INTERNATIONAL STANDARD

ISO 11451-4

Fourth edition
2022-05

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

Part 4:
Harness excitation methods

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

Partie 4: Méthodes d'excitation des faisceaux

Reference number
ISO 11451-4:2022(E)

Contents

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.

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. 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. www.iso.org/patents

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 fourth edition cancels and replaces the third edition (ISO 11451-4:2013), which has been technically revised.

The main changes are as follows:

— extension of BCI frequency range,

— addition of TWC test method,

— update of test plan and test report requirements,

— update of Annexes A, B and C for consistency with ISO 11452-4:2020.

A list of all parts in the ISO 11451 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.

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

Part 4: Harness excitation methods

1 Scope

This document specifies harness excitation methods for testing the electromagnetic immunity of electronic components for 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 disturbance considered in this document is limited to continuous narrowband electromagnetic fields.

ISO 11451-1 gives definitions, practical use and basic principles of the test methods.

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 11451-1, *Road vehicles — Vehicle 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 11451-1 apply.

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

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

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

4 Test conditions

The applicable frequency range 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 cover the applicable frequency range.

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

— of the BCI test method is 100 kHz to 1 GHz. When an alternative test method is not feasible, then BCI testing between 400 MHz and 1 GHz may be used and shall be agreed between the users of this document and documented in the test plan,

— 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 severity levels are given in Annex C. These test severity levels are expressed in terms of the equivalent root-mean-square value of the unmodulated wave.

Standard test conditions are given in ISO 11451-1 for the following:

— test temperature,

— supply voltage,

— modulation,

— dwell time,

— frequency step sizes,

— definition of test severity levels, and

— test signal quality.

5 Test location

The tests should be performed in a shielded enclosure.

The distance between the vehicle and all other conductive structures, such as the walls of a shielded room (with the exception of the ground plane underneath the vehicle) shall be a minimum of 0,5 m.

The test may be alternatively performed in an outdoor test site. The test facility shall be aware of (national) legal requirements regarding the transmission of electromagnetic fields.

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

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 wires of the device under test (DUT) are passed. Immunity tests are then carried out by varying the test severity level and frequency of the induced disturbance.

The following equipment is used:

— current injection probe(s);

— current measurement probe(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.

BCI shall be conducted on each individual system fitted to the vehicle.

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, 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 the vehicle. 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:

— tubular wave coupler;

— RF generator with internal or external modulation capability;

— power amplifier;

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

TWC shall be conducted on each individual system fitted to the vehicle.

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 BCI Test methods

There are two test methods for the BCI test: the substitution method and the closed-loop method (see 7.1.1 and 7.1.2, respectively).

7.1.1 Substitution method

Unless otherwise specified in the test plan, the current injection probe shall be mounted around the harness (150 ± 50) mm from the connector or the outlet aperture of the DUT being tested on the vehicle.

Where the harness contains a number of branches to DUT connectors, the test should be repeated with the current injection probe(s) clamped around each of the branches (150 ± 50) mm from the branch termination. Under these test conditions, the measuring probe, if used, shall be left at its previous distance from the DUT.

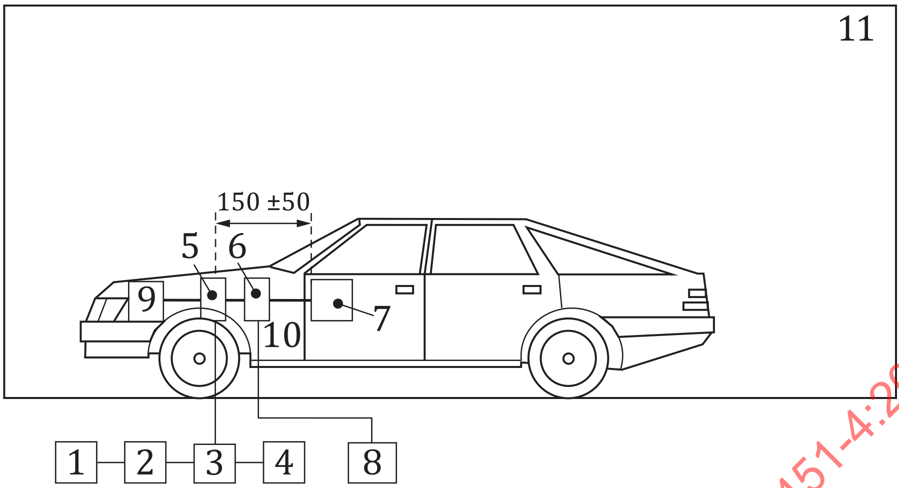
Using the pre-calibrated level of forward power, (described in 8.3.1.2.2), conduct a search for events over the frequency range of the injection probe.

For each event, record the lowest forward power to the probe as the threshold of immunity at different frequencies.

A current measurement probe may optionally be mounted between the current injection probe and the DUT. It may provide extra useful information, but it may also modify the test conditions. When this probe is used, the measured current cannot be used to determine the performance of the DUT, but should be retained and used during investigative work for the causes of events and the variances in test conditions after system modifications.

An example of a test configuration shown in Figure 1.

Dimensions in millimetres



Key

1 signal generators
2 broadband amplifier
3 RF 50 Ω directional coupler
4 RF power level measuring device or equivalent
5 RF injection probe
6 RF current measurement probe (optional)
7 DUT
8 spectrum analyser or equivalent (optional)
9 others vehicle devices
10 harness
11 shielded enclosure

It is recommended that appropriate ferrite chokes be placed on the coaxial cables to the injection and current measurement probes.

Figure 1 — Example of BCI test configuration – Substitution method

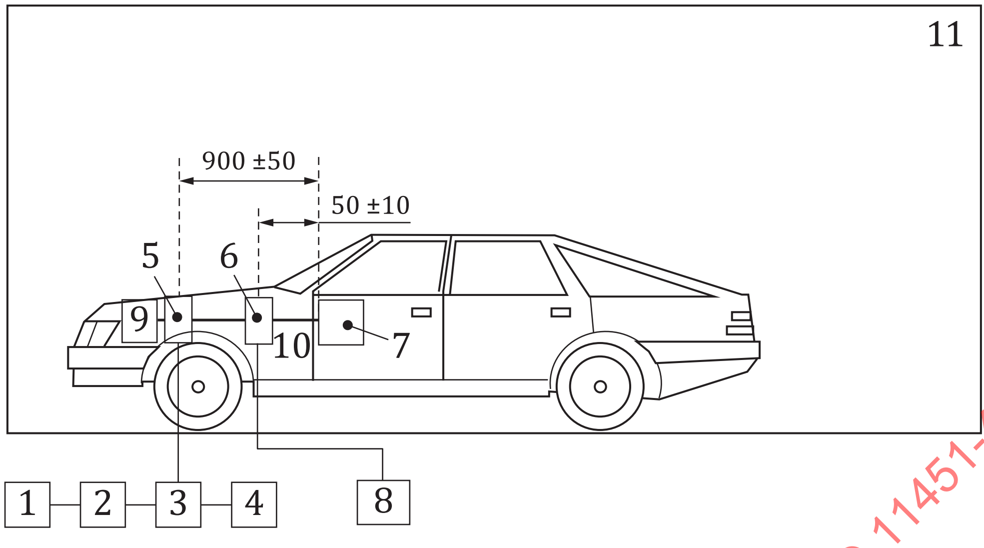
7.1.2 Closed-loop method with power limitation

Unless otherwise specified in the test plan, the injection probe should be placed at (900 ± 50) mm from the connector of the DUT.

Unless otherwise specified in the test plan, the current measurement probe shall be placed at (50 ± 10) mm from the connector of the DUT.

The vehicle and associated equipment are installed in the test location as described in Figure 2.

Dimensions in millimetres



Key

1 signal generators
2 broadband amplifier
3 RF 50 Ω directional coupler
4 RF power level measuring device or equivalent
5 RF injection probe
6 RF current measurement probe
7 DUT
8 spectrum analyser or equivalent
9 others vehicle devices
10 harness
11 shielded enclosure

It is recommended that appropriate ferrite chokes be placed on the coaxial cables to the injection and current measurement probes.

Figure 2 — Example of BCI test configuration – Closed-loop method

7.2 TWC Test methods

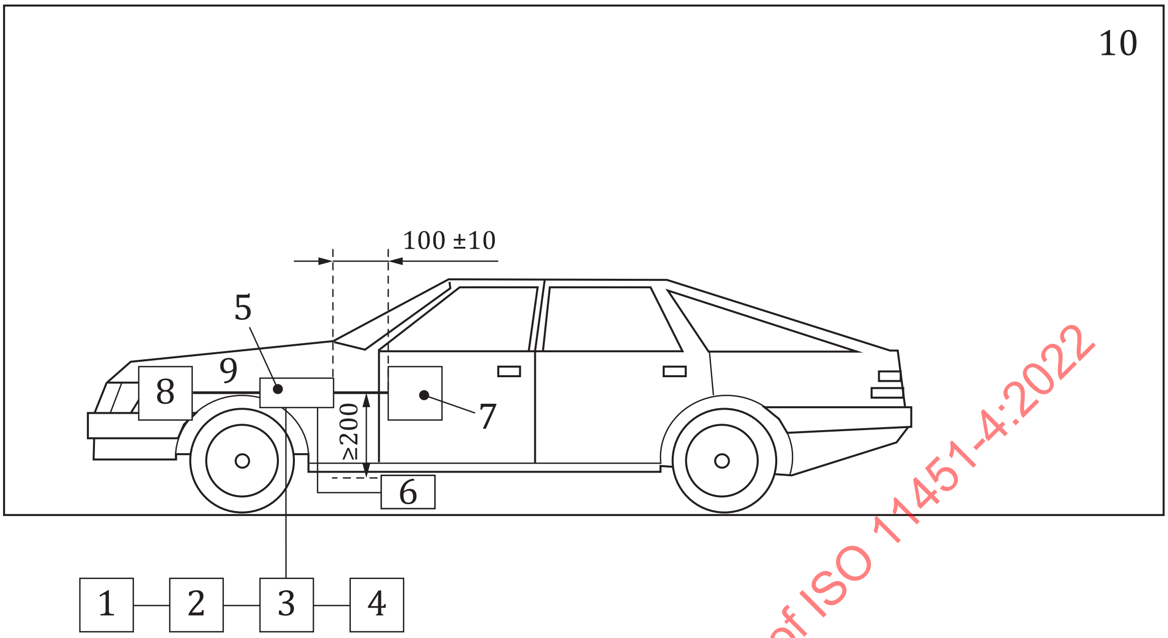
Measurements using this method can be affected by coupling between the TWC and the wiring harness as well as by reflected energy.

Unless otherwise specified in the test plan, the tubular wave coupler shall be placed at (100 ± 10) mm from the connector or the outlet aperture of the DUT being tested on the vehicle and isolated from any metallic part of the vehicle. 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 placed isolated from any metallic part of the vehicle at a minimum distance of 200 mm from the wiring harness and connected to the second port of the TWC.

Where the harness contains a number of branches to DUT connectors, the test should be repeated with the tubular wave coupler clamped around each of the branches (100 ± 10) mm from the branch termination.

The vehicle and associated equipment are installed in the test location as described in Figure 3.

Dimensions in millimetres



Key

1 signal generators
2 broadband amplifier
3 RF 50 Ω directional coupler
4 RF power level measuring device or equivalent
5 TWC
6 50 Ω load resistor
7 DUT
8 others vehicle devices
9 harness
10 shielded enclosure

Figure 3 — Example of TWC test configuration

8 Test procedure

8.1 General

The general arrangement of the disturbance source with respect to the vehicle harness and DUT represents a standardized test condition. Any deviations from this shall be agreed upon prior to testing and recorded in the test report.

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;

— injection and measurement probes locations;

— TWC location;

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

— test report content;

— and any special instructions and changes from the standard test.

Every DUT shall be tested under the most significant operating 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

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 vehicle.

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, as defined in Annex A, at frequency steps not greater than the maximum frequency step sizes defined in ISO 11451-1.

For smaller incremental test frequency steps, interpolation between calibration frequencies is allowed.

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.

8.3.1.2.3 Vehicle test

The vehicle and associated equipment are installed in the test location as described in Figure 1.

The test is conducted by subjecting the vehicle 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_{CWl} is determined using a calibration fixture.

The disturbance ($I_{\mathrm{disturbance}}$) 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 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 given by Formula (1):

$$P_{\mathrm{CWl}} = k\, P_{\mathrm{cal}} \tag{1}$$

where

P_{CWl} is the 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.

8.3.1.3.3 Vehicle test

The test setup is shown in Figure 2.

The test procedure uses a closed loop method with power limit (P_{CWl}). 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_{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 ± 50) 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 vehicle.

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 Ω shall be measured at frequency steps not greater than the maximum frequency step sizes defined in ISO 11451-1.

For smaller incremental test frequency steps, interpolation between calibration frequencies is allowed.

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.

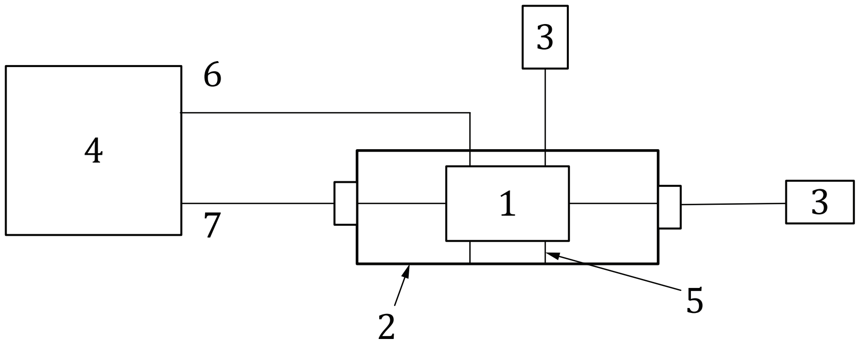
Since the tubular wave coupler and the calibration fixture are linear systems, the coupler insertion loss should be measured using a network analyser.

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

The analysing of coupler insertion loss 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
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 4 — Tubular wave coupler calibration set-up

The insertion loss of the coupler is given by Formula (2):

$$I_{\mathrm{LTWC}} = - |S_{21}| - C_{\mathrm{cf}} \qquad (2)$$

where

I_{LTWC} is the insertion loss of the tubular wave coupler, in dB;

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

C_{cf} is the correction factor of the calibration fixture, in dB.

8.3.2.2 Vehicle test

The vehicle and associated equipment are installed in the test location as described in Figure 2.

The forward power P_{fr} for DUT testing shall be calculated using Formula (3):

$$P_{\mathrm{fr}} = P_{\mathrm{t}} + I_{\mathrm{LTWC}} \qquad (3)$$

where

P_{t} is the required test power according to the test plan, in dBm;

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

I_{LTWC} 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_{ref}, P_{ref}, I_{fault}, P_{fault}, P_{CWl};

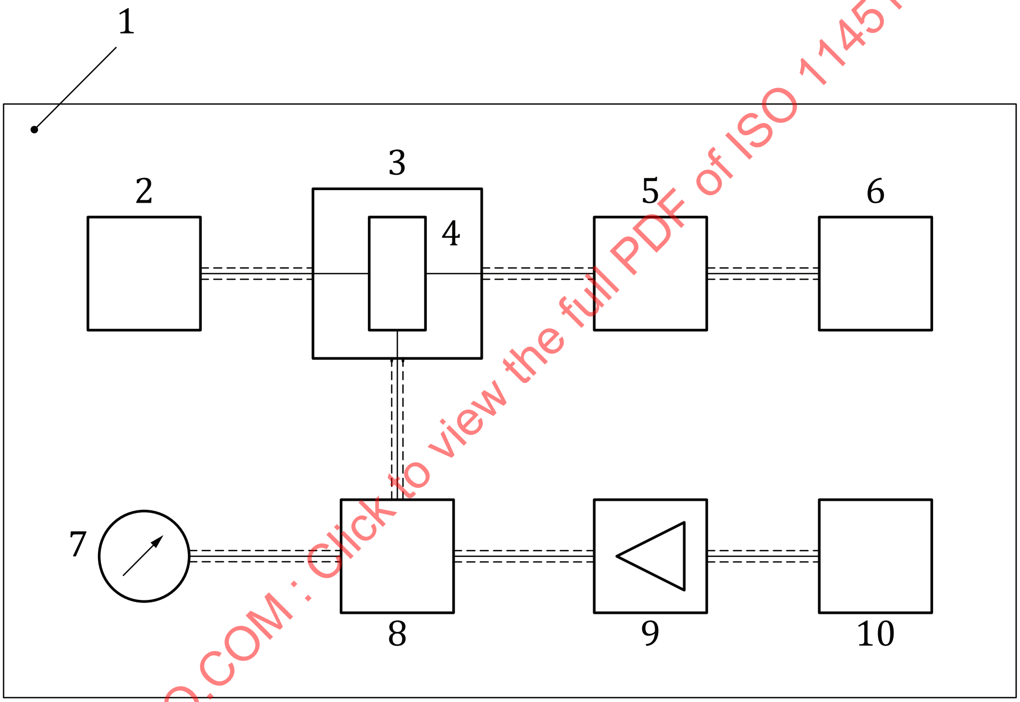
— the test setup transfer impedance (the voltage injected at the plane of the current injection probe divided by the current measured by the current measurement probe). An example of the test setup transfer impedance measurement or calculation methods is given in Annex B.

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.

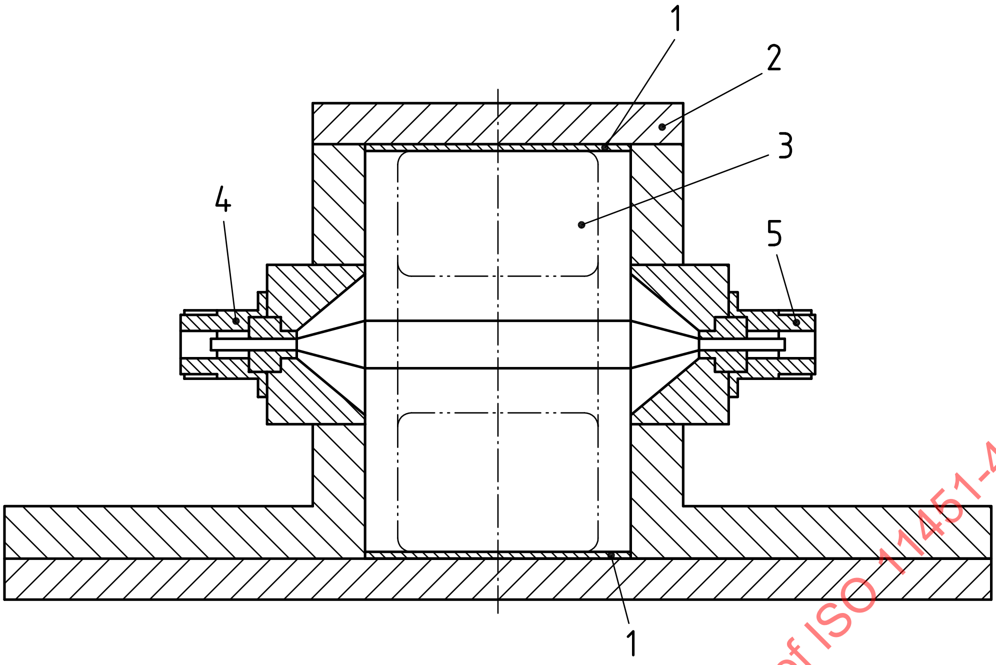
Mount the injection probe centred in the calibration fixture (see Figure A.2) and, while sweeping the test frequency range, measure the forward power required to achieve the current at which testing is to be conducted.



Key

1 shielded enclosure
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



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 follows in Formula (B.1).

$$Z_{tr} = \frac{V_{ind}}{I_{ind}} \tag{B.1}$$

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;

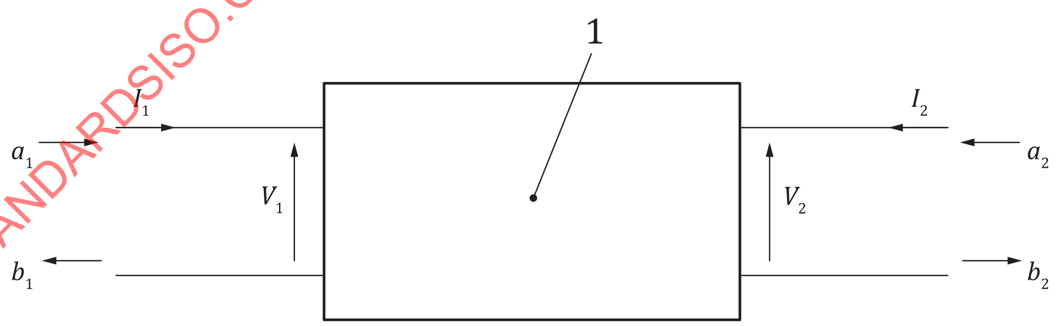
I_{ind} is the common mode current induced at the measurement point.

It is used to characterise the system (DUT, wiring harness and other vehicle 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 (Figure B.1)



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 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 Ω).

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 Ω).

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:

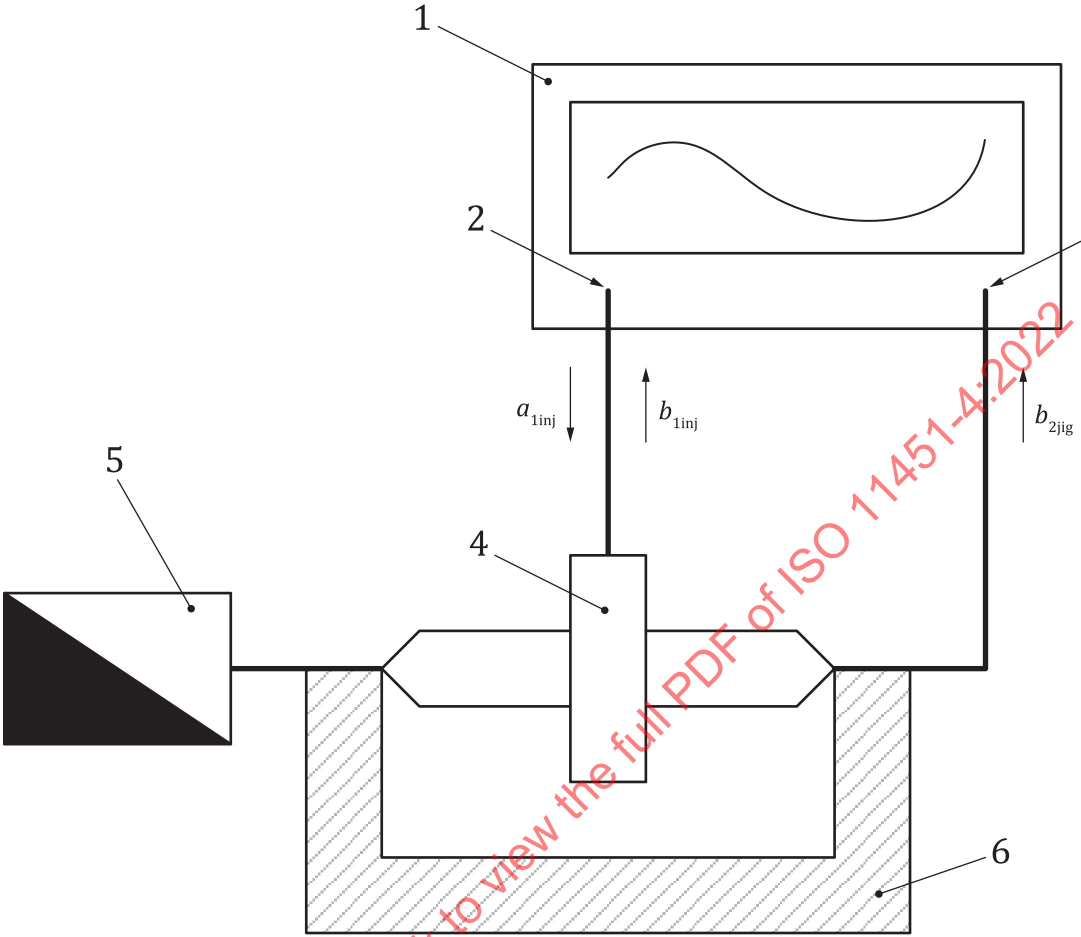
$$a_2 = 0\text{, therefore } b_1 = S_{11}a_1 \text{ and } b_2 = S_{21}a_1 \tag{B.7}$$

where

S_{11} is the coefficient of reflection;

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

B.2.2 Calibrating the current injection probe (Figure B.2)



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

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

$$I_{LCIP} = \frac{1}{|s_{21inj}|^2} = \frac{|a_{1inj}|^2}{|b_{2jig}|^2} \quad (B.8)$$

where

I_{LCIP} is the insertion loss of the current injection probe;

$|b_{2jig}|$ is the "reflected" wave magnitude induced on the calibration fixture port;

$|a_{1inj}|$ is the incident wave magnitude applied to the current injection probe;

$|S_{21\ inj}|$ is the transmission magnitude coefficient of the current injection probe.

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

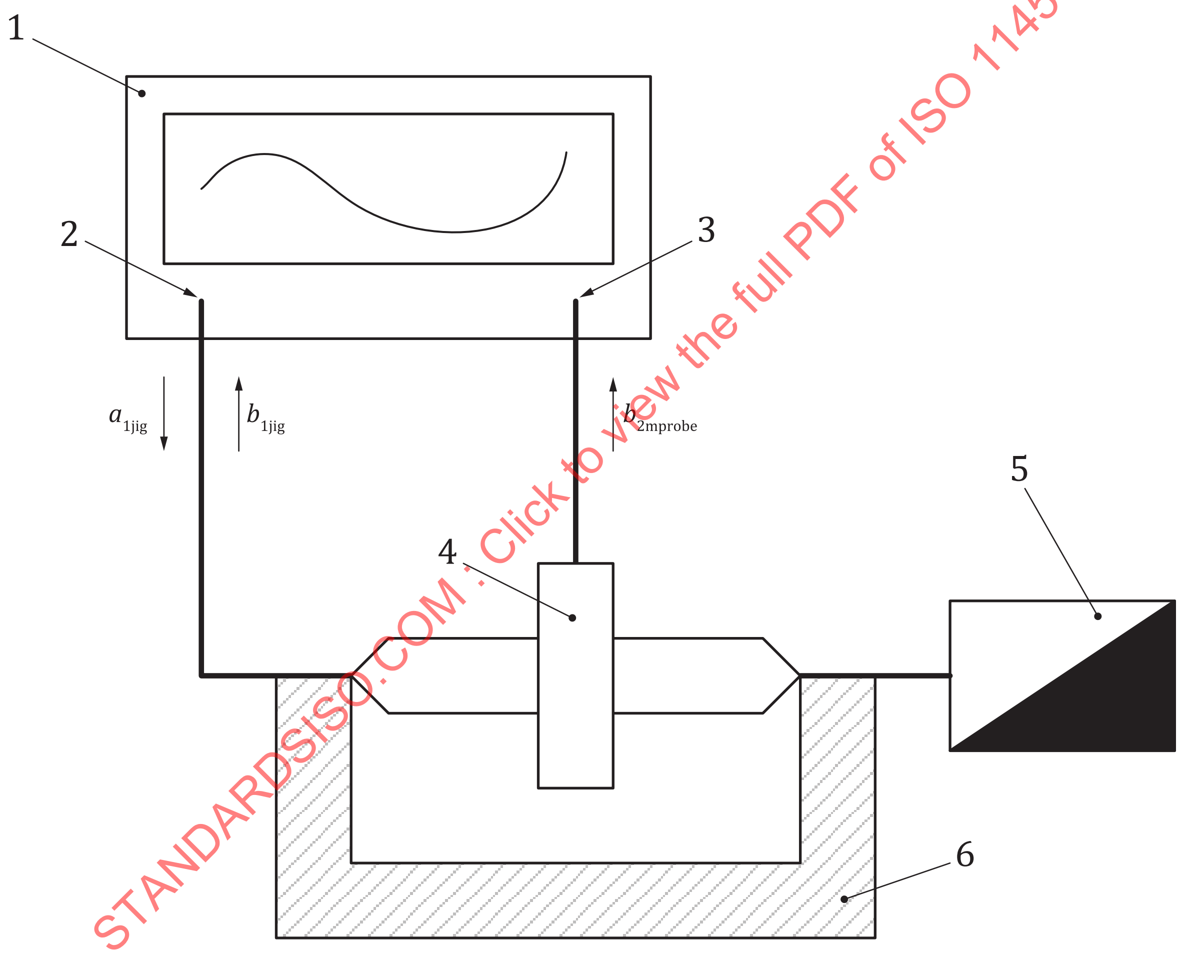
$$\left|b_{2jig}\right|^2 = \frac{1}{50}\left(\frac{\left|V_{ind}\right|}{2}\right)^2 \tag{B.9}$$

where $|V_{ind}|$ is the magnitude of the voltage induced by the current injection probe on the calibration fixture;

which induces:

$$\frac{\left|V_{ind}\right|}{\left|a_{1inj}\right|} = 2\sqrt{\frac{50}{I_{LCIP}}} \tag{B.10}$$

B.2.3 Calibrating the current measurement probe (Figure B.3)



Key

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

Figure B.3 — Calibrating the current measurement probe

The current measurement probe is characterised by its transfer impedance Z_{Tmprobe} given by Formula (B.11):

$$\left|Z_{\text{Tmprobe}}\right| = \frac{\left|V_{\text{ret}}\right|}{\left|I_{\text{ind}}\right|} \tag{B.11}$$

where

$|Z_{\text{Tmprobe}}|$ is the impedance magnitude of the current measurement probe

$|V_{\text{ret}}|$ is the voltage magnitude returned by the current measurement probe loaded by 50 Ω;

$|I_{\text{ind}}|$ is the current magnitude to be measured.

$$\left|b_{\text{2mprobe}}\right|^2 = \frac{\left|V_{\text{ret}}\right|^2}{50} \tag{B.12}$$

where $|b_{\text{2mprobe}}|^2$ is the reflected wave magnitude measured by the measurement probe

and

$$\left|a_{\text{1jig}}\right|^2 = 50\left|I_{\text{ind}}\right|^2 \tag{B.13}$$

where $|a_{\text{1jig}}|^2$ is the incident wave magnitude injected inside the jig when the measurement probe is set on for calibration.

Formula (B.14) comes from Formulae (B.11) and (B.12):

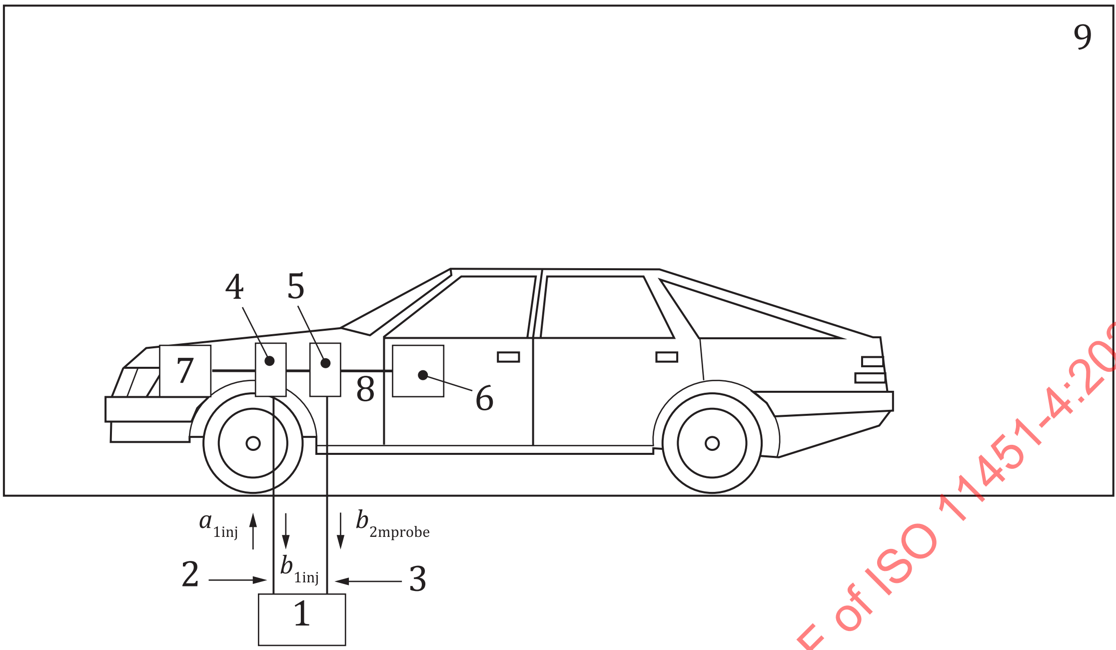
$$\frac{\left|b_{\text{2mprobe}}\right|}{\left|I_{\text{ind}}\right|} = \frac{\left|Z_{\text{Tmprobe}}\right|}{\sqrt{50}} \tag{B.14}$$

Formula (B.15) comes from Formulae (B13) and (B.14):

$$\left|Z_{\text{Tmprobe}}\right| = 50\frac{\left|b_{\text{2mprobe}}\right|}{\left|a_{\text{1jig}}\right|} = 50\left|S_{\text{21mprobe}}\right| \tag{B.15}$$

where $|S_{\text{21mprobe}}|$ is the forward transmission factor magnitude of the current measurement.

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 other vehicle devices
8 harness
9 shielded enclosure

Figure B.4 — Measuring the transfer impedance

The transfer impedance of the test setup is defined by Formula (B.16):

$$|Z_{\text{tr}}| = \frac{|V_{\text{ind}}|}{|I_{\text{ind}}|} = \frac{|V_{\text{ind}}|}{|a_{1\text{inj}}|} \frac{|a_{1\text{inj}}|}{|b_{2\text{mprobe}}|} \frac{|b_{2\text{mprobe}}|}{|I_{\text{ind}}|} \tag{B.16}$$

where $|Z_{\text{tr}}|$ is the impedance magnitude of the test setup

From the previous formulae, the transfer impedance of the test setup-can be calculated from S21 parameter measurement for Figure B.4 and the characteristics of the probes as follows in Formulae (B.17) and (B.18):

$$|Z_{\text{tr}}| = \frac{2|Z_{\text{Tmprobe}}|}{|S_{21\text{test}}|\sqrt{I_{\text{LCIP}}}} \tag{B.17}$$

where $|S_{21\ \text{test}}|$ is the transmission factor between the injection probe and the measurement probe during the test

$$Z_{\text{tr dB}} = 6 + Z_{\text{T dB}} - l_{\text{LCIP dB}} - S_{21\text{test dB}} \tag{B.18}$$