B.2.1 Defining the parameter relationships



Key

1 S parameter quadripole

Figure B.1 — Definition of incident and reflected waves

For a four-terminal network with given S parameters, the incident and reflected waves can be defined as follows.

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For port 1 of the network analyser follow Formulae (B.2) and (B.3):

$$a_1 = \frac{V_1 + Z_C\, I_1}{2\sqrt{Z_C}} \tag{B.2}$$

$$b_1 = \frac{V_1 - Z_C\, I_1}{2\sqrt{Z_C}} \tag{B.3}$$

where

a_1 is the incident wave;

b_1 is the reflected wave;

V_1 is the common mode voltage induced in the wiring harness by the current injection probe;

I_1 is the common mode current induced at the measurement point;

Z_C is the characteristic impedance (here, $Z_C = 50\ \Omega$).

For port 2 of the network analyser follow Formulae (B.4) and (B.5):

$$a_2 = \frac{V_2 + Z_C\, I_2}{2\sqrt{Z_C}} \tag{B.4}$$

$$b_2 = \frac{V_2 - Z_C\, I_2}{2\sqrt{Z_C}} \tag{B.5}$$

where

a_2 is the incident wave;

b_2 is the reflected wave;

V_2 is the common mode voltage induced in the wiring harness by the current injection probe;

I_2 is the common mode current induced at the measurement point;

Z_c is the characteristic impedance (here, $Z_C = 50\ \Omega$).

In physical terms, the incident and reflected waves carry the input and output power to and from the four-terminal network.

The relationship between the incident and reflected waves is given by the S parameters [Formulae (B.6) and (B.7)]:

$$b_1 = S_{11}a_1 + S_{12}a_2 \text{ and } b_2 = S_{21}a_1 + S_{22}a_2 \tag{B.6}$$

When the output of the network is loaded with 50 Ω:

$$a_2 = 0\text{, therefore } b_1 = S_{11}a_1 \text{ and } b_2 = S_{21}a_1 \tag{B.7}$$

where

S_{11} is the coefficient of reflection;

S_{21} is the coefficient of transmission of the four-terminal network.

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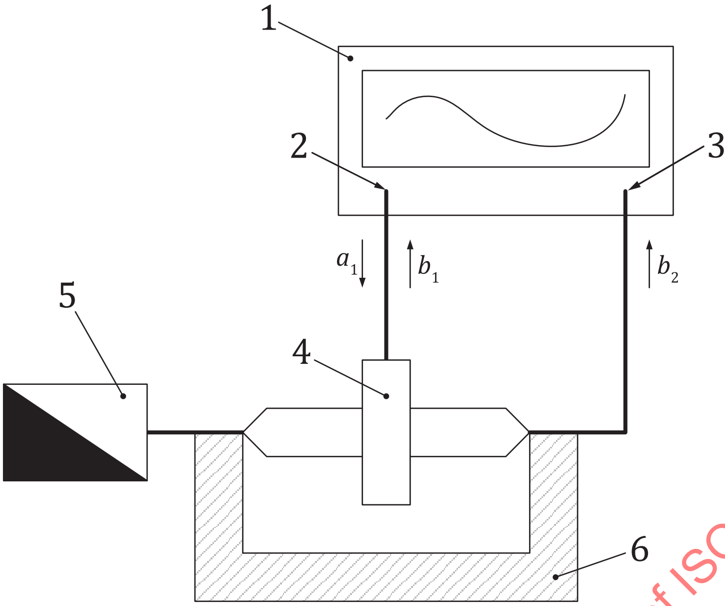
B.2.2 Calibrating the current injection probe



Key

1 network analyser
2 port 1
3 port 2
4 current injection probe
5 50 Ω load
6 calibration fixture with metal cover in place

Figure B.2 — Calibrating the current injection probe

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By definition, the insertion loss I_L of the current injection probe is given by Formulae (B.8) and (B.9):

$$I_L{}^2 = \frac{b_2^2}{a_1^2} = S_{21\ \text{inj}}^2 \qquad \text{(B.8)}$$

where

$I_L{}^2$ is the power insertion loss of the current injection probe, in decibels (dB);

b_2^2 is the power induced on the calibration fixture port, in decibels (dB);

a_1^2 is the power applied to the current injection probe, in decibels (dB);

$S_{21\ \text{inj}}^2$ is the power transmission coefficient of the current injection probe, in decibels (dB).

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