
**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

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 11452-4 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 3, *Electrical and electronic equipment*.

This fourth edition cancels and replaces the third edition (ISO 11452-4:2005), which has been technically revised.

ISO 11452 consists of the following parts, under the general title *Road vehicles — Component test methods for electrical disturbances from narrowband radiated electromagnetic energy*:

- *Part 1: General principles and terminology*
- *Part 2: Absorber-lined shielded enclosure*
- *Part 3: Transverse electromagnetic (TEM) cell*
- *Part 4: Harness excitation methods*
- *Part 5: Stripline*
- *Part 7: Direct radio frequency (RF) power injection*
- *Part 8: Immunity to magnetic fields*
- *Part 9: Portable transmitters*
- *Part 10: Immunity to conducted disturbances in the extended audio frequency range*
- *Part 11: Reverberation chamber*

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

Part 4: Harness excitation methods

1 Scope

This part of ISO 11452 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. For DUTs which are larger than a wavelength (e.g. 0,1 m at 3 GHz), direct field coupling to the printed circuit board (PCB) becomes of equal importance. The user of the TWC test method should take this into account and determine the applicability of the method.

The electromagnetic disturbances considered in this part of ISO 11452 are limited to continuous narrowband electromagnetic fields.

2 Normative references

The following referenced documents are indispensable for the application 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 11452-1:2005, *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.

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.

To test automotive electronic systems, the typical applicable frequency range

- of the BCI test method is 1 MHz to 400 MHz,
- of the TWC test method is 400 MHz to 3 GHz.

NOTE Current probes and tubular wave couplers are available which allow testing outside these frequency ranges.

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

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 network(s) [AN(s)];
- 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.

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 should be taken into consideration in establishing the test levels.

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, e.g. 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.

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(s) [AN(s)];
- 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.

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

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. The minimum length of the ground plane shall be

- 1 500 mm for the BCI method using the closed-loop method with power limitation,
- 2 000 mm for all other methods defined in this part of ISO 11452, or
- underneath the entire equipment plus 200 mm, whichever is larger.

The ground plane shall be bonded to the walls or the floor of the shielded enclosure such that the d.c. resistance shall not exceed 2,5 m Ω . 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.

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 μ H/50 Ω AN (see Annex C for artificial network schematic). Requirements vary depending 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 D).
- For a DUT locally grounded (vehicle power return line 200 mm or shorter), one AN is required for the positive supply (see Annex D).

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

The power supply return shall be connected to the test bench 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.

7.3 Location of the DUT

The DUT shall be placed on a non-conductive, low relative permittivity (dielectric constant) material ($\epsilon_r \leq 1,4$), 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 Length and 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:

- $(1\,700^{+300}_0)$ mm for all test methods defined in this part of ISO 11452 except for the BCI test method using the closed-loop method with power limitation;
- $(1\,000^{+200}_0)$ 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 part of ISO 11452 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 should pass through the current injection and current measurement probes or the tubular wave coupler. 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 ($\epsilon_r \leq 1,4$), 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

Preferably, 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.

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 $d = (450 \pm 50)$ mm and $d = (750 \pm 50)$ mm may be required.

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

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

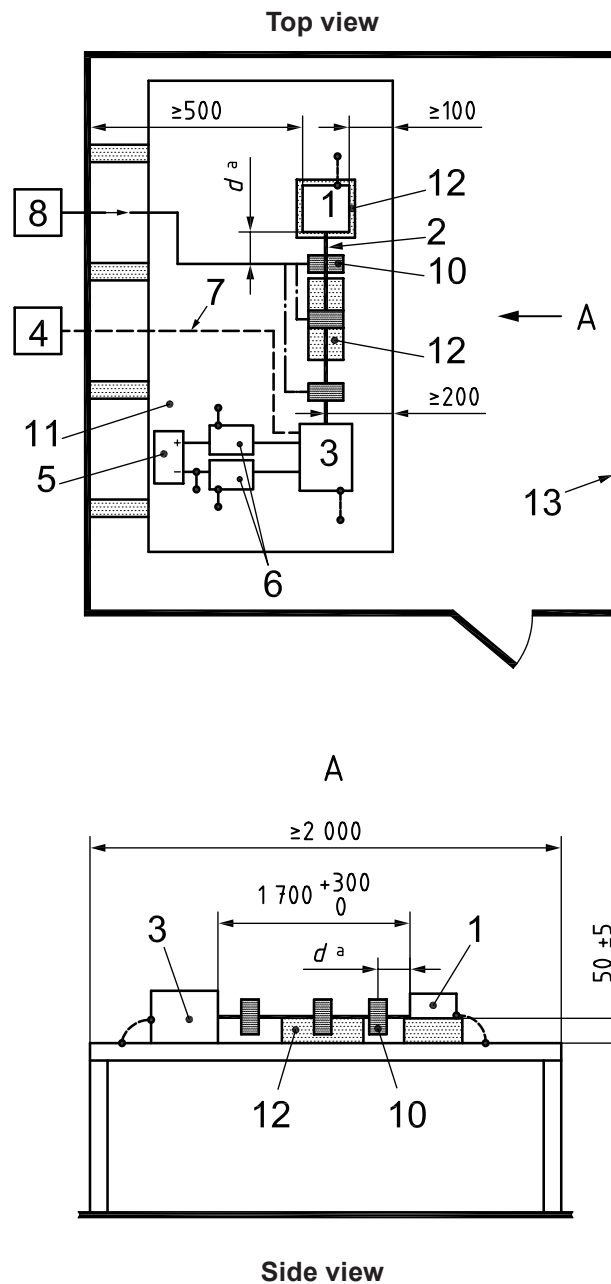
An example of a test configuration is shown in Figure 2.

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 50Ω load resistor shall be placed isolated from the ground plane 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.

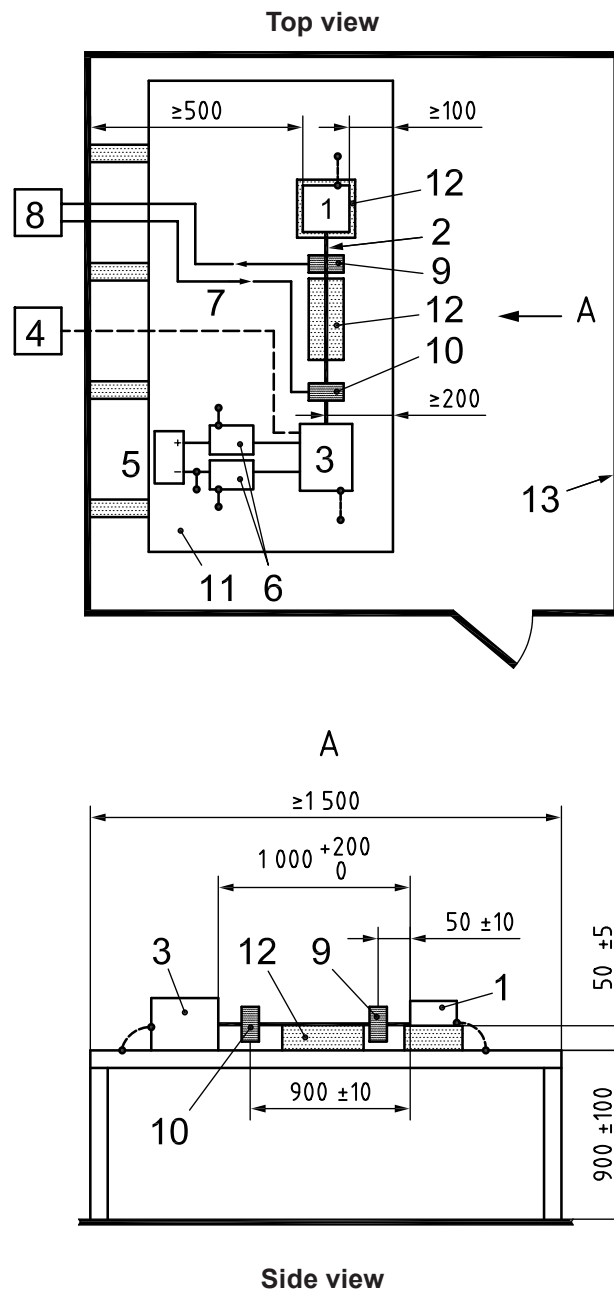
Dimensions in millimetres

**Key**

- | | |
|---|--|
| 1 DUT (connected to ground if specified in the test plan) | 8 high-frequency equipment |
| 2 wiring harness (S) | 9 optional current measurement probe (not shown in this figure, but shown in Figure 2) |
| 3 load simulator (placement and ground connection according to 7.5) | 10 injection probe (represented at 3 positions) |
| 4 stimulation and monitoring system | 11 ground plane (connected to the shielded room) |
| 5 power supply | 12 low relative permittivity support ($\epsilon_r \leq 1,4$) |
| 6 AN | 13 shielded room |
| 7 optical fibres | |

^a See 7.6.1.1.

Figure 1 — BCI configuration — Substitution method

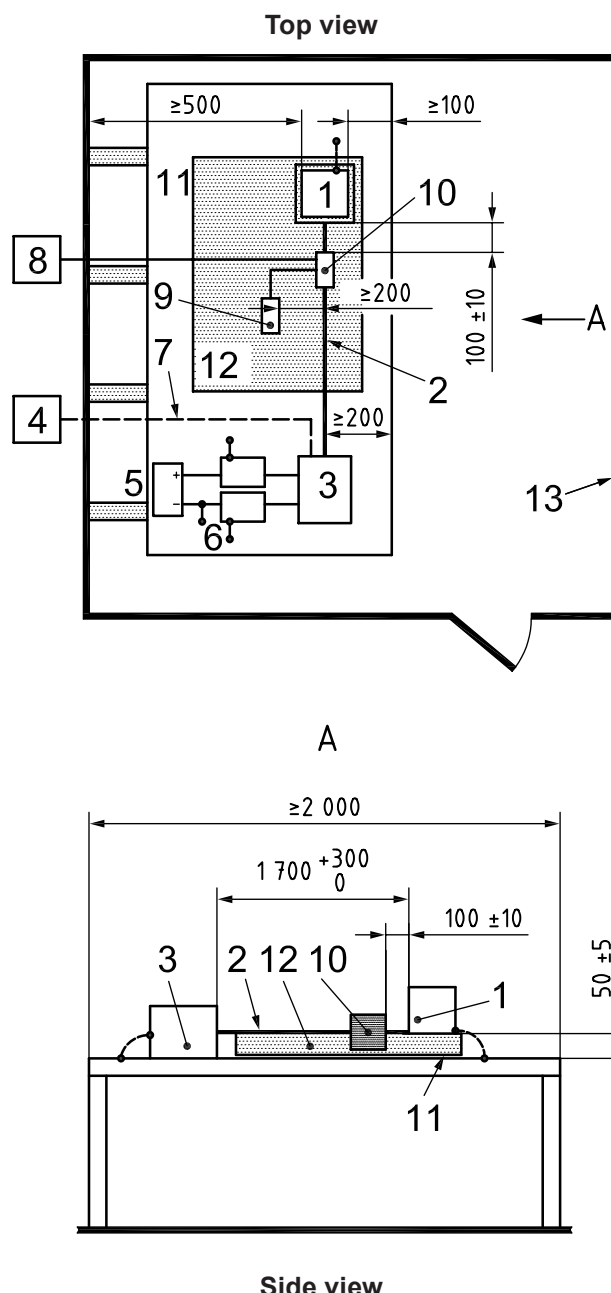


Key

- | | |
|---|--|
| 1 DUT (connected to ground if specified in the test plan) | 7 optical fibres |
| 2 wiring harness | 8 high-frequency equipment |
| 3 load simulator (placement and ground connection according to 7.5) | 9 current measurement probe |
| 4 stimulation and monitoring system | 10 injection probe |
| 5 power supply | 11 ground plane (connected to the shielded room) |
| 6 AN | 12 low relative permittivity support ($\epsilon_r \leq 1,4$) |
| | 13 shielded room |

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

Dimensions in millimetres

**Key**

- | | |
|---|--|
| 1 DUT (connected to ground if specified in the test plan) | 7 optical fibres |
| 2 wiring harness | 8 high-frequency equipment |
| 3 load simulator (placement and ground connection according to 7.5) | 9 50 Ω load |
| 4 stimulation and monitoring system | 10 tubular wave coupler |
| 5 power supply | 11 ground plane (connected to the shielded room) |
| 6 AN | 12 low relative permittivity support ($\epsilon_r \leq 1,4$) |
| | 13 shielded room |

Figure 3 — Tubular wave coupler test set-up

8 Test procedure

8.1 General

The general arrangement of the disturbance source and connecting harnesses, etc., represents a standardized test condition. Any deviations from the standard test harness length, etc., 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 must be clearly defined in the test plan to ensure that the supplier and customer are performing identical tests.

8.2 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;
- probe location;
- injection conditions for wiring with multiple connectors and/or multiple branches;
- test report content;
- load simulator;
- any special instructions and changes from the standard test.

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

8.3 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.

8.3.1 BCI test method

8.3.1.1 General

Two BCI test methods are specified:

- the substitution method;
- the closed-loop method with power limitation.

8.3.1.2 Substitution method

8.3.1.2.1 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.

8.3.1.2.2 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 (see 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 should 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 (see Annex A).

8.3.1.2.3 DUT test

The DUT, harness and associated equipment are installed on the test bench as shown in Figure 1.

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.

A current measurement probe may be mounted between the current injection probe and the DUT. The use of a current measurement probe is optional. 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.

8.3.1.3 Closed loop method with power limitation

8.3.1.3.1 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 $P_{CWlimit}$ is determined using a calibration fixture.

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

8.3.1.3.2 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 (see 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 (see 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 should 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 (see Annex A).

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

The power limit is:

$$P_{\text{CWlimit}} = k P_{\text{calibration}}$$

where

P_{CWlimit} is the power limit;

$P_{\text{calibration}}$ 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.

8.3.1.3.3 DUT test

The DUT, harness and associated equipment are installed on the test bench as shown in Figure 2.

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

The forward power applied to the current injection probe is increased and the injected current ($I_{\text{reference}}$) is measured until

- the measured current reaches the specified test level, or
- the forward power reaches the power limit (P_{CWlimit}).

In either case, the achieved current ($I_{\text{reference}}$) and the applied forward power ($P_{\text{reference}}$) 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.

8.3.2 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.

8.3.2.1 Calibration

For calibration, the insertion loss of the used tubular wave coupler in a calibration fixture with a characteristic impedance of $150\ \Omega$ 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 $50\ \Omega$ 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.

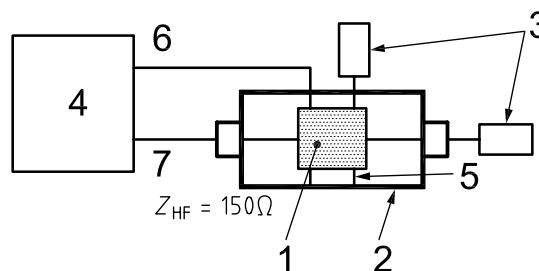
Since the tubular wave coupler and the calibration fixture are linear systems, the coupler insertion loss should be measured using a network analyser.

The calibration set-up using a network analyser is shown in Figure 4.

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 characterization of the cables.

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



Key

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

Figure 4 — Tubular wave coupler calibration set-up

The insertion loss of the coupler is given by:

$$I_L|_{\text{dB}} = -|S_{21}|_{\text{dB}} - F|_{\text{dB}}$$

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.

8.3.2.2 DUT test

The DUT, harness and associated equipment are installed on the test bench as shown in Figure 3.

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

$$P_{\text{forward}}|_{\text{dBm}} = P_{\text{test}}|_{\text{dBm}} + I_L|_{\text{dB}}$$

where

- P_{test} is the required test power according to the test plan, in dBm;
- P_{forward} is the forward power, in dBm;
- I_L is the insertion loss of the used tubular wave coupler, in dB.

8.4 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 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 $I_{\text{reference}}$, $P_{\text{reference}}$, I_{fault} , P_{fault} , P_{CWlimit} ;
- 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.

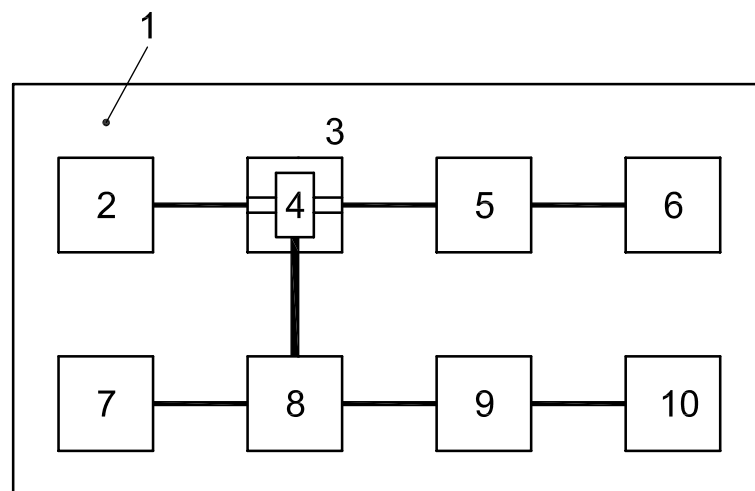
Annex A

(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.

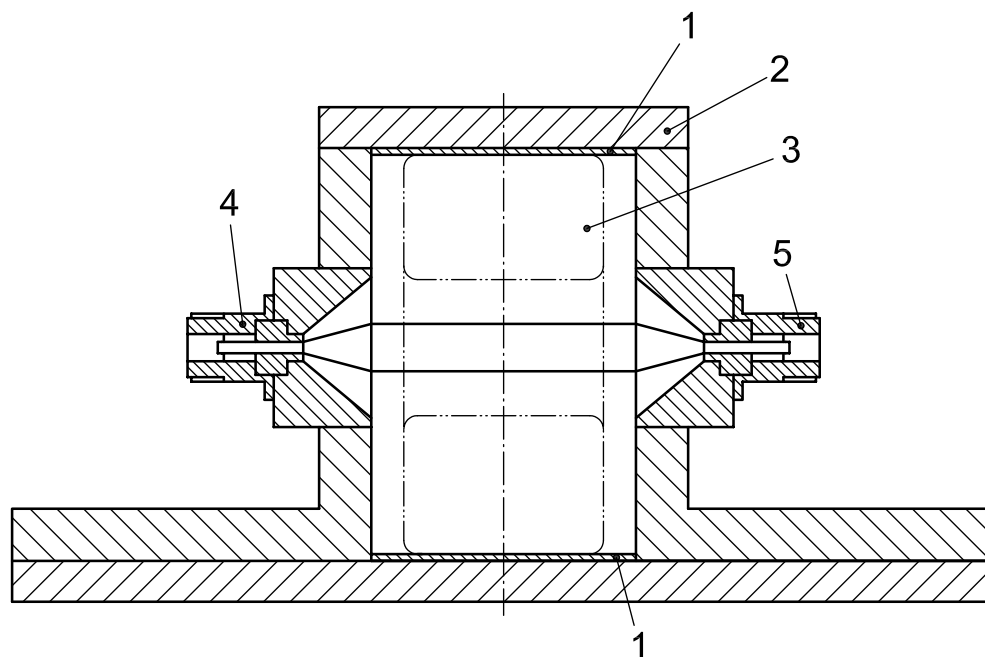
Mount the injection probe centred in the calibration fixture (see Figure A.2) and, while sweeping the test frequency range, measure the forward power required to achieve the current at which testing is to be conducted.



Key

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

Figure A.1 — Block diagram of calibration configuration



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.

Annex B (informative)

Test set-up transfer impedance

B.1 General

The test set-up transfer impedance is defined as:

$$Z_{\text{transfer}} = \frac{V_{\text{induced}}}{I_{\text{induced}}} \quad (\text{B.1})$$

where

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

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

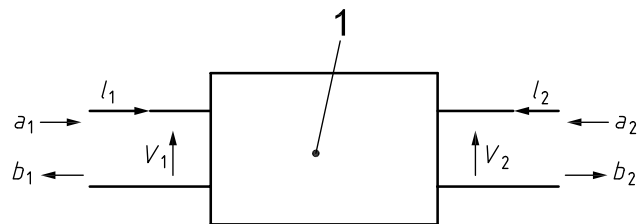
I_{induced} is the common mode current induced at the measurement point.

It is used to characterize 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.

For port 1 of the network analyser:

$$a_1 = \frac{V_1 + Z_C I_1}{2\sqrt{Z_C}} \quad (\text{B.2})$$

$$b_1 = \frac{V_1 - Z_C I_1}{2\sqrt{Z_C}} \quad (\text{B.3})$$

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:

$$a_2 = \frac{V_2 + Z_C I_2}{2\sqrt{Z_C}} \quad (\text{B.4})$$

$$b_2 = \frac{V_2 - Z_C I_2}{2\sqrt{Z_C}} \quad (\text{B.5})$$

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:

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

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

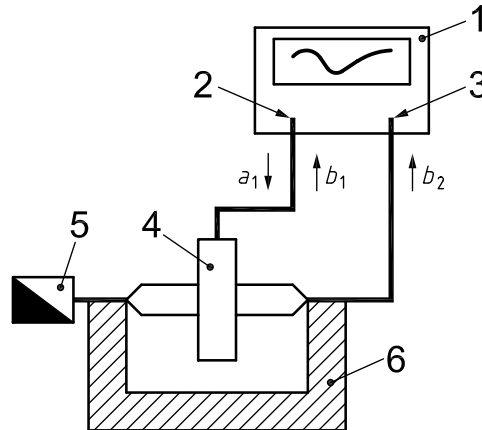
$$a_2 = 0, \quad \text{therefore} \quad b_1 = S_{11}a_1 \quad \text{and} \quad b_2 = S_{21}a_1 \quad (\text{B.7})$$

where

S_{11} is the coefficient of reflection;

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

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

Figure B.2 — Calibrating the current injection probe

By definition, the insertion loss L of the current injection probe is given by the following formula:

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

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

i.e.

$$I_L \text{ (dB)} = -|S_{21 \text{ injection}}| \text{ (dB)} \quad (\text{B.9})$$

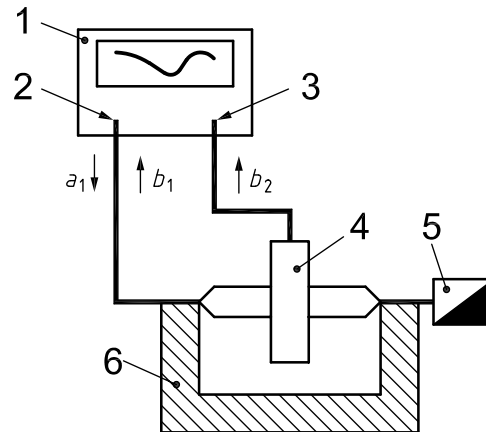
The current injection probe induces the voltage V_{induced} on the calibration fixture, i.e. $(V_{\text{induced}})/2$ on each of the 50 Ω loads on the fixture, therefore:

$$b_2^2 = \frac{1}{50} \left(\frac{V_{\text{induced}}}{2} \right)^2 \quad (\text{B.10})$$

From Equations (B.8) and (B.10):

$$\frac{V_{\text{induced}}}{a_1} = 2\sqrt{50} I_L \quad (\text{B.11})$$

B.2.3 Calibrating the current measurement probe



Key

- 1 network analyser
- 2 port 1
- 3 port 2
- 4 current measurement probe
- 5 50 Ω load
- 6 calibration fixture

Figure B.3 — Calibrating the current measurement probe

The current measurement probe is characterized by its transfer impedance Z_T given by the following formula:

$$Z_T = \frac{V_{\text{returned}}}{I_{\text{induced}}} \quad (\text{B.12})$$

where

V_{returned} is the voltage returned by the current measurement probe loaded by 50 Ω;

I_{induced} is the current to be measured.

$$b_2^2 = \frac{V_{\text{returned}}^2}{50} \quad (\text{B.13})$$

and

$$a_1^2 = 50 I_{\text{induced}}^2 \quad (\text{B.14})$$

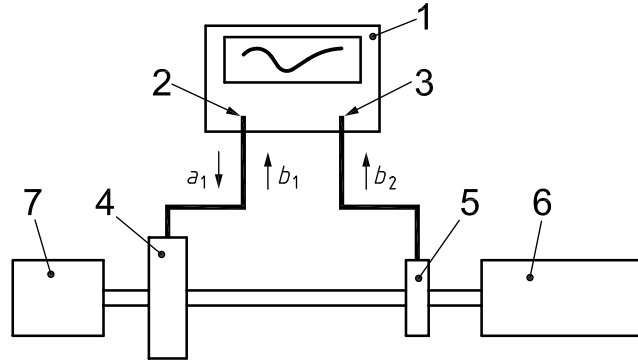
From Equations (B.12) and (B.13)

$$\frac{b_2}{I_{\text{induced}}} = \frac{Z_T}{\sqrt{50}} \quad (\text{B.15})$$

From Equations (B.14) and (B.15)

$$Z_T = 50 \frac{b_2}{a_1} = 50 S_{21 \text{ read}} \quad (\text{B.16})$$

B.2.4 Measuring the transfer impedance



Key

- 1 network analyser
- 2 port 1
- 3 port 2
- 4 current injection probe
- 5 current measurement probe
- 6 DUT
- 7 AN(s) under load

Figure B.4 — Measuring the transfer impedance

The transfer impedance of the test bench is defined by the following formula:

$$Z_{\text{transfer}} = \frac{V_{\text{induced}}}{I_{\text{induced}}} = \frac{V_{\text{induced}}}{a_1} \times \frac{a_1}{b_2} \times \frac{b_2}{I_{\text{induced}}} \quad (\text{B.17})$$

From Equations (B.11) and (B.16), the transfer impedance of the test bench can be calculated from S_{21} parameter measurement for Figure B.4 and the characteristics of the probes as follows:

$$Z_{\text{transfer}} = \frac{2 Z_T I_L}{S_{21}} \quad (\text{B.18})$$

or

$$Z_{\text{transfer}} (\text{dB}_\Omega) = 6 + Z_T (\text{dB}_\Omega) + I_L (\text{dB}) - S_{21} (\text{dB}) \quad (\text{B.19})$$

B.3 Calculating the transfer impedance

The transfer impedance Z_{transfer} can also be calculated from the measurements made during calibration and test, using the fact that the calibration fixture transfer impedance is 100Ω . By proportionality:

$$Z_{\text{transfer}} = 100 \frac{I_{\text{calibration}}}{I_{\text{induced}}} \sqrt{\frac{P_{\text{direct}}}{P_{\text{calibration}}}} \quad (\text{B.20})$$

where

- $I_{\text{calibration}}$ is the calibration current;
- I_{induced} is the current to be measured;

$P_{\text{calibration}}$ is the power applied to the current injection probe during calibration;

P_{direct} is the power applied to the calibration fixture.

or

$$Z_{\text{transfer}}(\text{dB}_{\Omega}) = 40 + I_{\text{calibration}}(\text{dB}_{\text{mA}}) - I_{\text{induced}}(\text{dB}_{\text{mA}}) + P_{\text{direct}}(\text{dB}_{\text{m}}) - P_{\text{calibration}}(\text{dB}_{\text{m}}) \quad (\text{B.21})$$

Annex C (informative)

Artificial network

C.1 General

The artificial network (AN) is used as a reference standard in the laboratory in place of the impedance of vehicle power lines in order to determine the behaviour of equipment and electrical and electronic devices. The AN shall be able to withstand a continuous load corresponding to the requirements of the DUT.

An example of the AN schematic is shown in Figure C.1.

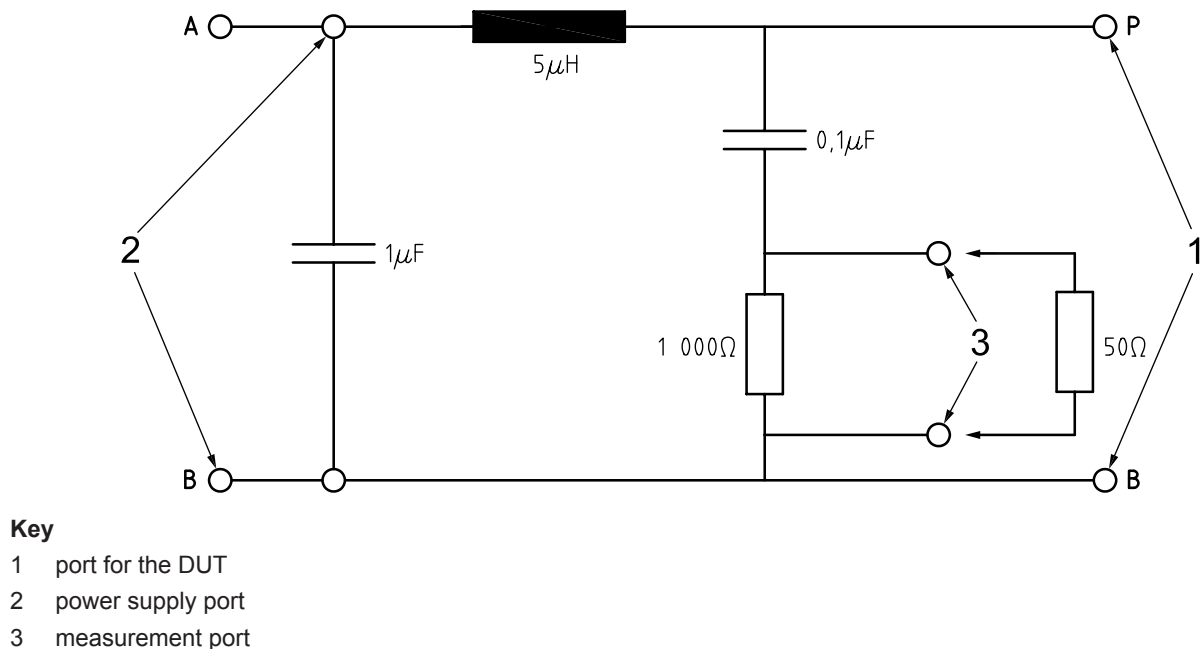
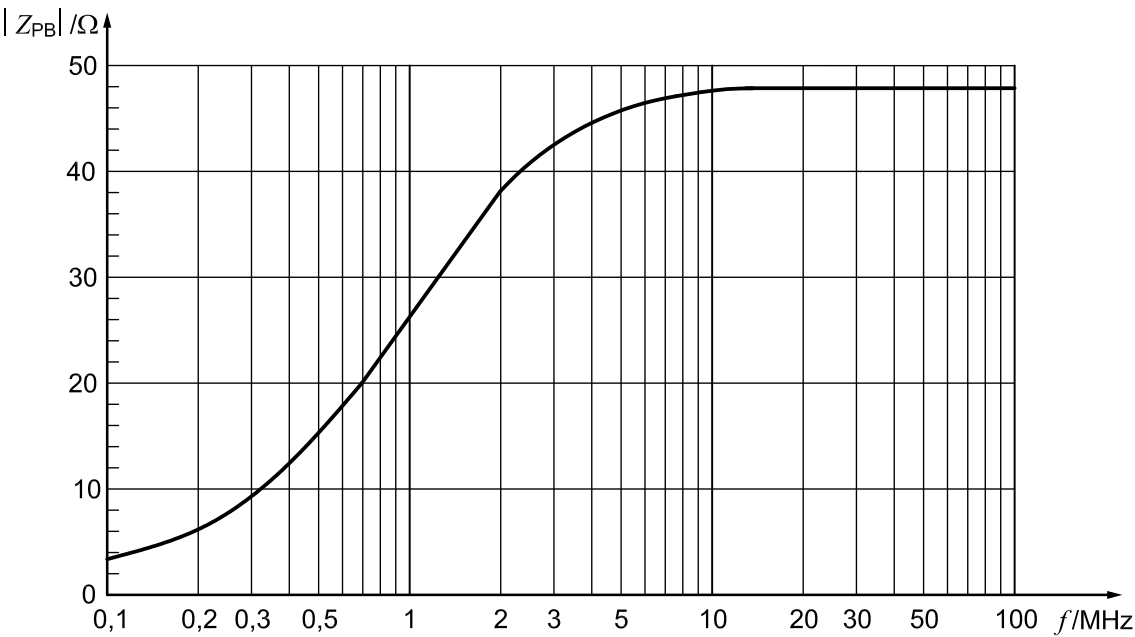


Figure C.1 — Example of AN schematic

C.2 AN impedance

The AN impedance $|Z_{PB}|$ in the measurement frequency range of 0,1 MHz to 100 MHz assuming ideal electrical components are shown in Figure C.2. In reality, a tolerance of $\pm 20\%$ is permitted. The impedance is measured between the terminals P and B ("1" of Figure C.1) with a 50Ω load on the measurement port ("3" of Figure C.1) and with terminals A and B ("2" of Figure C.1) short-circuited.



Key
 $|Z_{PB}|/\Omega$ absolute value of the impedance
 f/MHz frequency

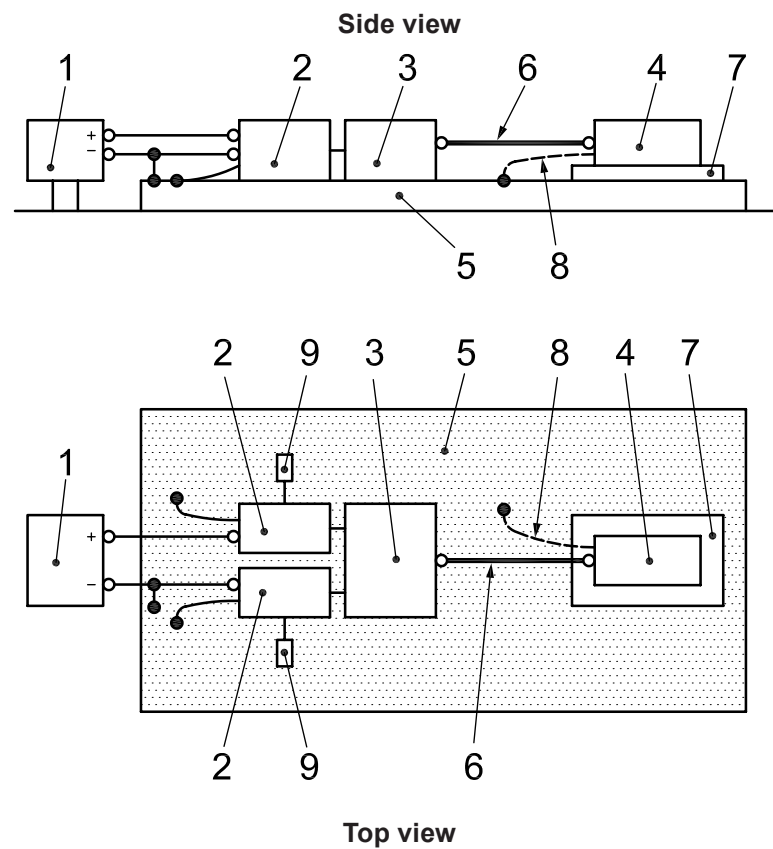
Figure C.2 — Characteristics of AN impedance $|Z_{PB}|$ as a function of frequency from 0,1 MHz to 100 MHz

Annex D (informative)

Grounding configurations

D.1 Remotely grounded DUT

The principle for connecting a remotely grounded DUT is shown in Figure D.1.



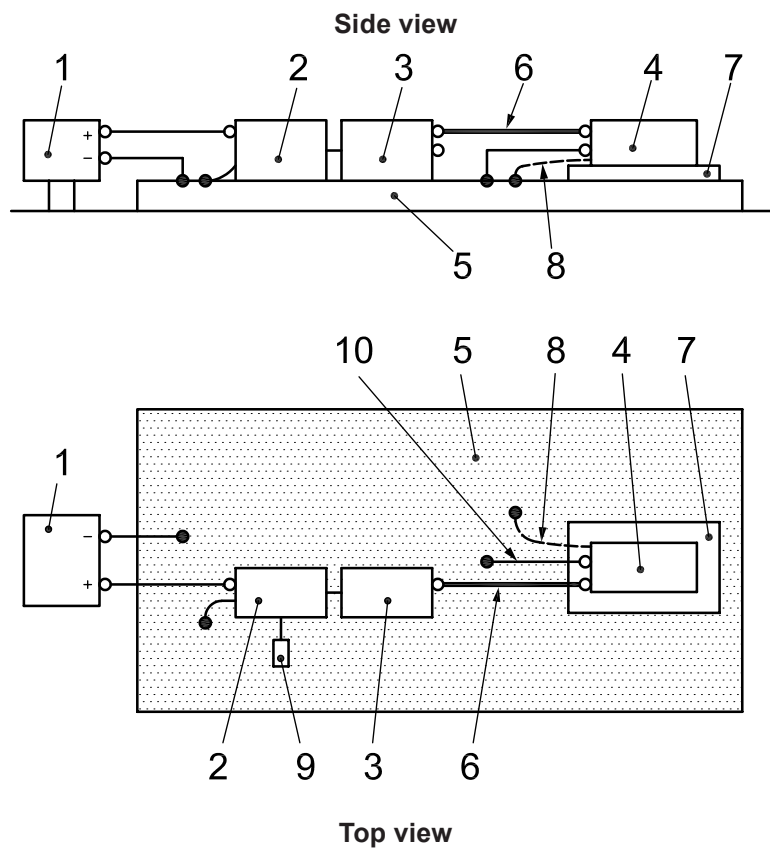
Key

- 1 power supply
- 2 AN
- 3 simulator
- 4 DUT
- 5 ground plane
- 6 wiring harness (containing power supply and return line)
- 7 insulating support
- 8 DUT housing not connected to ground plane unless specified in the test plan (see 7.3)
- 9 50 Ω load

Figure D.1 — Remotely grounded DUT

D.2 Locally grounded DUT

The principle for connecting a locally grounded DUT is shown in Figure D.2.



Key

- 1 power supply
- 2 AN
- 3 simulator
- 4 DUT
- 5 ground plane
- 6 wiring harness (containing power supply and return line)
- 7 insulating support
- 8 DUT housing not connected to ground plane unless specified in the test plan (see 7.3)
- 9 50 Ω load
- 10 power return line (maximum length: 200 mm)

Figure D.2 — Locally grounded DUT

Annex E
(informative)

Function performance status classification (FPSC)

E.1 General

This annex gives examples of test severity levels which should be used in line with the principle of functional performance status classification (FPSC) described in ISO 11452-1.

E.1.1 BCI test method

Examples of test severity levels for BCI are given in Table E.1 and Figure E.1.

Table E.1 — Example of test severity levels (BCI)

Frequency band MHz	Test level I mA	Test level II mA	Test level III mA	Test level IV mA	Test level V mA
1 to 3	$60 \times F_{(\text{MHz})} / 3$	$100 \times F_{(\text{MHz})} / 3$	$150 \times F_{(\text{MHz})} / 3$	$200 \times F_{(\text{MHz})} / 3$	Specific values agreed between the users of this part of ISO 11452
3 to 200	60	100	150	200	
200 to 400	$60 \times 200 / F_{(\text{MHz})}$	$100 \times 200 / F_{(\text{MHz})}$	$150 \times 200 / F_{(\text{MHz})}$	$200 \times 200 / F_{(\text{MHz})}$	

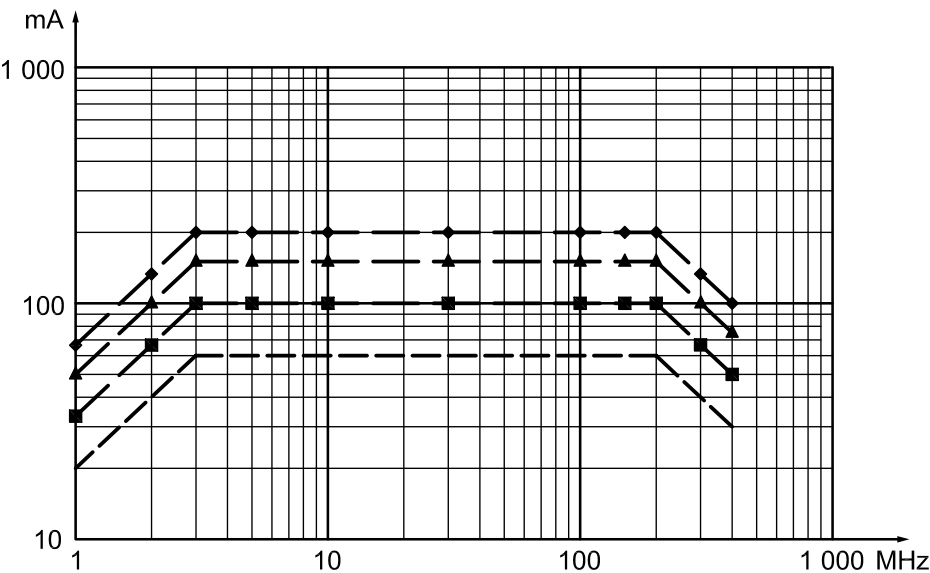


Figure E.1 — Test severity levels and frequency bands (BCI)

E.1.2 TWC test method

Examples of test severity levels for the TWC test method are given in Table E.2 and Figure E.2.

Table E.2 — Example of test severity levels (TWC)

Frequency band MHz	Test level I dBm	Test level II dBm	Test level III dBm	Test level IV dBm	Test level V dBm
400 to 1 000	$15 - [10,05 \times \lg (f/400)]^a$	$21 - [10,05 \times \lg (f/400)]^a$	$27 - [10,05 \times \lg (f/400)]^a$	$33 - [10,05 \times \lg (f/400)]^a$	Specific values agreed between the users of this part of ISO 11452
1 000 to 2 000	$11 - [9,97 \times \lg (f/1\,000)]^a$	$17 - [9,97 \times \lg (f/1\,000)]^a$	$23 - [9,97 \times \lg (f/1\,000)]^a$	$29 - [9,97 \times \lg (f/1\,000)]^a$	
2 000 to 3 000	8	14	20	26	

^{a)} In the formulae, *f* is in MHz and lg denotes the logarithm to base 10.

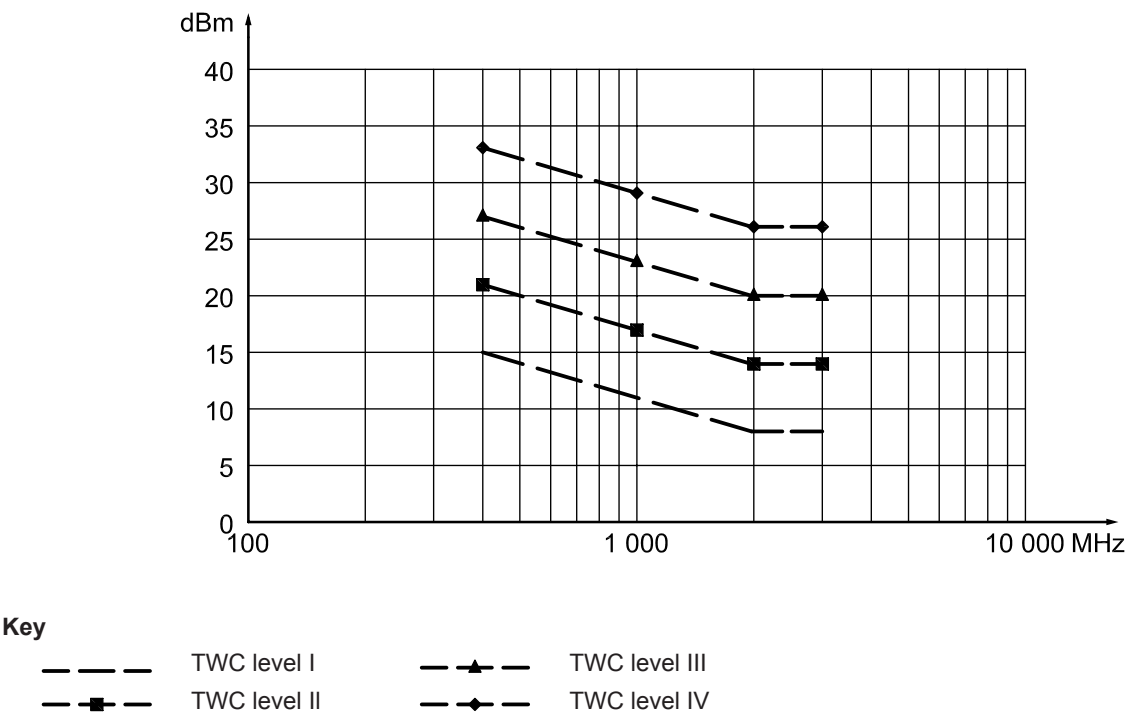


Figure E.2 — Example of test severity levels (TWC)

E.2 Example of FPSC application, using test severity levels

An example of severity levels is given in Table E.3. This table may be different for BCI and TWC test methods (levels from Tables E.1 and E.2).

Table E.3 — Example severity levels

Test severity levels	Category 1	Category 2	Category 3
L _{4i}	Level III	Level III	Level IV
L _{3i}	Level II	Level III	Level III
L _{2i}	Level I	Level II	Level II
L _{1i}	Level I	Level I	Level II

