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

**Part 9:
Portable transmitters**

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

Partie 9: Émetteurs portables

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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.

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 second edition cancels and replaces the first edition (ISO 11452-9:2012), which has been technically revised.

The main changes are as follows:

- change of the frequency range from 26 MHz – 5,85 GHz to 142 MHz – 6 GHz;
- suppression of test methodology with commercial transmitters;
- use of modulation from ISO 11452-1;
- modifications of ground plane dimensions;
- introduction of additional artificial networks (HV-AN, AMN, AAN) for DUT powered by a shielded power system;
- addition of test set-up descriptions and figures for HV power supply system;
- addition of wording for DUT, connector and harness testing;
- addition of new [Annex A](#) with description of test methodology for net power characterization procedure;
- addition in [Annex C](#) of microwave broadband dipole antenna and HF broadband sleeve antenna;
- addition of [Annex F](#) on broadband noise source with arbitrary waveform generator.

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.

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

Part 9: Portable transmitters

1 Scope

This document specifies test methods and procedures for testing electromagnetic immunity of electronic components for passenger cars and commercial vehicles to portable transmitters in close proximity, regardless of the propulsion system (e.g. spark-ignition engine, diesel engine, electric motor). The device under test (DUT), together with the wiring harness (prototype or standard test harness), is subjected to an electromagnetic disturbance generated by portable transmitters inside an absorber-lined shielded enclosure, with peripheral devices either inside or outside the enclosure. The electromagnetic disturbances considered 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, *Road vehicles — Component test methods for electrical disturbances from narrowband radiated electromagnetic energy — Part 1: General principles and terminology*

Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz). International Commission on Non-Ionizing Radiation Protection (ICNIRP)

3 Terms and definitions

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

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

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

3.1

reference position

geometrical centre of the radiation pattern of the antenna, which is determined by the manufacturer based on near field measurement

4 Test conditions

The applicable frequency range of the test method is 142 MHz to 6 GHz.

The user of this document shall specify the test severity level or levels over the frequency bands. The test severity level shall take into account:

- typical portable transmitter characteristics (frequency bands, power level and modulation), and
- the characteristics of the antenna(s) used for this test.

The user 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;
- dwell time;
- test signal quality;
- frequency steps;
- modulation.

NOTE Alternate modulations, if required, can be found in [Annex B](#). Users of this document are advised that [Annex B](#) is for information only and cannot be considered as an exhaustive description of various portable transmitters available in all countries.

5 Test location

The test shall be performed in an absorber lined shielded enclosure (ALSE).

6 Test instrumentation

6.1 General

The field-generating device shall be simulated portable transmitters, with a broadband amplifier connected to a transmit antenna.

Test personnel shall be protected in accordance with ICNIRP Guidelines.

NOTE National or other regulations can apply.

6.2 Simulated portable transmitters

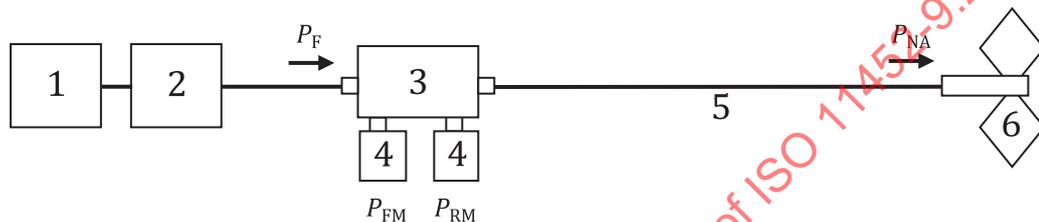
6.2.1 General

The following equipment is used:

- ground plane;
- radio frequency (RF) generator with internal or external modulation capability;
- power amplifier;
- power measuring instrumentation to measure the forward and reverse power;
- dual directional coupler;
- low loss coaxial cables;

- vector network analyser (VNA);
- transmit antenna;
- artificial networks (AN), and/or high voltage artificial networks (HV-AN), and/or artificial mains networks (AMN), and/or asymmetric artificial networks (AAN).

Figure 1 illustrates the basic setup for the RF generation equipment. Testing is based on a required net power (P_{NA}) applied to the test antenna. The net power level is derived from the forward power (P_{FM}) measured at the directional coupler, which is remotely connected to the transmit antenna via low loss coaxial cable. Requirements on directional coupler, cable and power sensors are listed in 6.2.2 to 6.2.4. The procedures delineated in Annex A shall be used determine the required forward power to achieve the net power levels listed in Annex A or within the test plan. Although not required, it is highly recommended to use a single directional coupler to cover the entire frequency band.



Key

1	RF signal generator	P_{FM}	measured forward power at the directional coupler
2	RF amplifier	P_{RM}	measured reverse power at the directional coupler
3	dual directional coupler	P_{NA}	net power delivered to antenna
4	power sensor or measurement receiver		
5	low loss coaxial cable with transmission loss		
6	transmit antenna		

Figure 1 — RF generation equipment setup

6.2.2 Dual directional coupler

The coupler shall exhibit the following characteristics:

- coupling factor: >20 dB (40 dB recommended),
- mainline port VSWR: <1,3,
- coupling port VSWR: <1,5,
- mainline transmission loss: <0,5 dB,
- directivity: >18 dB.

Selection of coupling factor (20 – 40 dB) shall be compatible with the sensitivity of the measurement equipment used to measure forward and reflected power (see 6.2.3 for details).

6.2.3 Power monitoring

Either power sensors or a spectrum analyser (or measurement receiver) shall be used for measurement of the forward and reflected power at the dual directional coupler.

When power sensors are used to measure forward and reflected power:

- CW or AM signal shall be measured either with an average or peak power sensor (peak conservation may be applied for AM per ISO 11452-1);

- pulsed power modulation shall be measured with a peak envelope power sensor;
- power sensors should be connected directly to the coupler ports;
- power sensors shall exhibit a VSWR $<1,2$ and a measurement accuracy $<0,5$ dB.

When a spectrum analyser (or measurement receiver) is used to measure forward and reflected power, it shall exhibit the same VSWR and measurement accuracy as required for power sensors.

When the sensors or a spectrum analyser (or measurement receiver) are connected to the coupler via coaxial cables, the cable's transmission loss shall be taken into account during characterization. See [Annex A](#) for details.

6.2.4 Low loss coaxial cable

The 50 Ω coaxial cable assembly (including all adaptors, switches, etc.) connecting the dual directional coupler to the transmit antenna shall exhibit a VSWR $<1,1$ and transmission loss <4 dB. Verification shall be performed in accordance with [Annex A](#).

6.2.5 Vector network analyser (VNA)

The VNA shall exhibit the following characteristics:

- frequency range: 142 MHz – 6 GHz,
- frequency step: specified by the manufacturer (logarithmic step recommended),
- dynamic range: >60 dB (IF bandwidth <3 kHz),
- return loss: >32 dB,
- transmission loss accuracy: $<0,1$ dB,
- power level: 0 dBm (recommended value),
- minimum averaging factor (optional),
- minimum number of points: 401 (with logarithmic sweep),
- IF bandwidth: selected to meet return and transmission loss requirements (typically 1 kHz),
- VNA calibration kit to facilitate TOSM (through, open, short, matched) measurements:
 - termination through: return loss >35 dB,
 - termination short/open: deviation in nominal phase $<2^\circ$,
 - termination match: return loss >40 dB,
 - it is recommended to use the same connector type to match that of the interconnecting cable assembly and transmit antenna (avoid using adaptors).

6.2.6 Transmit antenna

The transmit antenna shall be a passive antenna. For accurate exposure during testing, the following commercially available antennas are listed in [Table 1](#).

Details associated with each antenna are found in [Annex C](#). Only one type of antenna is required for the frequency range being tested.

Testing requires near field excitation of the DUT and its attached harness. To facilitate this, the transmit antennas listed in [Table 1](#) have specific reference positions where the magnitude of the electric and magnetic fields are at a maximum, dependent on the test frequency. To ensure testing is accurately

executed, the reference positions shall be clearly defined by the antenna manufacturer for each transmitting antenna (see [Annex C](#) for guidance).

Table 1 — Transmit antenna types

Antenna description	Frequency coverage
Folded dipole antennas	142 MHz – 246 MHz
Sleeve antennas	380 MHz – 460 MHz ^a
Broadband dipole antenna	360 MHz – 2 700 MHz
Broadband sleeve antenna	700 MHz – 3 200 MHz
Microwave broadband dipole antenna	2 000 MHz – 6 000 MHz
HF broadband sleeve antenna	2 400 MHz – 6 000 MHz
^a Requires antenna tuning for selected test frequencies (see Annex C).	

6.2.7 Stimulation and monitoring of the DUT

The DUT shall be operated in accordance with the test plan by actuators which have a minimum effect on the electromagnetic characteristics, for example, plastic blocks on the pushbuttons, 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 types 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.

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

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, 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 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.

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 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 LV power supply system

[Figures 2](#) and [3](#) show the test bench setup when using only a LV power supply system.

Each DUT power supply lead shall be connected to the power supply through an artificial network (AN).

Power shall be applied to the DUT via a 5 μ H/50 Ω AN. Whether two ANs or only one is required depends on the intended DUT installation in the vehicle:

- for remotely grounded DUTs (vehicle power return line longer than 200 mm), two ANs are required, one AN for the positive supply line and the other AN for the power return line (see [Annex E](#));
- for locally grounded DUTs (vehicle power return line 200 mm or shorter), only one AN is required, for the positive supply (see [Annex E](#)).

The AN(s) shall be mounted directly on the ground plane. AN cases 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.

7.3 HV power supply system

[Figures 4](#) to [7](#) show the test bench setup when using an HV power supply system.

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 μ H/50 Ω HV AN (see ISO 11452-1:2015, Annex B for the schematic).
- AC supply shall be applied to the DUT via a 50 μ H/50 Ω AMN (see ISO 11452-1:2015, Annex B 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 HV 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.

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

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

7.4 Location of the DUT

For LV power supply system, unless otherwise specified, the DUT shall be placed on non-conductive material of low relative permittivity (dielectric constant) ($\epsilon_r \leq 1,4$) at least 50 mm above the ground plane. The height shall be selected to assure that no portion of the transmit antenna is any closer than 50 mm to the ground plane. The DUT height selected shall be documented in the test plan.

The case of the DUT shall not be grounded to the ground plane unless it is intended to simulate the actual vehicle configuration.

For HV power supply system, 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 DUT shall be located at least 100 mm from the edge of the ground plane.

7.5 Location of the test harness

For LV power supply system, the total length of the test harness between the DUT and the load simulator (or the RF boundary) shall be $(1\,700 + 300/0)$ mm. The part of the test harness parallel to the front edge of the ground plane shall be at least 1 400 mm.

For HV power supply system, unless otherwise specified in the test plan (e.g. use of original vehicle harnesses), the total length of harnesses shall be as follows:

- $(1\,700 + 300/0)$ mm for the LV lines and the length of the LV test harness parallel to the front of the ground plane shall be at least 1 400 mm;
- $(1\,700 + 300/0)$ mm for the HV lines and the length of the HV test harness parallel to the front of the ground plane shall be at least 1 400 mm;
- $(1\,700 + 300/0)$ mm for the AC lines and the length of the AC test harness parallel to the front of the ground plane shall be at least 1 400 mm and
- less than 1 000 mm for the three phase lines between DUT and electric motor(s).

If the HV test harness is over 2 000 mm, the HV test harness length should be defined in the test plan and described in the test report.

The wiring type (e.g. single wires, twisted wire pairs) is defined by the actual system application and requirement.

The test harness shall be placed on non-conductive material of low relative permittivity (dielectric constant) ($\epsilon_r \leq 1,4$) at (50 ± 5) mm above the ground plane.

The LV test harness shall be located at least 200 mm from the edge of the ground plane. The long segment of the shielded HV power harness, if present, shall be located at $100 + 100/0$ mm from the LV harness.

For an inverter/charger device, the setup in [Figures 6](#) and [7](#) are examples of further HV and LV load simulators and supplies attached to the DUT, e.g. 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.

7.6 Location of the load simulator

Unless otherwise specified in the test plan, the load simulator (designed to simulate typical loading as in the vehicle) shall 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).

7.7 Location of the simulated portable transmitter equipment.

The interconnection between the directional coupler and the transmit antenna is a critical factor in minimizing error in the net power delivered to the antenna.

There are two alternative configurations.

- Configuration 1 locates the RF signal generation equipment, dual directional coupler and power monitoring equipment outside of the ALSE. In this configuration, the coupler and coaxial cable are connected via a single bulkhead connector.
- Configuration 2 locates the RF signal generation equipment, dual direction coupler and power monitoring equipment inside the ALSE. In this configuration, the coaxial cable connects directly to coupler. Use of this configuration requires powering of the equipment internal to the test chamber. Also, sufficient separation between the equipment and the transmit antenna should be considered to avoid possible functional issues due to RF fields produced.

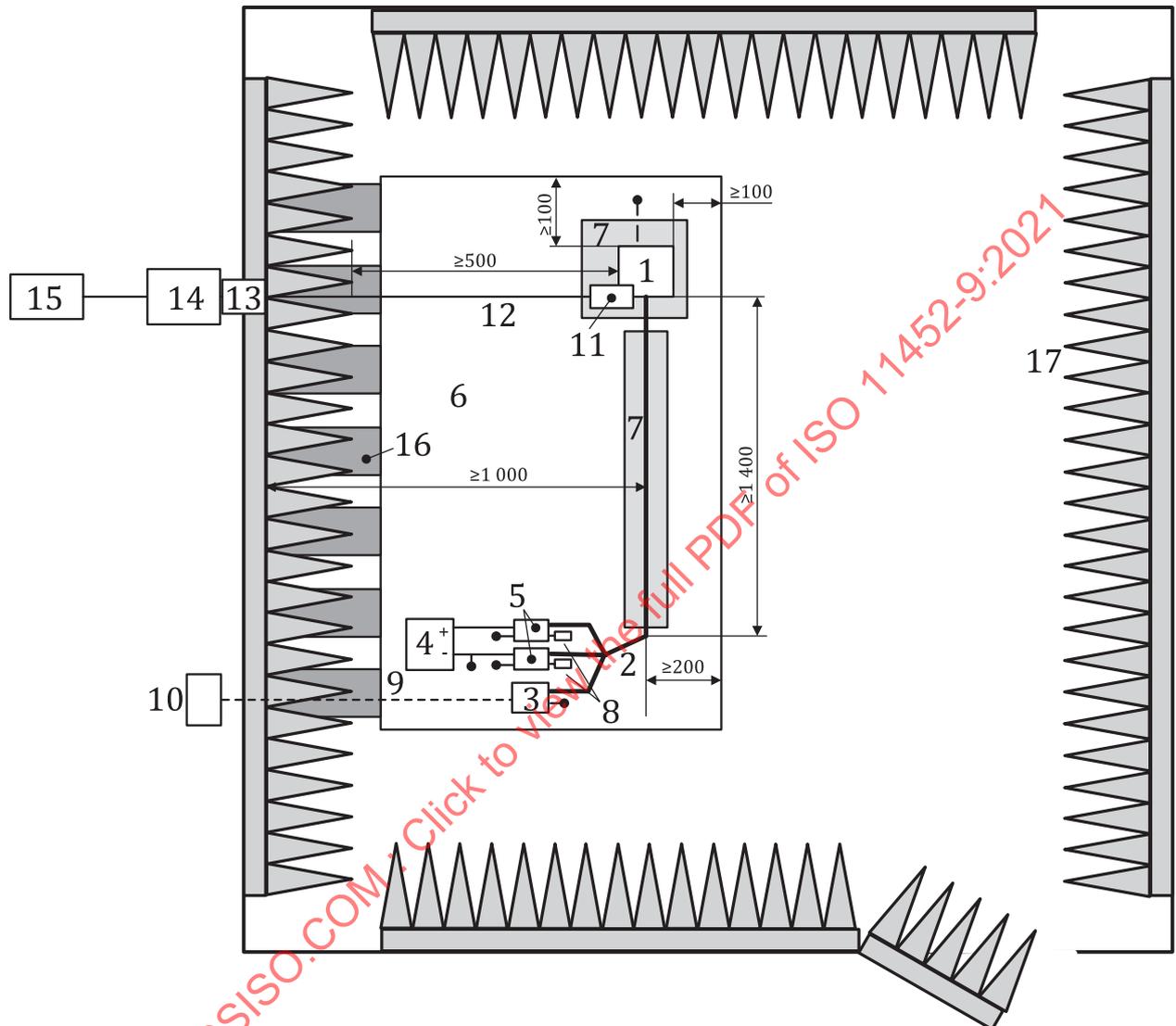
In both cases, a single low loss coaxial cable serves as the interconnection between the dual directional coupler and the antenna. Use of in-line connectors and/or adaptors should be avoided wherever possible to reduce error due to the accumulated impedance mismatch introduced by use of these devices. The impedance mismatch directly affects the net power.

Examples of test set-ups are shown in [Figures 2](#) and [3](#) (for LV power supply system in configurations 1 and 2) and in [Figures 4](#) to [7](#) (for HV power supply system in configurations 1 and 2).

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Dimensions in millimetres

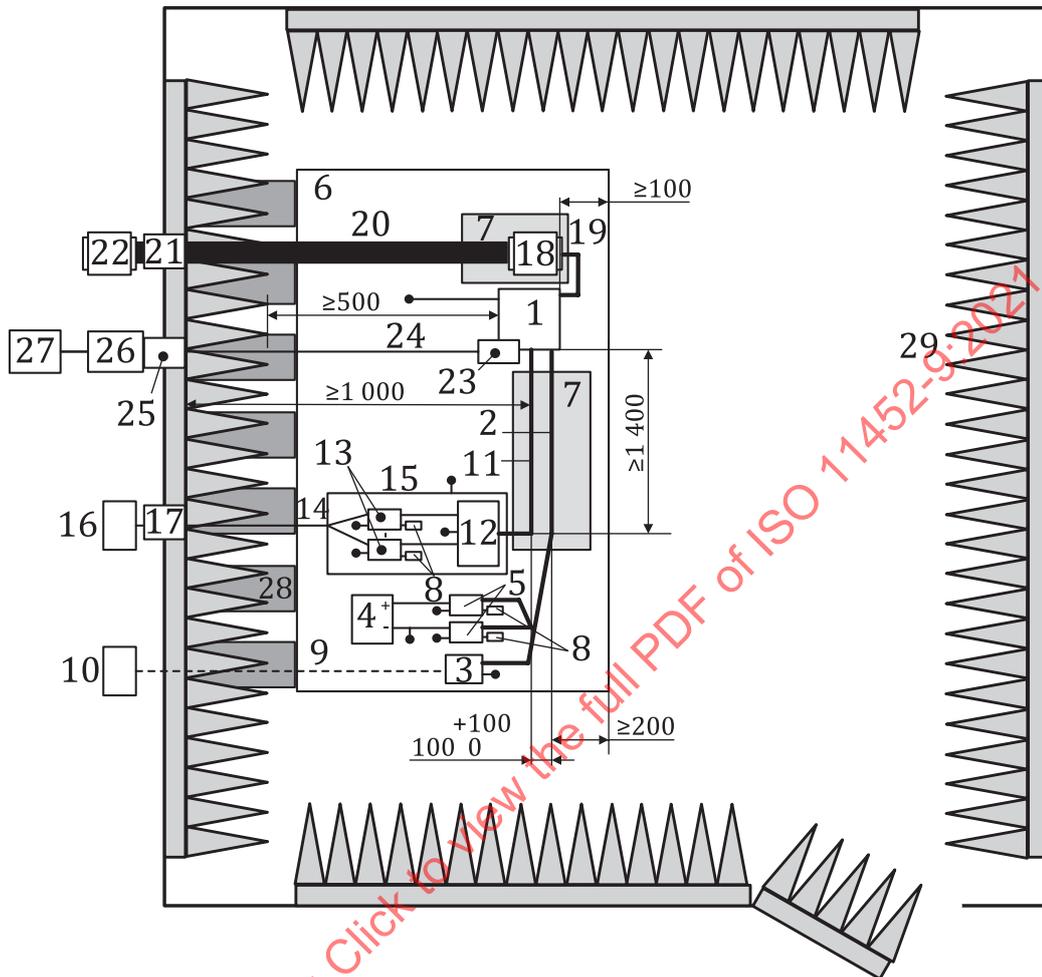
Upper view

**Key**

- | | |
|---|--|
| 1 DUT (grounded locally if required in test plan) | 10 stimulation and monitoring system |
| 2 LV test harness | 11 simulated portable transmitter antenna |
| 3 load simulator (placement and ground connection according to 6) | 12 high-quality double-shielded coaxial cable (50 Ω) |
| 4 power supply (location optional) | 13 bulkhead connector |
| 5 artificial network (AN) | 14 dual directional coupler |
| 6 ground plane (bonded to shielded enclosure) | 15 RF generation and power monitoring equipment |
| 7 low relative permittivity support ($\epsilon_r \leq 1,4$) | 16 ground straps |
| 8 50 Ω load | 17 RF absorber material |
| 9 optical fibre | |

Figure 2 — Example of LV power supply system test setup (configuration 1)

Upper view



Key

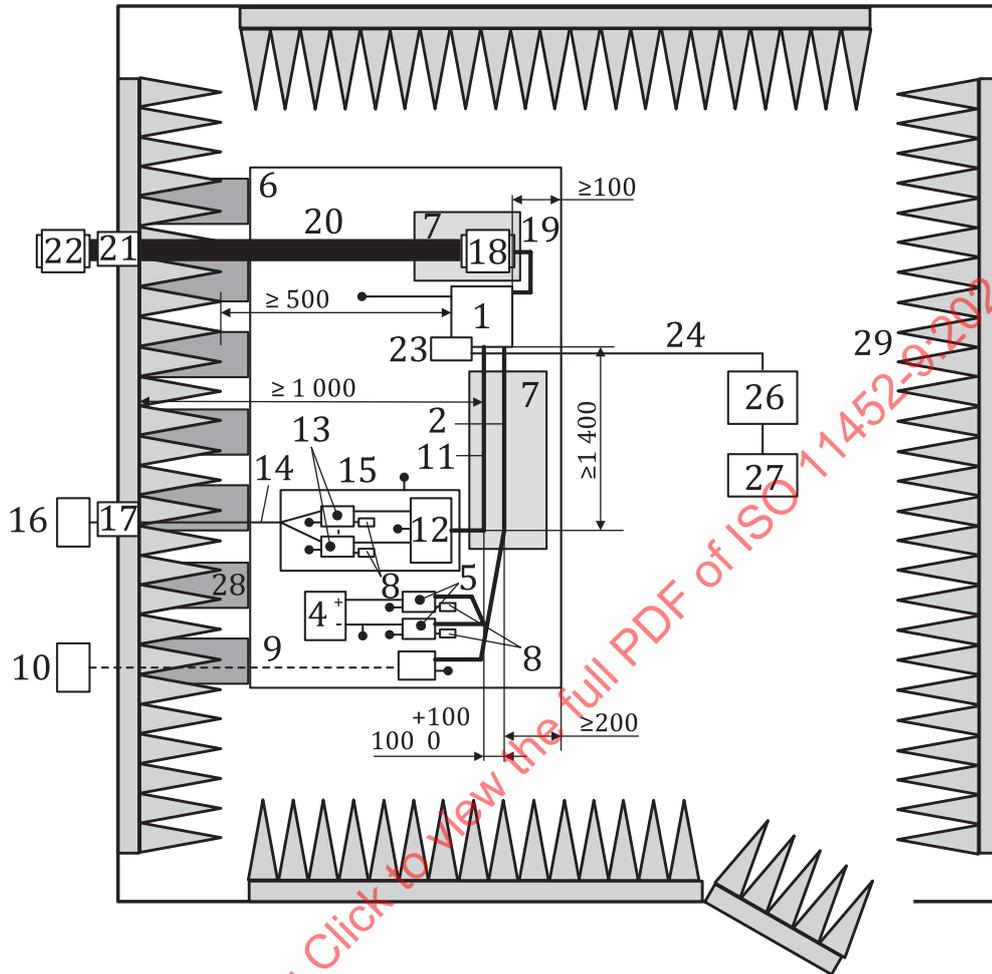
1	DUT (grounded locally if required in test plan)	11	HV lines (HV+, HV-)	21	filtered mechanical bearing
2	LV test harness	12	impedance matching network (optional) (see ISO 11452-1)	22	brake or propulsion motor
3	load simulator (placement and ground connection according to 7.6)	13	HV AN	23	simulated portable transmitter antenna
4	power supply (location optional)	14	HV supply lines	24	high-quality double-shielded coaxial cable (50 Ω)
5	artificial network (AN)	15	additional shielded box	25	bulkhead connector
6	ground plane (bonded to shielded enclosure)	16	HV power supply (shielded if placed inside ALSE)	26	dual directional coupler
7	low relative permittivity support ($\epsilon_r \leq 1,4$)	17	power line filter	27	RF generation and power monitoring equipment
8	50 Ω load	18	electric motor	28	ground straps
9	optical fibre	19	three phase motor supply lines	29	RF absorber material

- | | | | |
|----|-----------------------------------|----|---|
| 10 | stimulation and monitoring system | 20 | mechanical connection (e.g. non-conductive) |
|----|-----------------------------------|----|---|

Figure 4 — Example of HV power supply system test setup for DUTs with electric motor attached to the bench (configuration 1)

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Upper view



Key

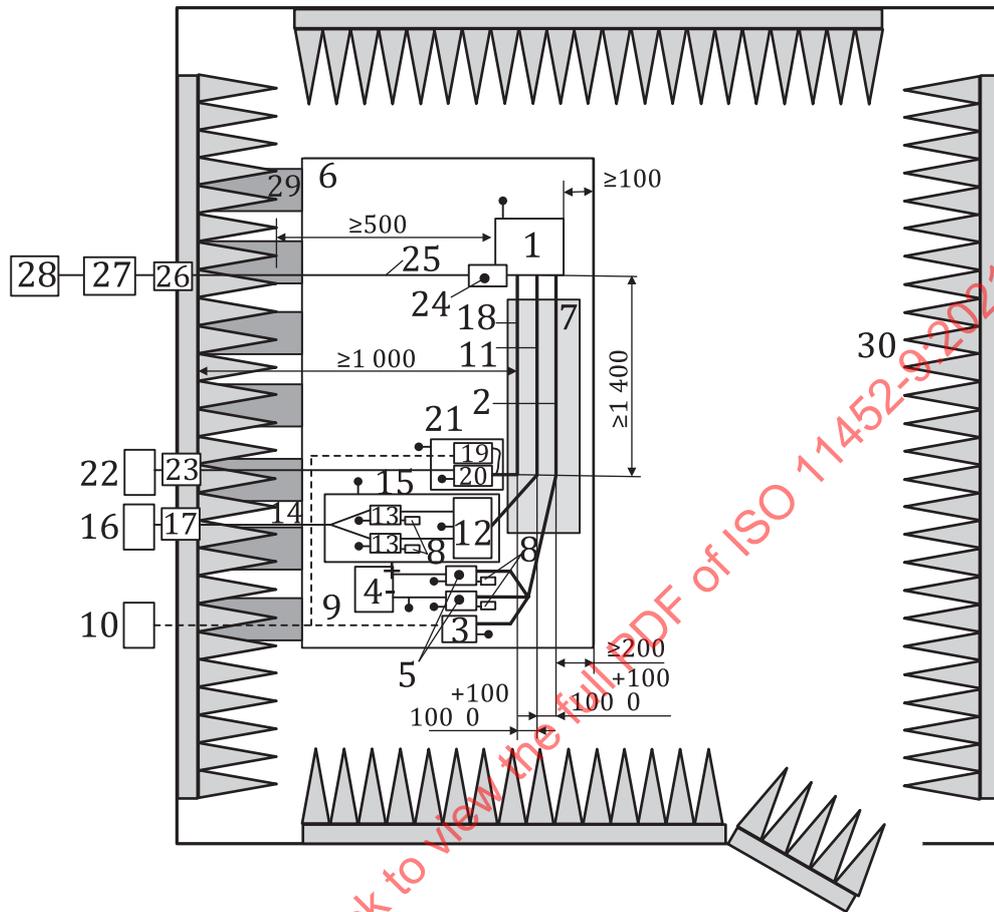
1	DUT (grounded locally if required in test plan)	11	HV lines (HV+, HV-)	21	filtered mechanical bearing
2	LV test harness	12	impedance matching network (optional) (see ISO 11452-1)	22	brake or propulsion motor
3	load simulator (placement and ground connection according to 7.6)	13	HV AN	23	simulated portable transmitter antenna
4	power supply (location optional)	14	HV supply lines	24	high-quality double-shielded coaxial cable (50 Ω)
5	artificial network (AN)	15	additional shielded box	26	dual directional coupler
6	ground plane (bonded to shielded enclosure)	16	HV power supply (shielded if placed inside ALSE)	27	RF generation and power monitoring equipment
7	low relative permittivity support ($\epsilon_r \leq 1,4$)	17	power line filter	28	ground straps
8	50 Ω load	18	electric motor	29	RF absorber material
9	optical fibre	19	three phase motor supply lines		

- | | | | |
|----|-----------------------------------|----|---|
| 10 | stimulation and monitoring system | 20 | mechanical connection (e.g. non-conductive) |
|----|-----------------------------------|----|---|

Figure 5 — Example of HV power supply system test setup for DUTs with electric motor attached to the bench (configuration 2)

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Upper view

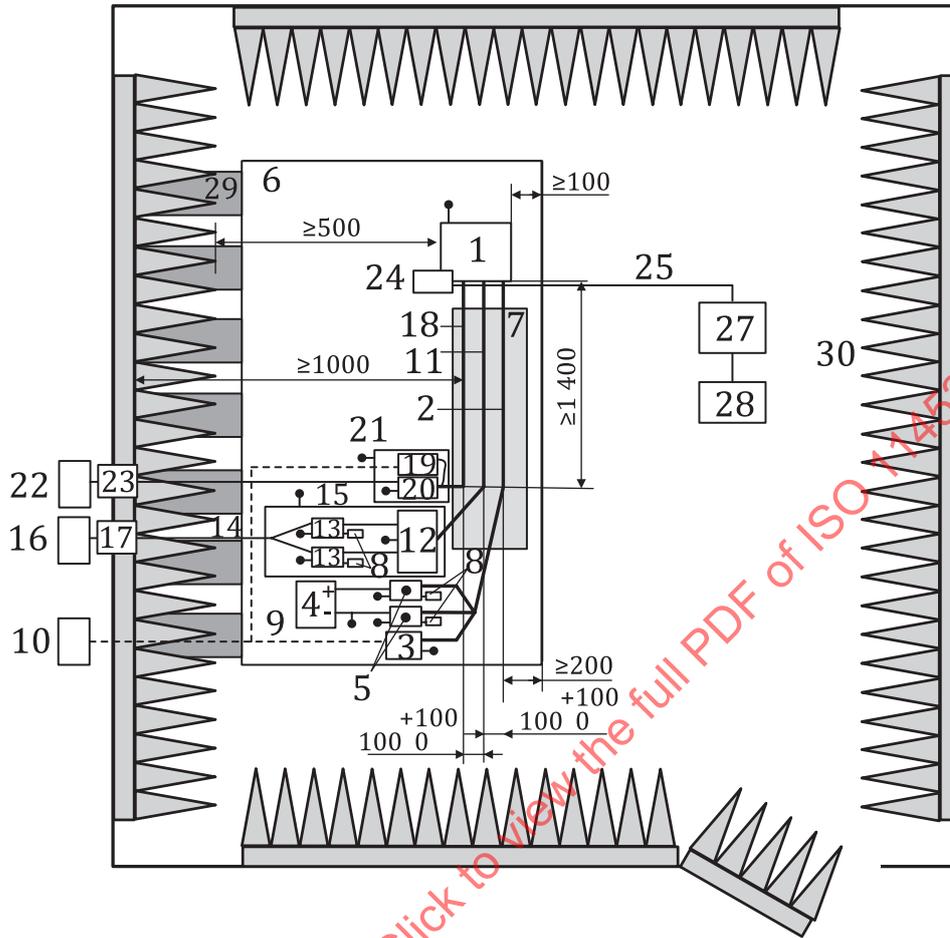


Key

1	DUT (grounded locally if required in test plan)	11	HV lines (HV+, HV-)	21	additional shielded box
2	LV test harness	12	impedance matching network (optional) (see ISO 11452-1)	22	AC power main
3	load simulator (placement and ground connection according to 7.6)	13	HV AN	23	power line filter
4	power supply (location optional)	14	HV supply lines	24	simulated portable transmitter antenna
5	artificial network (AN)	15	additional shielded box	25	high-quality double-shielded coaxial cable (50 Ω)
6	ground plane (bonded to shielded enclosure)	16	HV power supply (shielded if placed inside ALSE)	26	bulkhead connector
7	low relative permittivity support ($\epsilon_r \leq 1,4$)	17	power line filter	27	dual directional coupler
8	50 Ω load	18	AC lines	28	RF generation and power monitoring equipment
9	optical fibre	19	AC charging load simulator	29	ground straps
10	stimulation and monitoring system	20	AMN for AC power mains	30	RF absorber material

Figure 6 — Example of HV power supply system test setup for DUTs with inverter/charger device (configuration 1)

Upper view



Key

1	DUT (grounded locally if required in test plan)	11	HV lines (HV+, HV-)	21	additional shielded box
2	LV test harness	12	impedance matching network (optional) (see ISO 11452-1)	22	AC power main
3	load simulator (placement and ground connection according to 7.6)	13	HV AN	23	power line filter
4	power supply (location optional)	14	HV supply lines	24	simulated portable transmitter antenna
5	artificial network (AN)	15	additional shielded box	25	high-quality double-shielded coaxial cable (50 Ω)
6	ground plane (bonded to shielded enclosure)	16	HV power supply (shielded if placed inside ALSE)	27	dual directional coupler
7	low relative permittivity support ($\epsilon_r \leq 1,4$)	17	power line filter	28	RF generation and power monitoring equipment
8	50 Ω load	18	AC lines	29	ground straps
9	optical fibre	19	AC charging load simulator	30	RF absorber material

10 stimulation and monitoring system 20 AMN for AC power mains system

Figure 7 — Example of HV power supply system test setup for DUTs with inverter/charger device (configuration 2)

8 Test procedure

8.1 General

The general arrangement of the disturbance source and connecting harnesses represents a standardized test condition. Any deviations from this document shall be agreed upon prior to testing.

The DUT load simulator shall be designed to simulate typical loading as in the vehicle. The DUT shall be tested under the most significant conditions, e.g. in stand-by mode and in a mode by which all the actuators can be excited. These operating conditions shall be clearly defined in the test plan to ensure supplier and customer perform identical tests.

8.2 Test plan

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

- test set-up,
- frequency range,
- DUT mode of operation,
- DUT acceptance criteria,
- test severity levels,
- DUT monitoring conditions,
- DUT exposure methodology,
- simulated portable transmitter antenna,
- antenna positions for coupling to DUT and/or harness,
- DUT surfaces to be tested and associated DUT positioning,
- test report content, and
- any special instructions and changes from the standard test.

8.3 Test procedure

8.3.1 General

CAUTION — Hazardous voltages and fields can exist within the test area. Ensure that all requirements for limiting the exposure of humans to RF energy and high voltage are met.

Testing is performed using either of two methods for coupling to the DUT and attached wiring harnesses. In both methods, the adjustment of the required net power delivered to the transmit antenna shall be performed via adjustment of the forward power derived from the characterization procedure in [Annex A](#). Typical net power values are provided in [Annex B](#).

Testing is based on a specified net power (P_{NA}) applied to the transmit antenna. The net power level is derived from the forward power (P_{FM}) measured at the dual directional coupler, which is remotely connected to the transmit antenna via low loss coaxial cable.

The measured reflected power (P_{RM}) serves as a means to monitor the stability of the test setup between characterizations. Although not required, it is recommended to use a single directional coupler to cover the entire frequency band.

The characterization procedure described in [Annex A](#) does not need to be performed prior to each DUT test. However, it should be done periodically or if any component of the transmission path (directional coupler, cables, adaptors, antenna) is replaced or modified (e.g. repaired).

8.3.2 DUT test

The test on the DUT shall be performed at the various positions indicated in the test plan (example of antenna positioning for coupling to the DUT/connector and/or harness are defined in [8.3.3](#) and [8.3.4](#)).

The test on the DUT shall be performed with a forward power within (0/ +0,5) dB from the forward power level recorded during the determination of the net power (test level setting).

For amplitude modulation (AM) and pulse modulation (PM) signals, the test on the DUT shall be performed with power level adjustment, in order to fulfil the peak conservation principle given in ISO 11452-1.

Positioning of the antenna can be done manually using a handling support or automatically using a suitable robot assisted system.

If manual positioning of the antenna is required while the RF power is switched on, then care shall be taken, according to ICNIRP Guidelines, to minimize the exposure of the operator to the generated field. It is recommended that a minimum distance of 0,5 m from the operator to the simulated portable transmitter be maintained in order to limit operator influence.

NOTE National or other regulations can apply.

Perform the test at frequencies within the designed bandwidth of the test antenna — at least at the lower and upper band edges, at middle frequency.

Continue testing until all frequency bands, modulations, polarizations and simulated portable transmitter locations specified in the test plan are completed.

Testing is performed using either of two methods for coupling to the DUT and/or attached wiring harnesses.

8.3.2.1 Test method 1

The surfaces of the DUT, including connectors, are partitioned into square cells, the size of which is dependent on the selected transmit antenna as listed in [Table 2](#). The reference position(s) of the unpowered antenna is positioned in the centre of the selected cell 50 mm above the DUT and connector/harness surface. At each test frequency, the corresponding net power is applied to the transmit antenna while monitoring the DUT function. Dwell time at each test frequency shall be 2 s or longer depending on the DUT function. Testing is repeated for each cell and antenna placement (see 8.3.2.3). [Figure 9](#) illustrates use of this method for testing the DUT.

Any portion of the transmit antenna shall be at least at a 50 mm distance from the ground plane

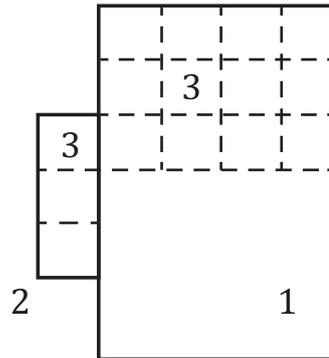
Table 2 — Cell size requirements for transmit antennas (test method 1)

Antenna type	Cell size “d” [mm]
Broadband dipole antenna	100
Broadband sleeve antenna	50

Table 2 (continued)

Antenna type	Cell size "d" [mm]
Sleeve antennas	50
Folded dipole antenna	100
Microwave broadband dipole antenna	50
HF broadband sleeve antenna	50

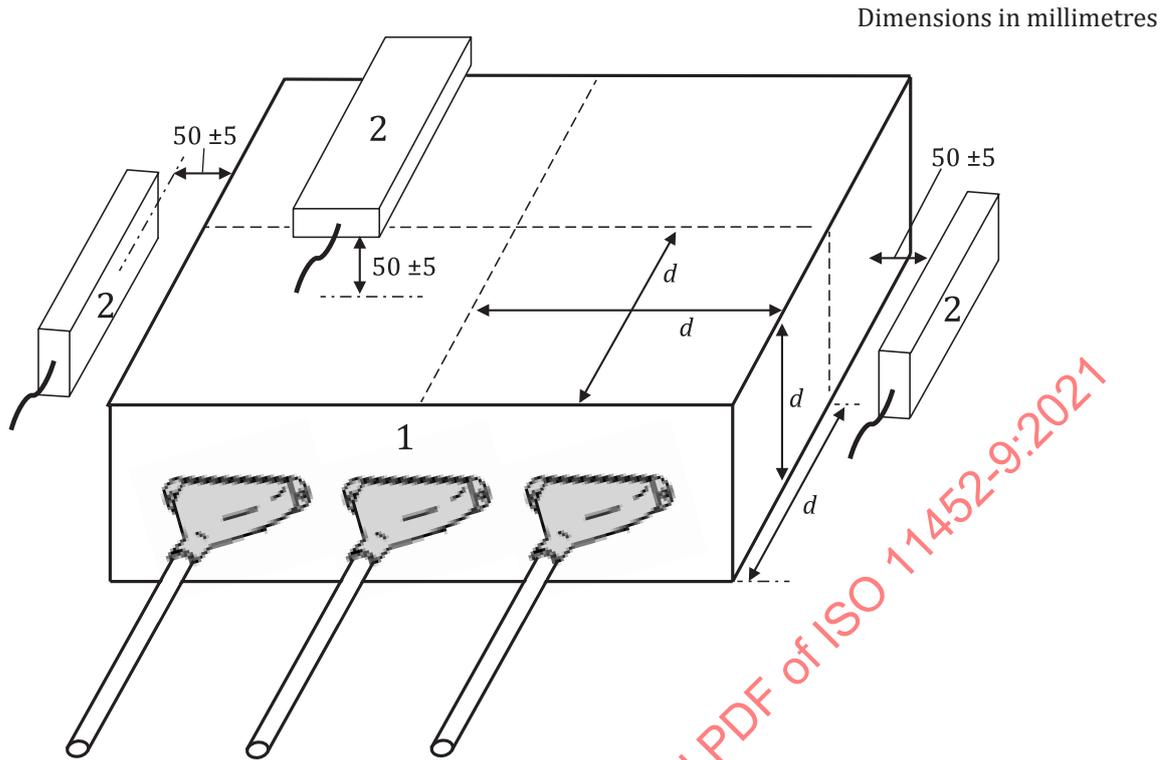
An example of DUT and DUT connector partitioning is shown in [Figure 8](#).



Key

- 1 DUT
- 2 DUT connector
- 3 DUT or DUT connector cells

Figure 8 — Example of DUT and DUT connector cells



- Key**
- 1 DUT
 - 2 transmit antenna
 - d cell size (see [table 2](#))

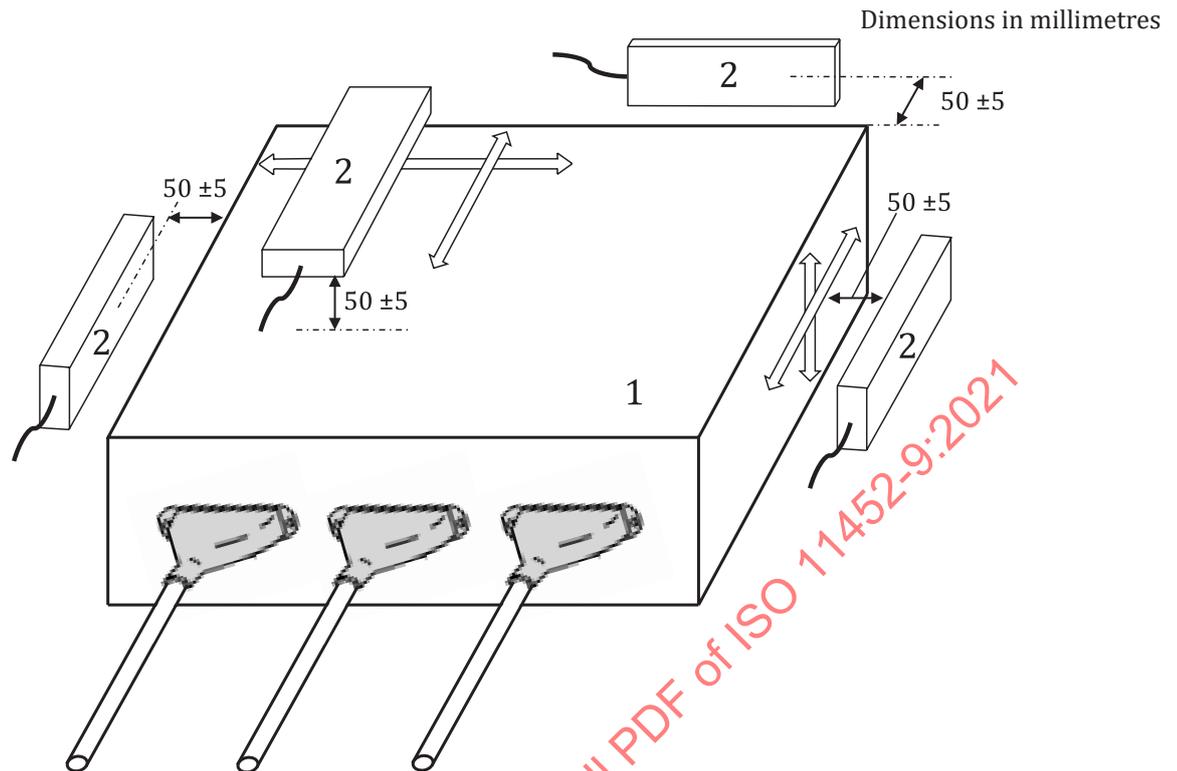
Figure 9 — DUT testing using method 1

8.3.2.2 Test method 2

At each specified test frequency, apply the corresponding net power to the transmit antenna. While holding the transmit antenna 50 mm from the DUT, including connectors, slowly scan the antenna across the DUT surfaces while monitoring the DUT function. [Figure 10](#) illustrates use of this method for testing the DUT.

Scan rate, which is dependent on DUT function, shall be defined in the test plan. Scanning is performed without any change in the forward power level. When using this approach care should be taken to minimize the exposure of the operator to the generated field. It is recommended that a minimum distance of 500 mm from the operator to the transmit antenna be maintained in order to limit interaction between the operator and the antenna.

Any portion of the transmit antenna shall be at least at a 50 mm distance from the ground plane.

**Key**

- 1 DUT
2 transmit antenna

Figure 10 — DUT testing using method 2

8.3.3 Antenna positioning for coupling to the DUT/connectors

Testing of the DUT, including connectors, requires specific positioning of the transmit antenna relative to the DUT/connector surfaces. Positioning is dependent on the transmit antenna reference position(s) selected.

8.3.3.1 Testing with broadband dipole antenna

When using test method 1 from 8.3.2.1, all surfaces of the DUT (including connectors), which are to be tested, shall be partitioned into square cells of (100 × 100) mm per Table 2. Cell locations shall be documented in the test plan. The antenna radiation element (see Annex C) shall be placed and maintained at a distance of 50 mm above the centre of each cell (see Figure 10). Each cell is exposed to both the centre and outer elements of the antenna in two orthogonal orientations (four exposures in total). This is necessary because the antenna's E and H field patterns are dependent on the test frequency. Placement of the antenna is illustrated in Figure 11. Specific positioning shall conform the reference position(s) of the antenna (see 6.2.6 for details).

- a) Place the antenna parallel with the DUT/connectors aligned with the centre of the first cell. Expose the DUT to the stress levels provided in the test plan. See Figure 11, position 1.
- b) Repeat step a) with the antenna rotated 90°. See Figure 11, position 2.
- c) Align the antenna with the centre of the next cell and repeat steps a) and b) until all the cells have been exposed to two the orthogonal orientations of the antenna.

- d) Move the antenna back to the first cell. Align the antenna element in the centre of the test cell (edges of the element aligned with the centre of the cell) and expose the DUT to the stress levels given in the test plan. See [Figure 11](#), position 3.
- e) Repeat step d) with the antenna rotated 90°. See [Figure 11](#), position 4.
- f) Align the antenna with the centre of the next cell and repeat steps d) and e) until all the cells have been exposed to the two orthogonal orientations of the antenna.

When testing DUTs and connectors with multiple cells, adjacent test cells may also be exposed to elements of the antenna. Under these conditions, overall test time may be reduced. This approach, if adopted, shall be documented in the test plan and test report.

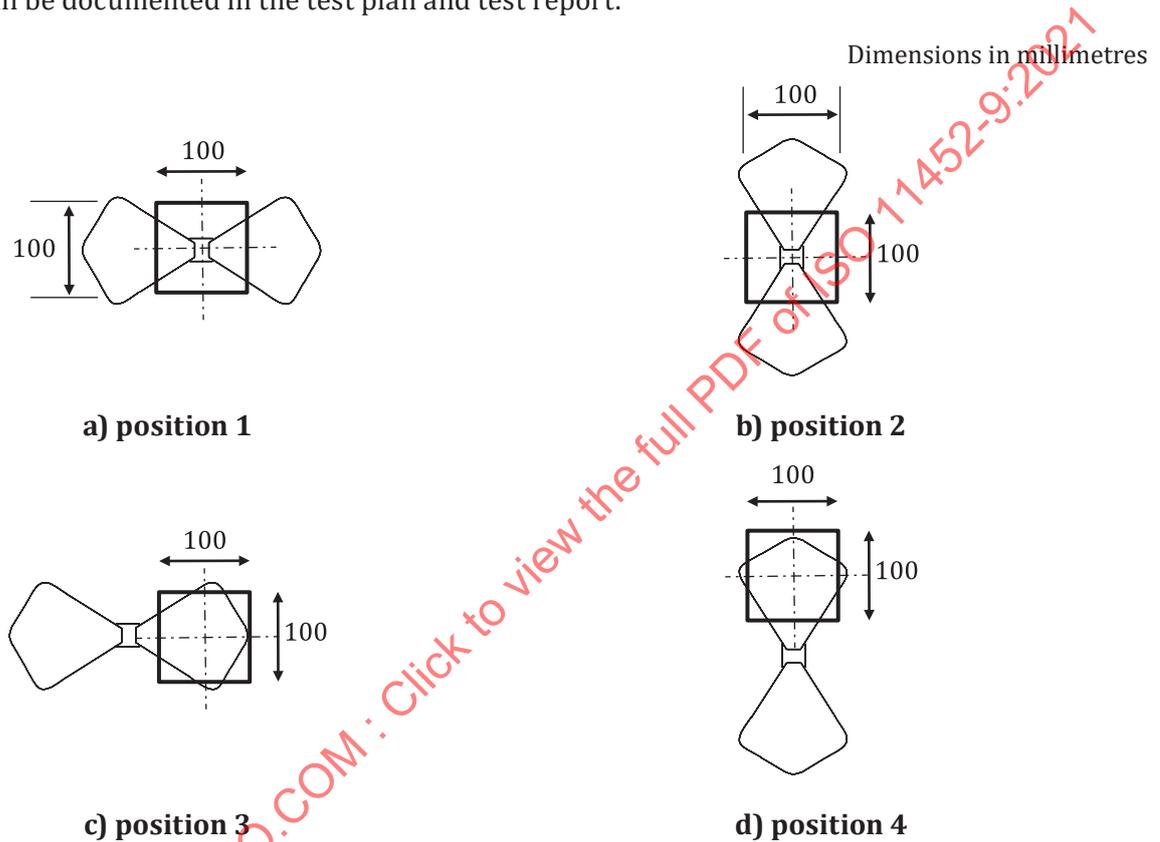
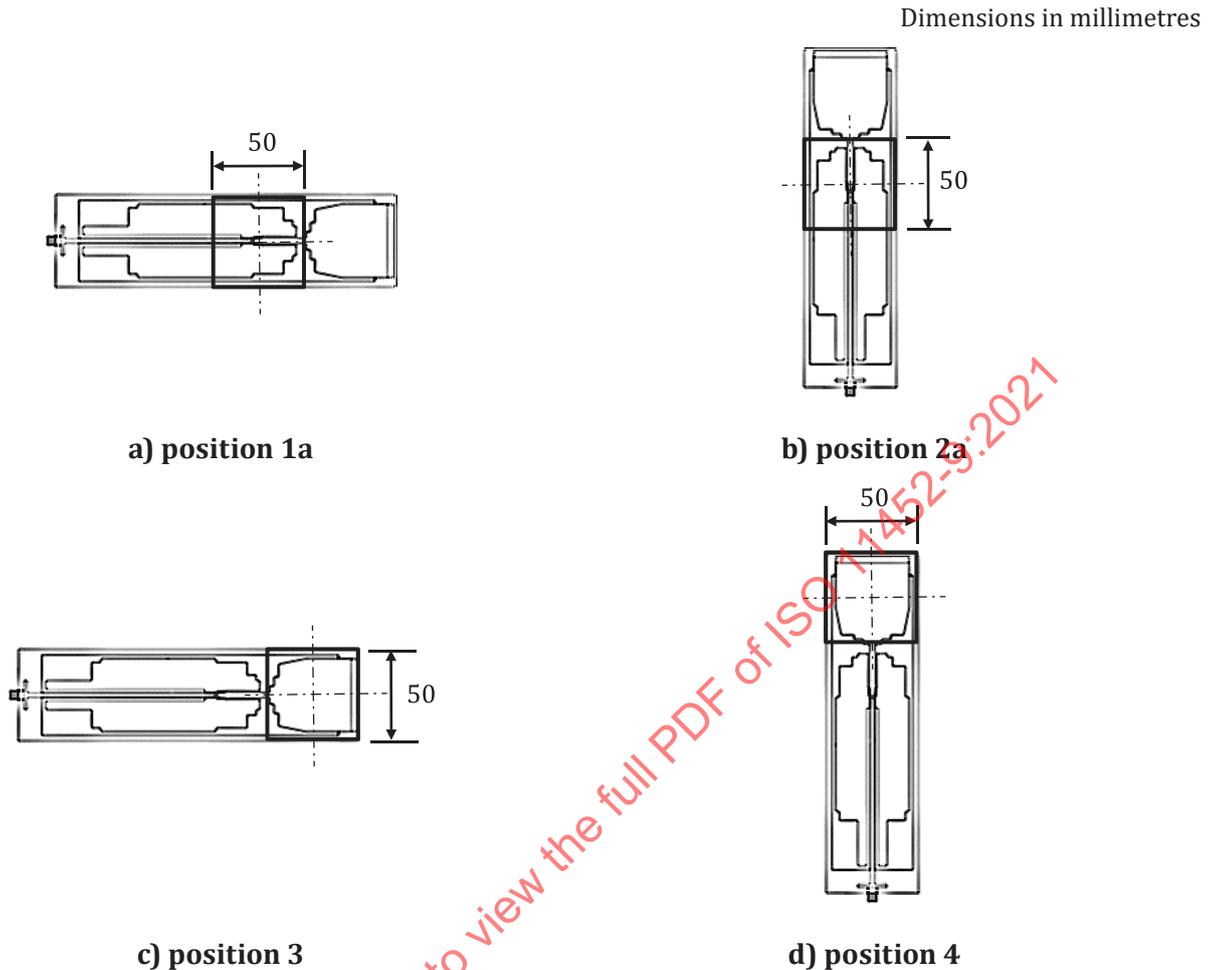


Figure 11 — Method 1 testing with broadband dipole antenna

When using test method 2 from [8.3.2.2](#), for each surface of the DUT/connectors, place the antenna with its centre at a distance of 50 mm from the DUT’s surface (see [Figure 10](#)). The axis of the broadband dipole antenna shall be parallel to the surface of the DUT. Specific details regarding DUT surfaces for scanning along with maximum scan rate shall be defined in the test plan. Two orthogonal polarizations of the antenna shall be used when scanning the surface of the DUT, similar to that used in test method 1 ([8.3.2.1](#)).

8.3.3.2 Testing with broadband sleeve antenna

When using test method 1 from [8.3.2.1](#), the procedures for using the broadband sleeve antenna are identical to those used for the broadband dipole antenna ([8.3.3.1](#)). All surfaces of the DUT/connectors, which are to be tested, shall be partitioned into square cells of (50 × 50) mm per [Table 2](#). Placement of the antenna is illustrated in [Figure 12](#). Specific positioning shall conform to the reference position(s) of the antenna (see [6.2.6](#) for details).



^a Positions 1 and 2 are only applicable when testing below 1 GHz.

Figure 12 — Method 1 testing with broadband sleeve antenna

When using test method 2 from [8.3.2.2](#), the procedures for using the broadband sleeve antenna are identical to those used for the broadband dipole antenna ([8.3.3.1](#)).

8.3.3.3 Testing with sleeve antennas

When using test method 1 from [8.3.2.1](#), the procedures for using the sleeve antenna are identical to those used for the broadband dipole antenna ([8.3.3.1](#)). All surfaces of the DUT/connectors, which are to be tested, shall be partitioned into square cells of (50 × 50) mm per [Table 2](#). Placement of the antenna is illustrated in [Figure 13](#) (for positions 3 and 4, the tip of the rod should be 25 mm away from the centre of the cell). Specific positioning shall conform to the reference position(s) of the antenna (see [6.2.6](#) for details).

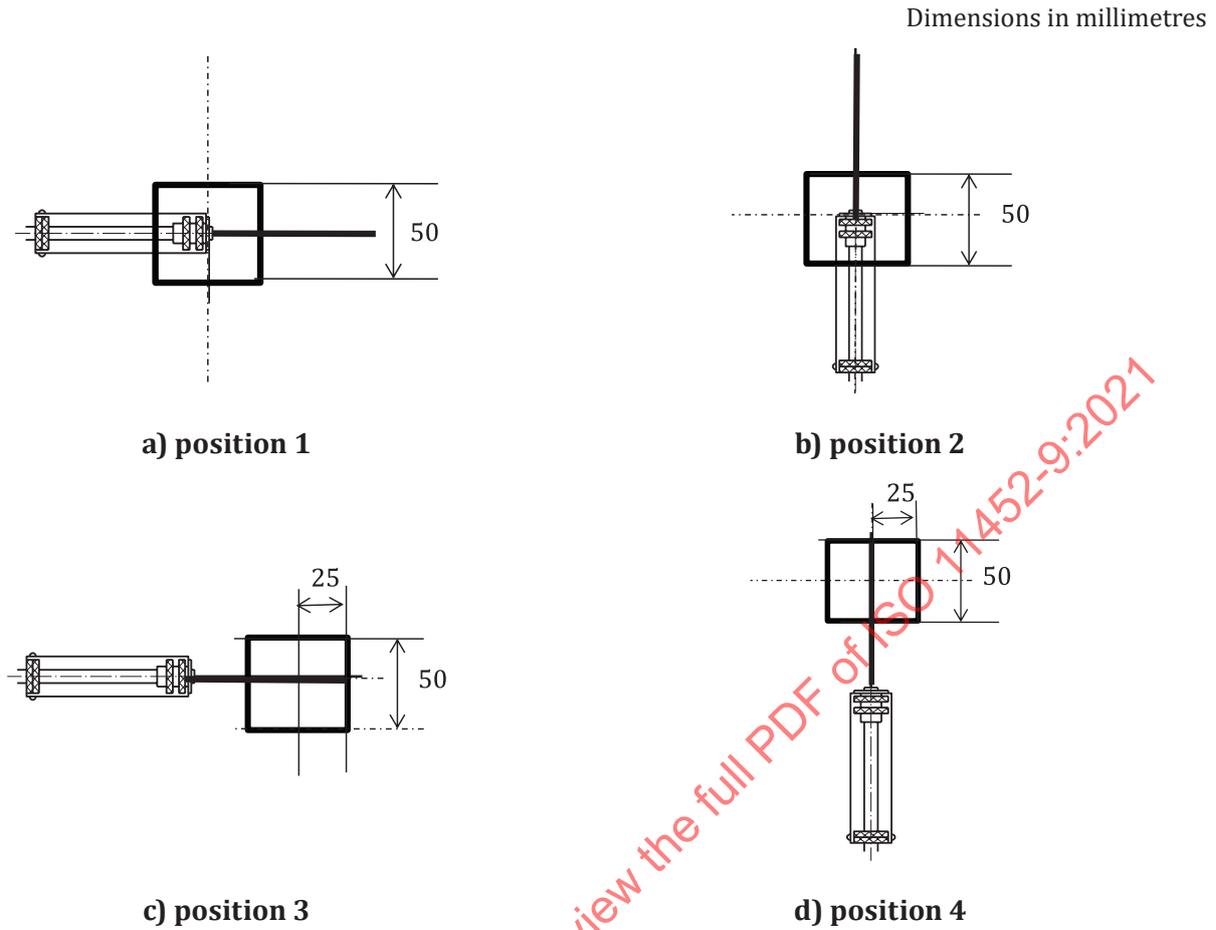


Figure 13 — Method 1 testing with sleeve antenna

When using test method 2 from 8.3.2.2, the procedures for using the sleeve antenna are identical to those used for the broadband dipole antenna (8.3.3.1).

8.3.3.4 Testing with folded dipole antennas

When using test method 1 from 8.3.2.1, the procedures for using the folded dipole antenna are identical to those used for broadband dipole antenna (8.3.3.1). All surfaces of the DUT/connectors, which are to be tested, shall be partitioned into square cells of (100 × 100) mm per Table 2. Placement of the antenna is illustrated in Figure 14. Specific positioning shall conform to the reference position(s) of the antenna (see 6.2.6 for details).

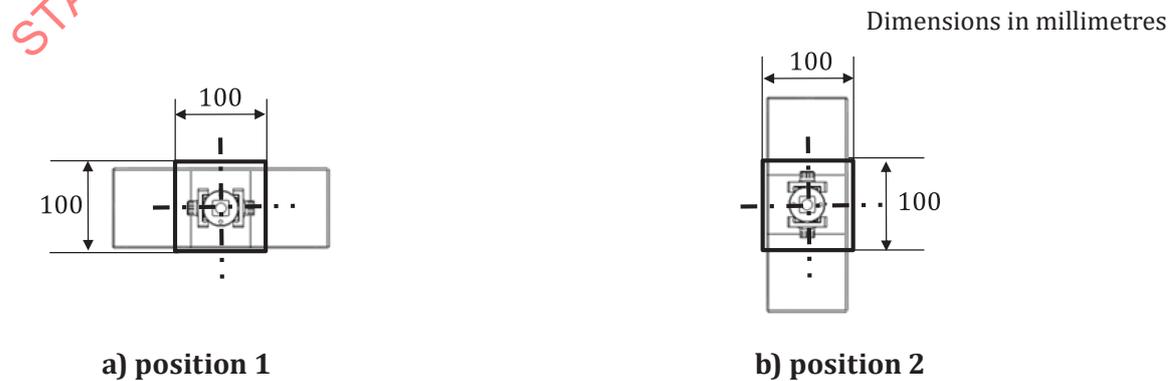




Figure 14 — Method 1 testing with folded dipole antenna

When using test method 2 from 8.3.2.2, the procedures for using the folded dipole antenna are identical to those used for broadband dipole antenna (8.3.3.1).

8.3.3.5 Testing with microwave broadband dipole antenna

When using test method 1 from 8.3.2.1, the procedures for using the microwave broadband antenna are identical to those used for the broadband dipole antenna (8.3.3.1). All surfaces of the DUT/connectors, which are to be tested, shall be partitioned into square cells of (50×50) mm per Table 2. Placement of the antenna is illustrated in Figure 15. Specific positioning shall conform to the reference position(s) of the antenna (See 6.2.6 for details).

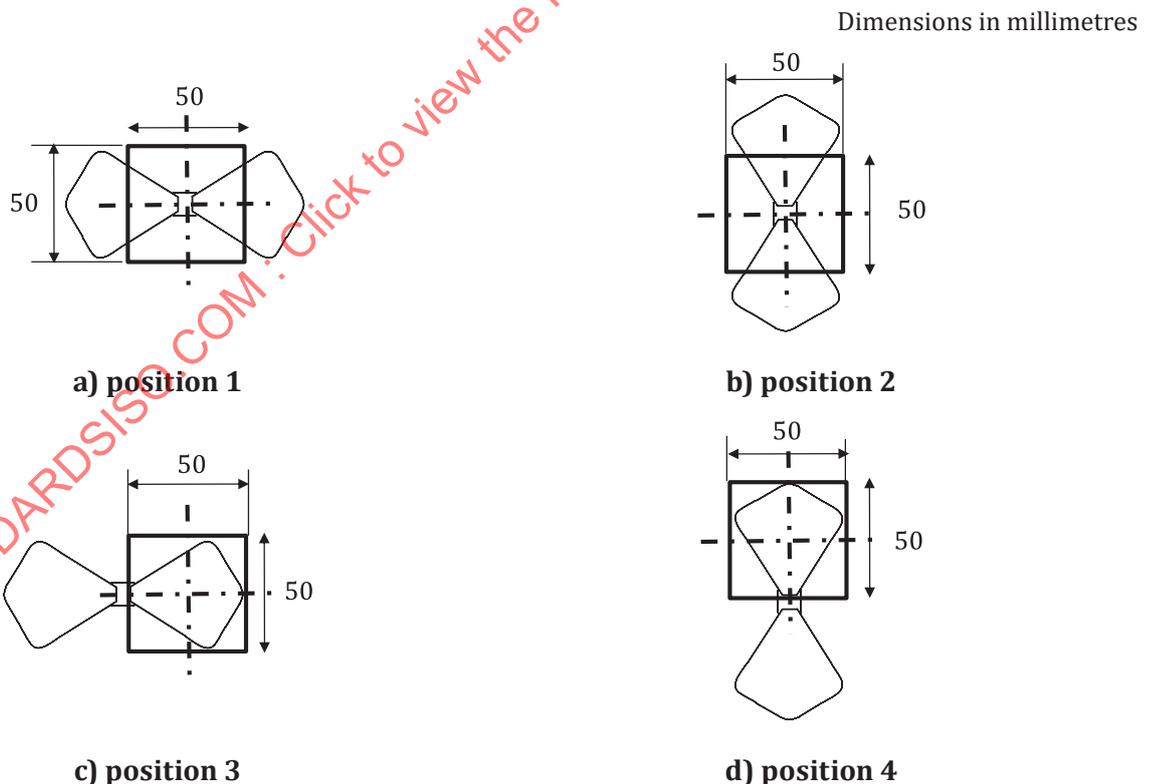


Figure 15 — Method 1 testing with microwave broadband dipole antenna

When using test method 2 from 8.3.2.2, the procedures for using the microwave broadband dipole antenna are identical to those used for the broadband dipole antenna (8.3.3.1).

8.3.3.6 Testing with HF broadband sleeve antenna

When using test method 1 from 8.3.2.1, the procedures for using the HF broadband sleeve antenna are identical to those used for the broadband dipole antenna (8.3.3.1). All surfaces of the DUT/connectors, which are to be tested, shall be partitioned into square cells of (50 x 50) mm per Table 2. Placement of the antenna is illustrated in Figure 16. Specific positioning shall conform to the reference position(s) of the antenna (see 6.2.6 for details).

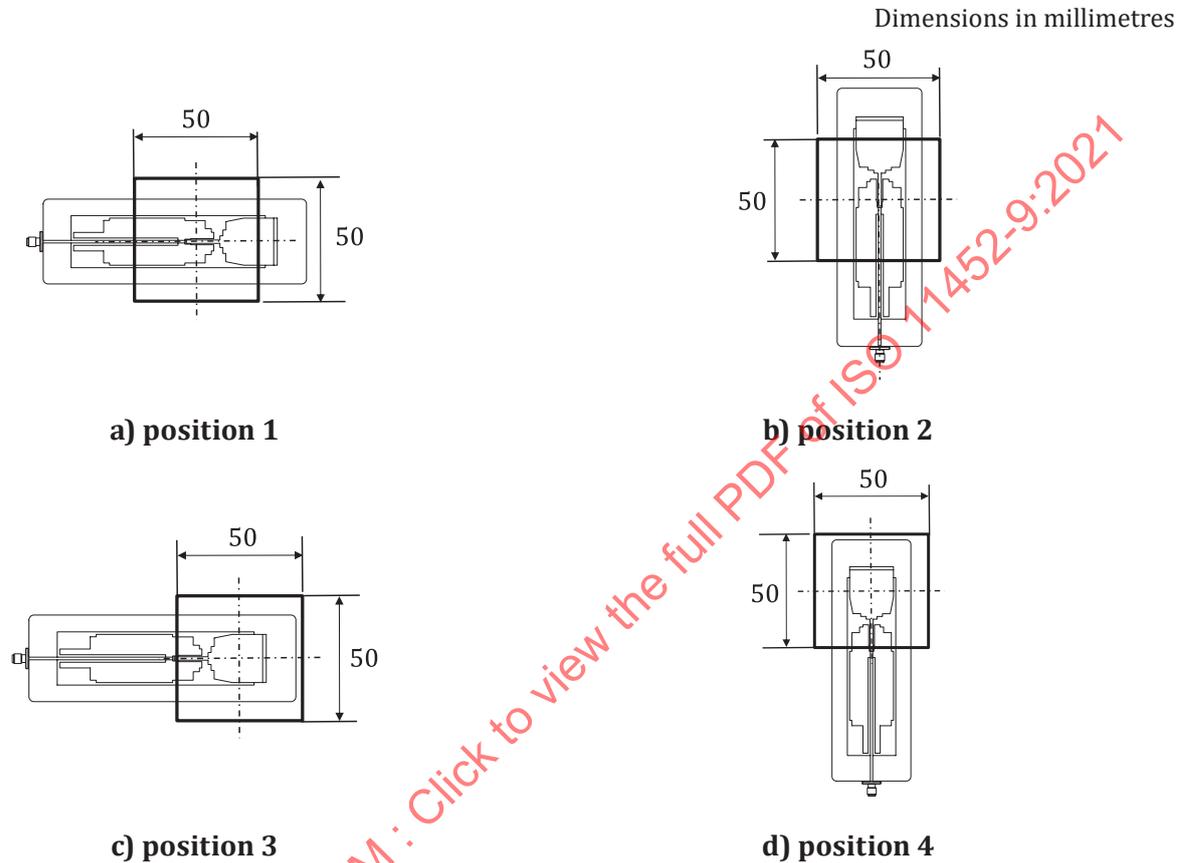


Figure 16 — Method 1 testing with HF broadband sleeve antenna

When using test method 2 from 8.3.2.2, the procedures for using the HF broadband sleeve antenna are identical to those used for the broadband dipole antenna (8.3.3.1).

8.3.4 Antenna positioning for coupling to harness

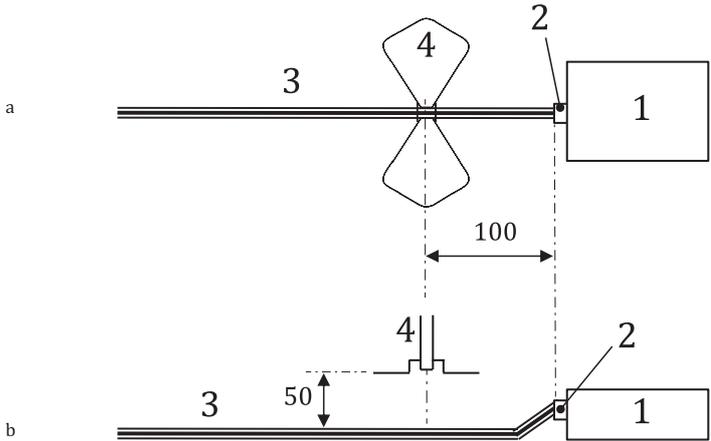
8.3.4.1 Testing with broadband dipole antennas

Refer to Figures 17 and 18 for placement of the transmit antenna.

- a) Unless otherwise specified in the test plan, place the antenna at a distance of 100 mm from the DUT connector (position X_1) and parallel to the harness. Position the antenna with its reference point at a distance of 50 mm from the harness. See Figure 17 for details.
- b) Carry out testing using procedures for test method 1 (see 8.3.3.1).
- c) Repeat step b) at positions X_2 and X_3 .
- d) Repeat steps a) through c) for each DUT connector.

Alternatively, test method 2 (see 8.3.3.2) may be used by scanning between positions X_1 and X_3 .

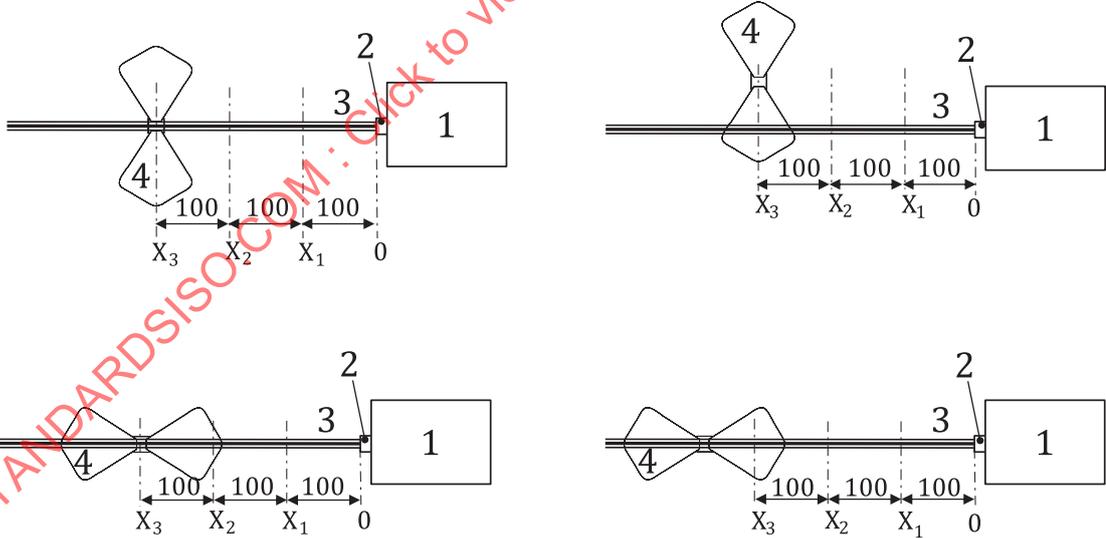
Dimensions in millimetres



- Key**
- 1 DUT
 - 2 DUT connector
 - 3 DUT harness
 - 4 transmit antenna
 - a Plan view.
 - b Side view.

Figure 17 — Initial location of broadband dipole antenna for harness coupling

Dimensions in millimetres



- Key**
- 1 DUT
 - 2 DUT connector
 - 3 DUT harness
 - 4 transmit antenna
- $X_1 = 100$ mm (from reference "0")
 $X_2 = 200$ mm (from reference "0")
 $X_3 = 300$ mm (from reference "0")

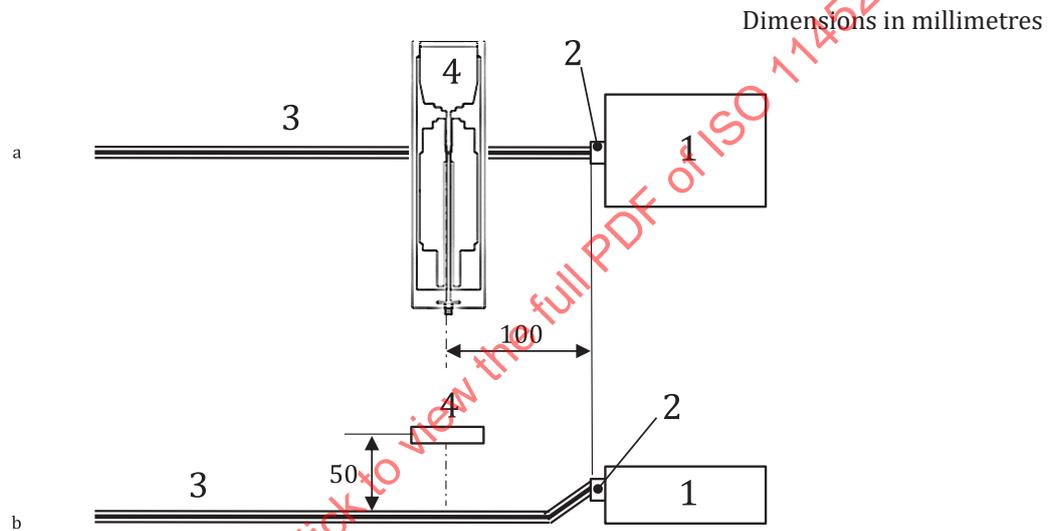
Figure 18 — Testing harness with broadband dipole antenna

8.3.4.2 Testing with the broadband sleeve antenna

Refer to [Figures 19](#) and [20](#) for placement of the transmit antenna.

- a) Unless otherwise specified in the test plan, place the antenna at a distance of 100 mm from the DUT connector (position X_1) and parallel to the harness. Position the antenna with its reference point at a distance of 50 mm from the harness. See [Figure 19](#) for details.
- b) Carry out testing using procedures for test method 1 (see [8.3.3.1](#)).
- c) Repeat step b) at positions X_2 , X_3 , X_4 and X_5 .
- d) Repeat steps a) through c) for each DUT connector.

Alternatively, test method 2 (see [8.3.3.2](#)) may be used by scanning between positions X_1 and X_5 for each DUT connector



- Key**
- 1 DUT
 - 2 DUT connector
 - 3 DUT harness
 - 4 transmit antenna
 - a Plan view.
 - b Side view.

Figure 19 — Initial location broadband sleeve antenna for harness coupling

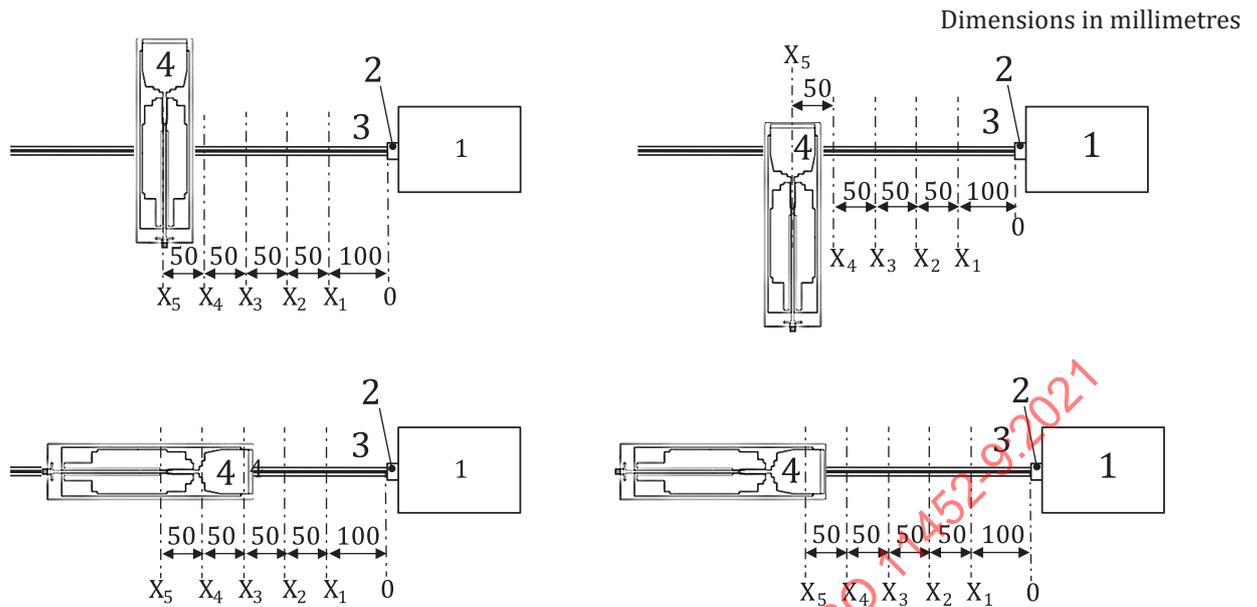


Figure 20 — Testing harness with broadband sleeve antenna

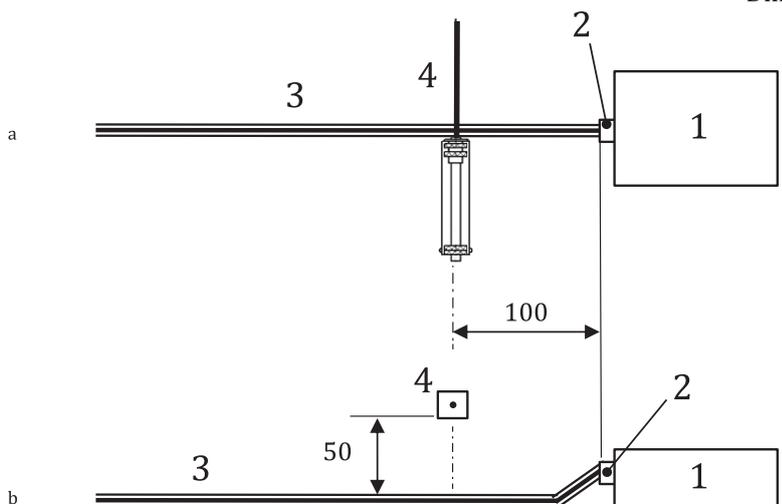
8.3.4.3 Testing with sleeve antenna

Refer to [Figures 21](#) and [22](#) for placement of the transmit antenna.

- Unless otherwise specified in the test plan, place the antenna at a distance of 100 mm from the DUT connector (position X_1) and parallel to the harness. Position the antenna with its reference point at a distance of 50 mm from the harness. See [Figure 21](#) for details.
- Carry out testing using procedures for test method 1 (see [8.3.3.1](#)).
- Repeat step b) at positions X_2 , X_3 , X_4 and X_5 .
- Repeat steps a) through c) for each DUT connector.

Alternatively, test method 2 (see [8.3.3.2](#)) may be used by scanning between positions X_1 and X_5 for each DUT connector

Dimensions in millimetres



Key

- 1 DUT
- 2 DUT connector
- 3 DUT harness
- 4 transmit antenna
- a Plan view.
- b Side view.

Figure 21 — Initial location of sleeve antenna for harness coupling

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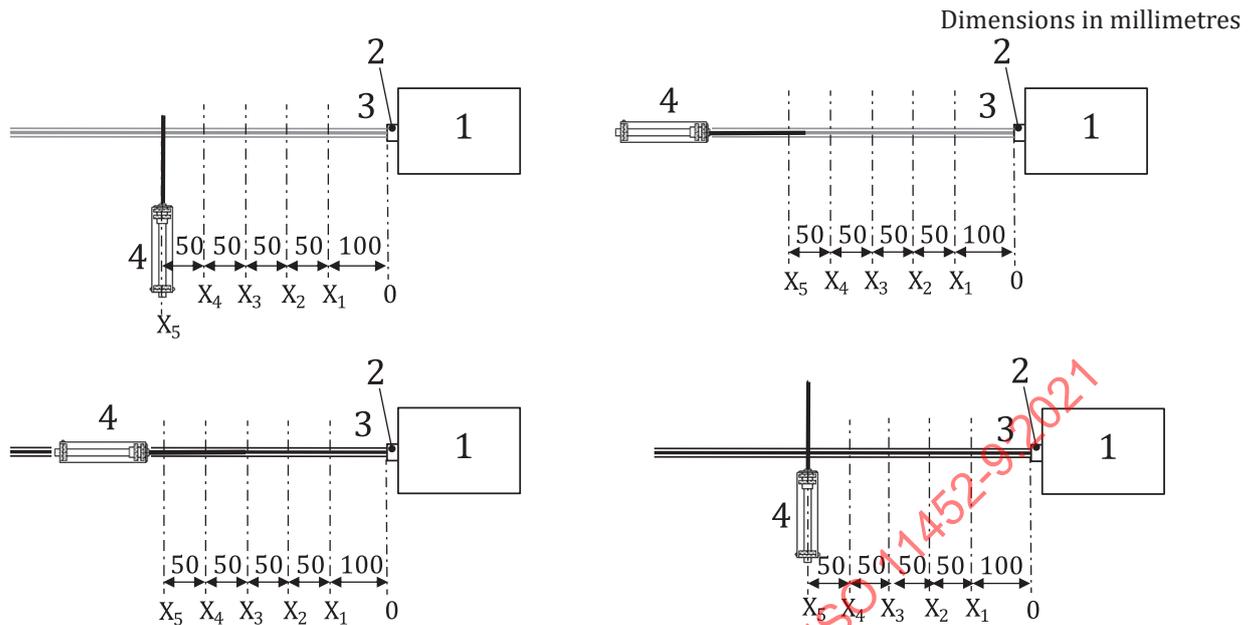


Figure 22 — Testing harness with sleeve antenna

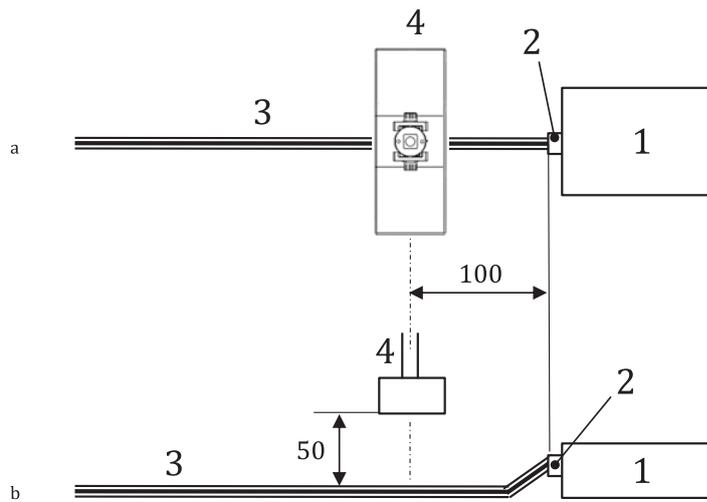
8.3.4.4 Testing with folded dipole antenna

Refer to [Figures 23](#) and [24](#) for placement of the transmit antenna.

- Unless otherwise specified in the test plan, place the antenna at a distance of 100 mm from the DUT connector (position X_1) and parallel to the harness. Position the antenna with its reference point at a distance of 50 mm from the harness. See [Figure 23](#) for details.
- Carry out testing using procedures for test method 1 (see [8.3.3.1](#)).
- Repeat step b) at positions X_2 and X_3 .
- Repeat steps a) through c) for each DUT connector.

Alternatively, test method 2 (see [8.3.3.2](#)) may be used by scanning between positions X_1 and X_3 for each DUT connector

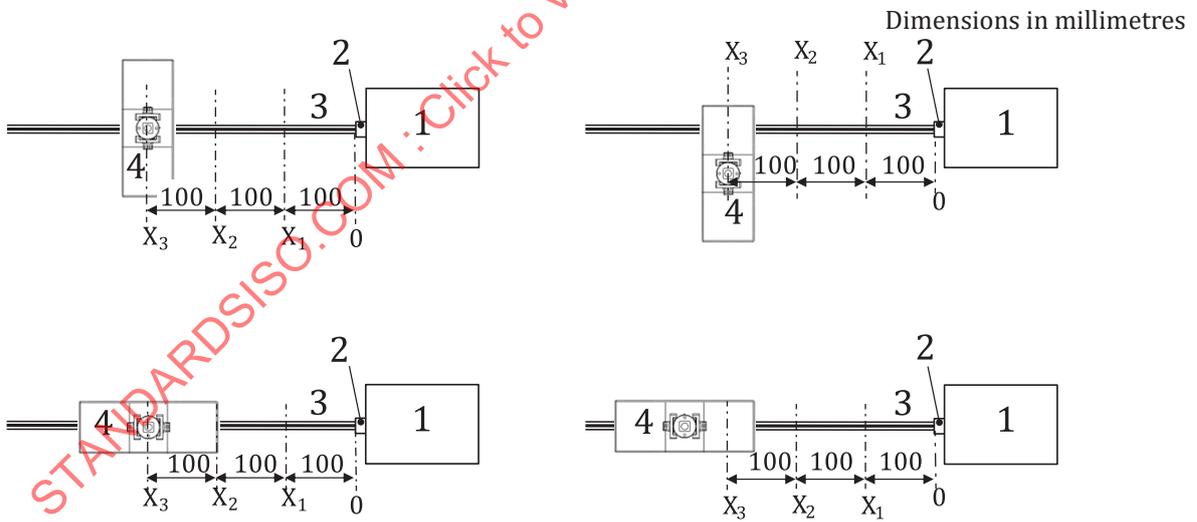
Dimensions in millimetres



Key

- 1 DUT
- 2 DUT connector
- 3 DUT harness
- 4 transmit antenna
- a Plan view.
- b Side view.

Figure 23 — Initial location of folded dipole antenna for harness coupling



Key

- 1 DUT
- 2 DUT connector
- 3 DUT harness
- 4 transmit antenna

- $X_1 = 100$ mm (from reference "0")
- $X_2 = 200$ mm (from reference "0")
- $X_3 = 300$ mm (from reference "0")

Figure 24 — Testing harness with folded dipole antenna

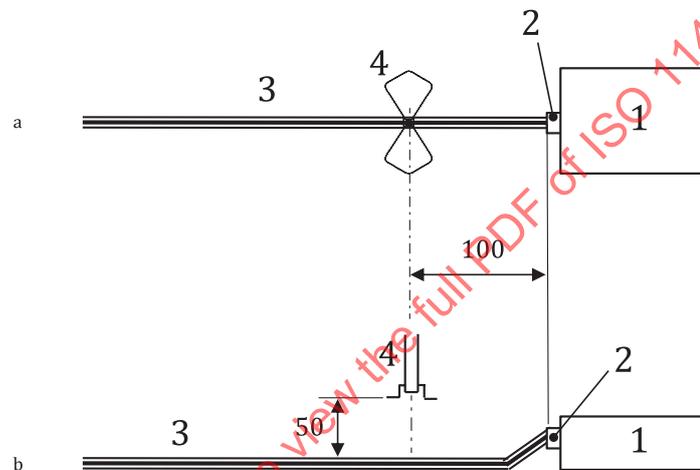
8.3.4.5 Testing with microwave broadband dipole antenna

Refer to [Figures 25](#) and [26](#) for placement of the transmit antenna.

- Unless otherwise specified in the test plan, place the antenna at a distance of 100 mm from the DUT connector (position X_1) and parallel to the harness. Position the antenna with its reference point at a distance of 50 mm from the harness. See [Figure 25](#) for details.
- Carry out testing using procedures for test method 1 (see [8.3.3.1](#)).
- Repeat step b) at positions X_2 , X_3 , X_4 and X_5 .
- Repeat steps a) through c) for each DUT connector.

Alternatively, test method 2 (see [8.3.3.2](#)) may be used by scanning between positions X_1 and X_5 .

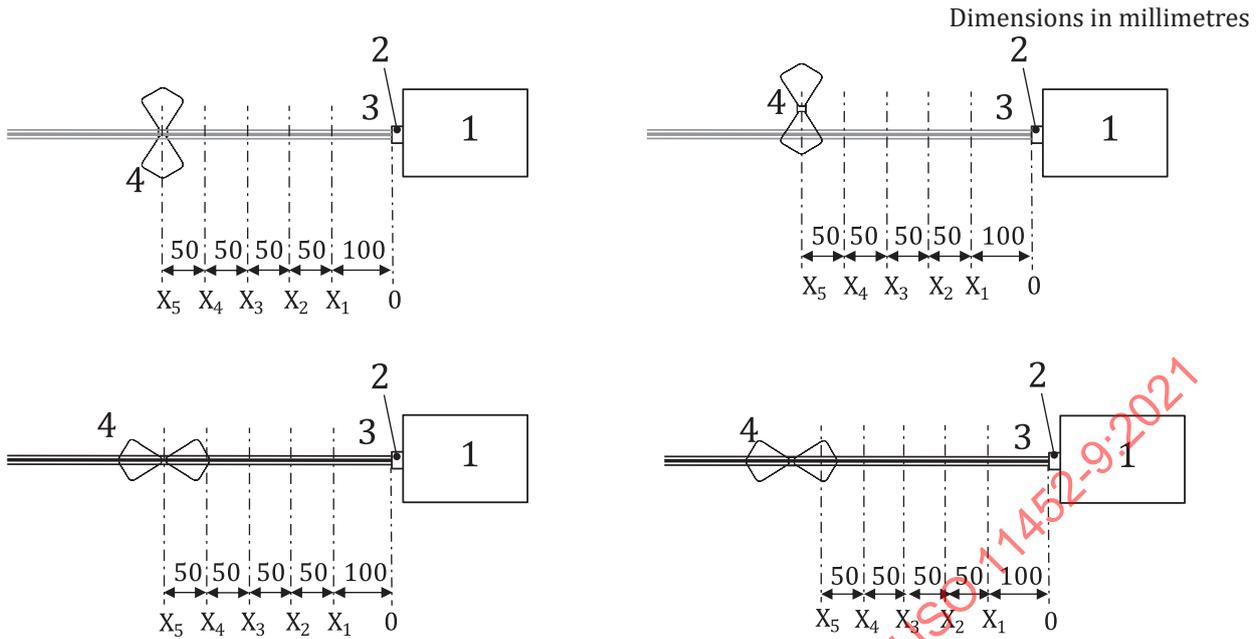
Dimensions in millimetres



Key

- DUT
 - DUT connector
 - DUT harness
 - transmit antenna
- a Plan view.
b Side view.

Figure 25 — Initial location of microwave broadband dipole antenna for harness coupling



Key

- | | |
|--|---|
| <p>1 DUT</p> <p>2 DUT connector</p> <p>3 DUT harness</p> <p>4 transmit antenna</p> | <p>$X_1 = 100$ mm (from reference "0")</p> <p>$X_2 = 150$ mm (from reference "0")</p> <p>$X_3 = 200$ mm (from reference "0")</p> <p>$X_4 = 250$ mm (from reference "0")</p> <p>$X_5 = 300$ mm (from reference "0")</p> |
|--|---|

Figure 26 — Testing harness with microwave broadband dipole antenna

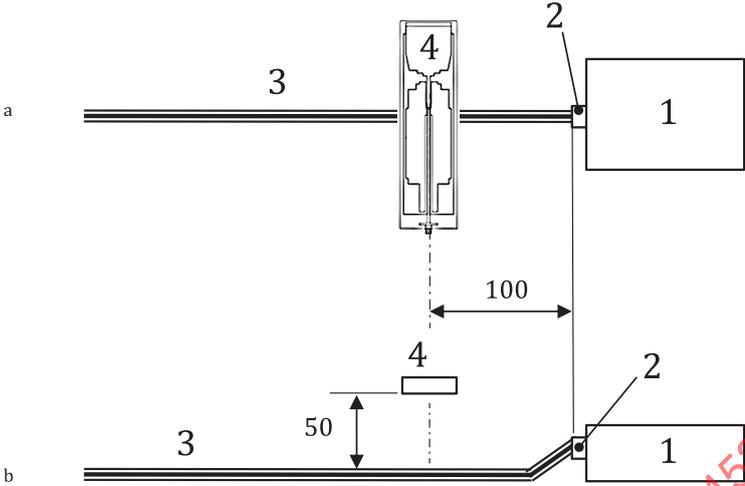
8.3.4.6 Testing with HF broadband sleeve antenna

Refer to [Figures 27](#) and [28](#) for placement of the transmit antenna.

- a) Unless otherwise specified in the test plan, place the antenna at a distance of 100 mm from the DUT connector (position X_1) and parallel to the harness. Position the antenna with its reference point at a distance of 50 mm from the harness. See [Figure 27](#) for details.
- b) Carry out testing using procedures for test method 1 (see [8.3.3.1](#)).
- c) Repeat step b) at positions X_2 , X_3 , X_4 and X_5 .
- d) Repeat steps a) through c) for each DUT connector.

Alternatively, test method 2 (see [8.3.3.2](#)) may be used by scanning between positions X_1 and X_5 .

Dimensions in millimetres



- Key**
- 1 DUT
 - 2 DUT connector
 - 3 DUT harness
 - 4 transmit antenna
 - a Plan view.
 - b Side view.

Figure 27 — Initial location of HF broadband sleeve antenna for harness coupling

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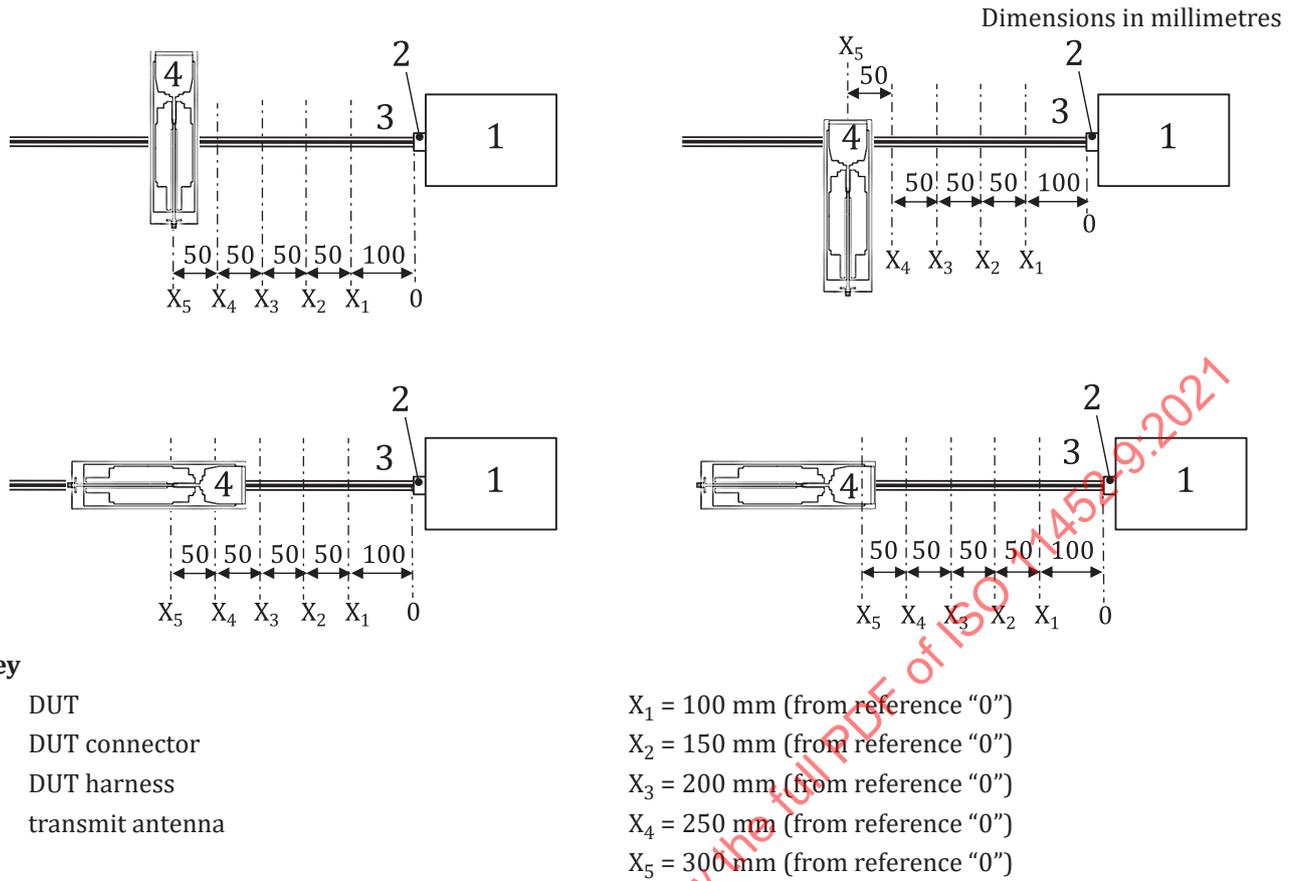


Figure 28 — Testing harness with HF broadband sleeve antenna

8.4 Test report

According to the test plan, a test report shall be submitted detailing information regarding the test equipment, test area, systems tested, frequencies, test modulation, power levels, DUT exposure methodology (method 1 or method 2), the portable transmitter used, antenna VSWR values, system interactions and any other relevant information regarding testing.

Annex A (normative)

Net power characterization procedure

A.1 Introduction

The calibration procedure detailed herein facilitates accurate delivery of net power to the transmit antenna. The net power is derived from the forward power measured at the directional coupler remotely connected to the antenna via low loss coaxial cable. This procedure fully considers the effects of mismatch losses that, if not controlled, will impact the accuracy of the net power delivered to the transmit antenna.

Figure A.1 illustrates a simplified test equipment setup for simulated portable transmitter testing. In this setup, there is a single cable connecting the directional coupler directly to the antenna. Also, the peak wideband power sensors are connected directly to the coupler (i.e. no interconnecting cable). Power sensors shall exhibit a VSWR <1,2 and a measurement accuracy <0,5 dB.



Key

- | | | | |
|---|---|----------|---|
| 1 | RF signal generator and amplifier | P_{FM} | measured forward power at the directional coupler |
| 2 | dual directional coupler | P_{RM} | measured reverse power at the directional coupler |
| 3 | power sensor or measurement receiver | P_{NA} | net power delivered to antenna |
| 4 | transmit antenna | | |
| 5 | low loss coaxial cable with transmission loss A | | |

Figure A.1 — Simplified simulated portable transmitter equipment setup

The relationship between the measured forward and reflected power (P_{FM} , P_{RM}) and net power (P_{NA}) delivered to the antenna is presented in [Formulae \(A.1\)](#) and [\(A.2\)](#).

$$P_{FM} = \frac{C_{FF} \cdot P_{NA}}{(A \cdot A_{DC}) \cdot (1 - \rho^2)} \quad (\text{A.1})$$

$$P_{RM} = \frac{C_{FR} \cdot A \cdot \rho^2 \cdot P_{NA}}{(1 - \rho^2)} \quad (\text{A.2})$$

where

- P_{NA} is the net power (watts) delivered to antenna;
- P_{FM} is the measured forward power (watts) at the directional coupler;
- P_{RM} is the measured reflected power (watts) at the directional coupler;

ρ is the magnitude of reflection coefficient of transmit antenna:

$$\rho = |S_{11}| = \frac{V_{SWR} - 1}{V_{SWR} + 1}$$

V_{SWR} is the voltage standing wave ratio of transmit antenna;

A is the transmission loss of the cable (<1):

$$A = 10^{\frac{A_{lg}}{10}} \quad A_{lg} < 0;$$

A_{lg} is the transmission loss of the cable in dB;

A_{DC} is the transmission loss of the directional coupler:

$$A_{DC} = 10^{\frac{A_{DClg}}{10}} \quad A_{DClg} < 0;$$

A_{DClg} is the transmission loss of the directional coupler in dB;

C_{FF} is the forward coupling factor (<1):

$$C_{FF} = 10^{\frac{C_{FFlg}}{10}} \quad C_{FFlg} < 0;$$

C_{FFlg} is the forward coupling factor in dB;

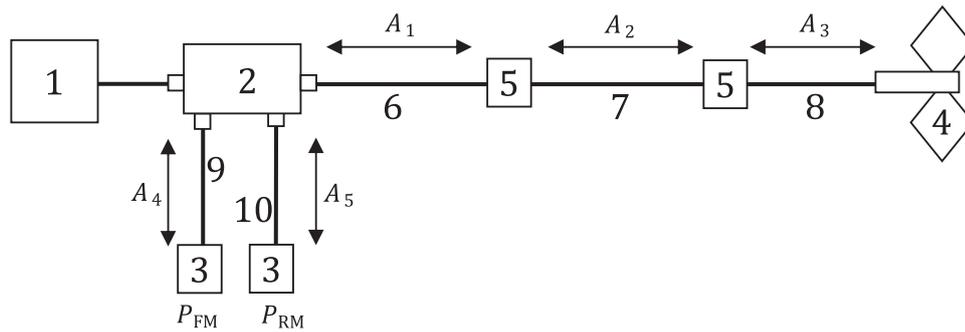
C_{FR} is the reflected coupling factor (<1):

$$C_{FR} = 10^{\frac{C_{FRlg}}{10}} \quad C_{FRlg} < 0;$$

C_{FRlg} is the reflected coupling factor in dB.

The reflected power measured at the directional coupler, is not required for determining the net power delivered to the transmit antenna. However, the reflected power should be monitored and recorded during characterization to provide feedback regarding the stability of the net power over time. For this reason, this annex includes procedures for parameter characterization required to facilitate measurement of the reflected power during characterization.

In most implementations of the test equipment setup, other components (e.g. adaptors, bulkhead connectors) may be included in the test setup. [Figure A.2](#) illustrates an example of a more complex test equipment setup.



Key

- | | | | |
|---|---|----------|---|
| 1 | RF signal generator and amplifier | 7 | low loss coaxial cable with transmission loss A_2 |
| 2 | dual directional coupler | 8 | low loss coaxial cable with transmission loss A_3 |
| 3 | power sensor or measurement receiver | 9 | low loss coaxial cable with transmission loss A_4 |
| 4 | transmit antenna | 10 | low loss coaxial cable with transmission loss A_5 |
| 5 | coaxial in-line connectors, adaptors, etc. | P_{FM} | measured forward power |
| 6 | low loss coaxial cable with transmission loss A_1 | P_{RM} | measured reverse power |

Figure A.2 — Typical simulated portable transmitter test equipment setup

For this more general test setup, the relationship between the measured forward and reflected power (P_{FM} , P_{RM}) and net power (P_{NA}) delivered to the antenna is presented in [Formulae \(A.3\)](#) and [\(A.4\)](#).

$$P_{FM} = \frac{T_3 \cdot P_{NA}}{T_2 \cdot (1 - \rho^2)} \tag{A.3}$$

$$P_{RM} = \frac{T_4 \cdot T_1 \cdot \rho^2 \cdot P_{NA}}{(1 - \rho^2)} \tag{A.4}$$

where

$T_1 = A_1 \cdot A_2 \cdot A_3$ is the transmission loss between coupler output and antenna
 ($T_1, A_1, A_2, A_3 < 1$);

$T_2 = A_1 \cdot A_2 \cdot A_3 \cdot A_{DC}$ is the transmission loss between coupler output and antenna
 ($T_2, A_1, A_2, A_3, A_{DC} < 1$);

$T_3 = A_4 \cdot C_{FF}$ is the transmission loss between coupler and forward power measurement point
 ($T_3, A_4, C_{FF} < 1$);

$T_4 = A_5 \cdot C_{FR}$ is the transmission loss between coupler and reflected power measurement point
 ($T_4, A_5, C_{FR} < 1$);

A_1, A_2, A_3, A_4, A_5 are the transmission loss of interconnecting cables;

A_{DC} is the transmission loss of dual directional coupler
 ($A_{DC} < 1$).

The formulae for the measured forward and reflected power do not include the transmission losses due to the adaptors and coaxial interconnects (e.g. test chamber bulkhead connectors). More importantly, the formulae neglect the effect of mismatch losses, which can affect the net power if not controlled.

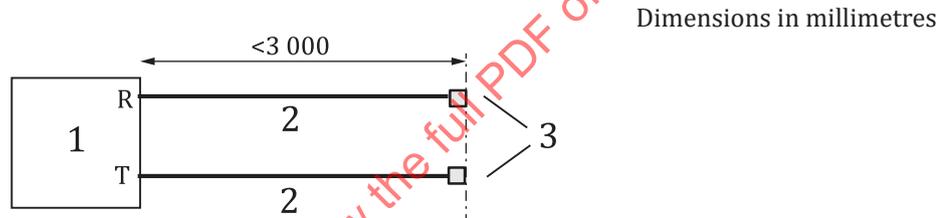
To assure accurate delivery of the net power to the transmit antenna, all transmission and mismatch losses shall be accounted for. For this reason, characterization requires:

- 1) VSWR and transmission loss measurements of selected individual components that comprise the simulated portable transmitter setup;
- 2) in-situ characterization measurements of the VSWR and transmission losses of the interconnection system.

A.2 Vector network analyser calibration

All measurements shall be performed using a vector network analyser (VNA) with S-parameter measurement capability. The VNA shall be calibrated using the TOSM (through, open, short, matched) method via high quality reference (traceable) standards. VNA calibration shall be performed over the frequency band used for performing testing. Cable connections between the VNA and sample shall consist of low loss cables of sufficient length to facilitate connection. Cable length shall not exceed 3 000 mm. The cables shall be included in the VNA calibration per [Figure A.3](#). Adaptors should be avoided, but if used, they shall be included in the VNA calibration.

Refer to [Figure A.2](#) for component references for all measurements presented herein.



Key

- 1 vector network analyser
- 2 low loss 50 Ω coaxial cable
- 3 measurement reference plane per TOSM calibration
- R port facilitates measurement of S_{11} and S_{12}
- T port facilitates measurement of S_{22} and S_{21}

Figure A.3 — VNA TOSM calibration

It is important to realize that S parameters relate to voltages of an N-port network. VNA measurements of these parameters may be reported in a variety of formats as shown below (example given for reporting of S_{21}).

Linear-complex: $S_{21} = R_e + jI_m$ (A.5)

Linear-magnitude: $|S_{21}| = |R_e + jI_m| = \sqrt{R_e^2 + I_m^2}$ $|S_{21}| < 1$ (A.6)

dB: $S_{21|g} = 20 \cdot \log|S_{21}|$ (A.7)

However, when determining the transmission loss parameters for [Formulae \(A.1\)](#) and [\(A.2\)](#), the format is linear-magnitude and are in terms of power. This relationship is shown in [Formula \(A.8\)](#) for T_N :

$$T_N = |S_{21}|^2 = 10^{\frac{S_{21lg}}{10}} = (R_e^2 + I_m^2) \quad (A.8)$$

where $T_N = T_1, T_2, T_3, T_4$.

It is critical to understand this relationship so that accurate characterization may occur.

A.3 Directional coupler parameter verification

The directional coupler used in the test setup shall be characterized using the following procedures.

A.3.1 VSWR and transmission loss measurement procedure

- 1) Connect the VNA to the directional coupler as illustrated in [Figure A.4](#). Connect 50 Ω terminations to the P3 and P4. The termination shall have a VSWR less than 1,1 over the test frequency range.
- 2) Measure and record the magnitude of S_{11} and S_{22} of P1 and P2 over the test frequency range. Calculate and verify that the VSWR at P1 and P2 is less than 1,3.

$$V_{SWRP1} = \frac{1 + |S_{11}|}{1 - |S_{11}|} \quad (A.9) \quad V_{SWRP2} = \frac{1 + |S_{22}|}{1 - |S_{22}|} \quad (A.10)$$

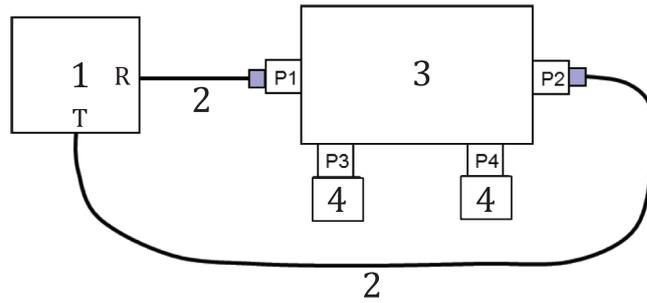
$$|S_{11}| = 10^{\frac{S_{11lg}}{20}} \quad (A.11) \quad |S_{22}| = 10^{\frac{S_{22lg}}{20}} \quad (|S_{11}| \text{ and } |S_{22}| < 1) \quad (A.12)$$

- 3) Measure and record $|S_{21}|$ over the test frequency range. Record the transmission loss A_{DC} , where:

$$A_{DC} = |S_{21}|^2 \quad (A.13)$$

- 4) Verify A_{DClg} is less than 0,5 dB, where:

$$A_{DClg} = 20 \cdot \log |S_{21}| \quad (A.14)$$



Key

- | | | | |
|---|-------------------------------|----|----------------------------------|
| 1 | vector network analyser (VNA) | T | transmission port |
| 2 | low loss 50 Ω coaxial cable | R | reflection port |
| 3 | dual directional coupler | P1 | coupler input |
| 4 | 50 Ω termination (VSWR < 1,1) | P2 | coupler output |
| | | P3 | forward power measurement port |
| | | P4 | reflected power measurement port |

Figure A.4 — P1, P2 VSWR and transmission loss verification

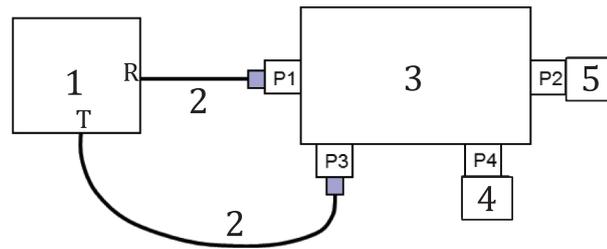
A.3.2 VSWR and forward coupling factor measurement

- 1) Connect the VNA to the directional coupler as illustrated in Figure A.5. Connect a reference matched 50 Ω termination (used for VNA calibration) to P2. Connect a 50 Ω termination (VSWR < 1,1) to P4.
- 2) Measure and record $|S_{22}|$ at P3 over the test frequency range. Calculate and verify that the VSWR is less than 1,5.
- 3) Measure and record $|S_{21}|$ over the test frequency range. Record the forward coupling factor, C_{FF} , where:

$$C_{FF} = |S_{21}|^2 \tag{A.15}$$

- 4) Verify C_{FFdB} is greater than 20 dB, where:

$$C_{FFdB} = 20 \cdot \log |S_{21}| \tag{A.16}$$



Key

- | | | | |
|---|---|----|----------------------------------|
| 1 | vector network analyser (VNA) | T | transmission port |
| 2 | low loss 50 Ω coaxial cable | R | reflection port |
| 3 | dual directional coupler | P1 | coupler input |
| 4 | 50 Ω termination (VSWR < 1,1) | P2 | coupler output |
| 5 | suitable reference 50 Ω termination (see A.2) | P3 | forward power measurement port |
| | | P4 | reflected power measurement port |

Figure A.5 — Setup for forward coupling factor (C_{FF}) and P3 VSWR verification

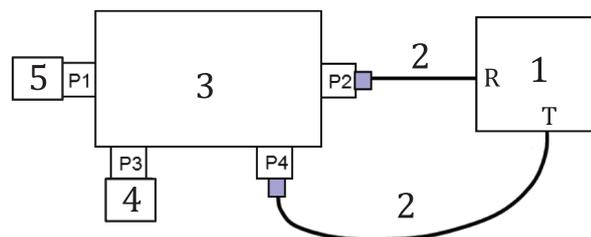
A.3.3 VSWR and reflected coupling factor measurement

- 1) Connect the VNA to the directional coupler as illustrated in Figure A.6. Connect a reference matched 50 Ω termination (used for VNA calibration) to P1. Connect 50 Ω terminations (VSWR < 1,1) to P3.
- 2) Measure and record S_{22} at P4 over the test frequency range. Calculate and verify that the VSWR is less than 1,5.
- 3) Measure and record $|S_{21}|$ over the test frequency range. Record the forward coupling factor, C_{FR} , where:

$$C_{FR} = |S_{21}|^2 \tag{A.17}$$

- 4) Verify C_{FRdB} is greater than 20 dB, where:

$$C_{FRlg} = 20 \cdot \log |S_{21}| \tag{A.18}$$



Key

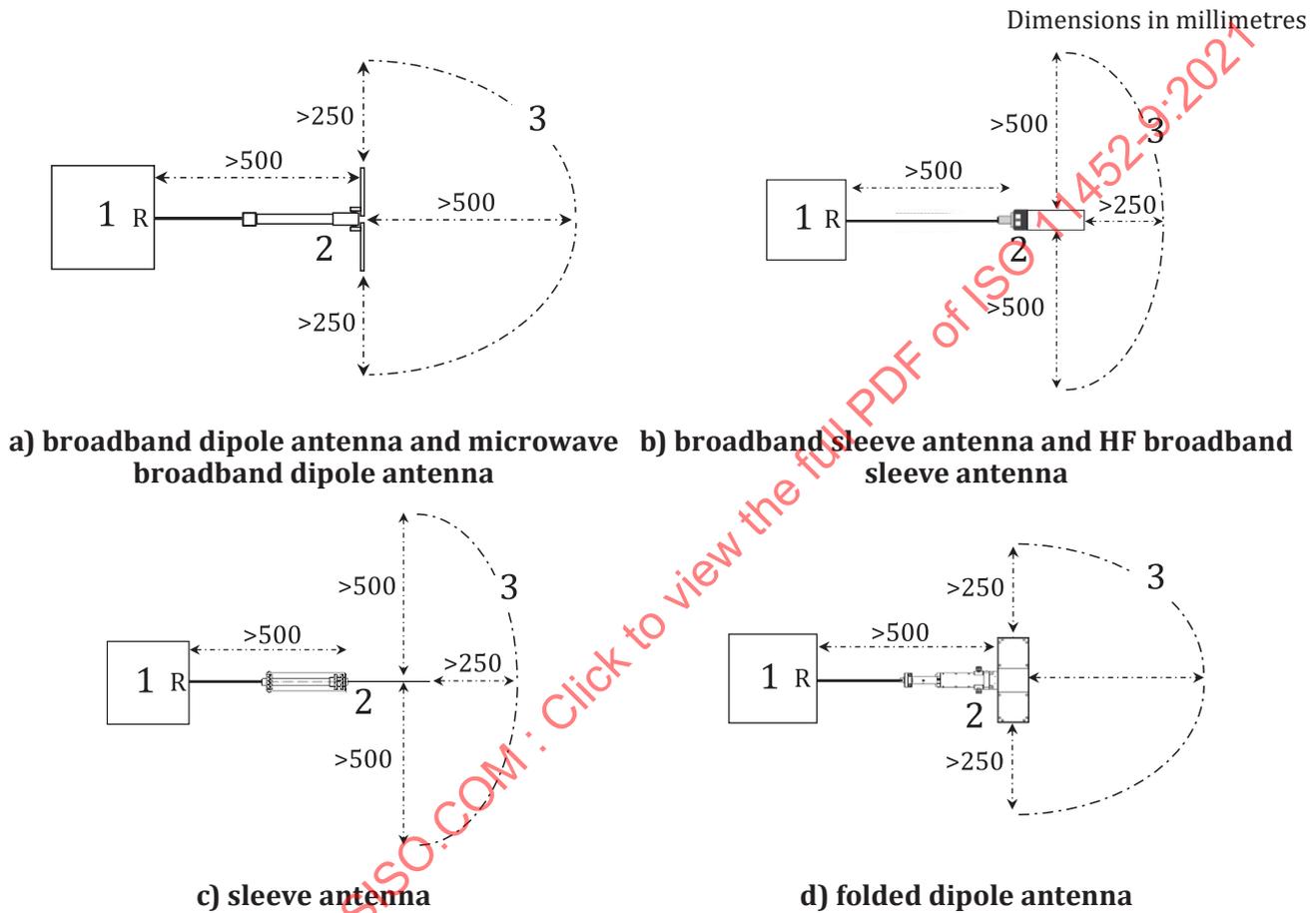
- | | | | |
|---|---|----|----------------------------------|
| 1 | vector network analyser (VNA) | T | transmission port |
| 2 | low loss 50 Ω coaxial cable | R | reflection port |
| 3 | dual directional coupler | P1 | coupler input |
| 4 | 50 Ω termination (VSWR < 1,1) | P2 | coupler output |
| 5 | reference 50 Ω termination standard used for TOSM calibration (see A.2) | P3 | forward power measurement port |
| | | P4 | reflected power measurement port |

Figure A.6 — Setup for reflected coupling factor (C_{FR}) and P4 VSWR verification

A.4 Transmit antenna reflection coefficient measurement

Connect the VNA to any of the transmit antennas as shown in Figure A.7 (see 6.2.4 for description of transmit antennas). The antenna shall be positioned so that it is separated from the VNA and conducting surfaces as shown in Figure A.7. Measure and record the reflection coefficient “ρ” (i.e. magnitude of S_{11}) of antenna over at all test frequencies.

$$\rho = |S_{11}| = 10^{\frac{S_{11}lg}{20}} \tag{A.19}$$



Key

- 1 vector network analyser
- 2 low loss 50 Ω coaxial cable
- 3 boundary for location of any conducting surface
- T transmission port
- R reflection port

Figure A.7 — Measurement of reflection coefficient for transmit antenna

A.5 Characterization of VSWR and transmission loss of the antenna interconnect

Characterization requires in-situ measurement of the VSWR and transmission loss for the interconnection between the directional coupler and antenna.

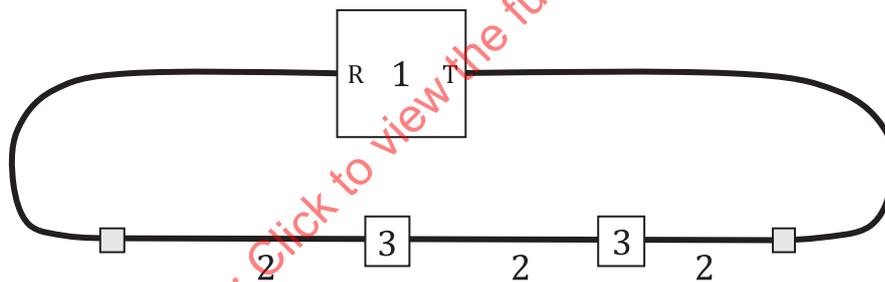
- 1) Connect the VNA to the antenna interconnect cable assembly as illustrated in [Figure A.8](#). The assembly includes all in-line coaxial connectors and adaptors in addition to any coaxial switching devices.
- 2) Measure and record $|S_{11}|$ and $|S_{22}|$ over the test frequency range. Calculate and verify that the VSWR at each connector is less than 1,1.
- 3) Measure and record $|S_{21}|$ over the test frequency range. Record the transmission loss T_1 , where:

$$T_1 = |S_{21}|^2 \quad (\text{A.20})$$

- 4) Verify that T_{1lg} is less than 4 dB where:

$$T_{1lg} = |20 \cdot \log(S_{21})| \quad (\text{A.21})$$

The interconnection between the directional coupler and transmit antenna should ideally have no intermediate connections including cable interconnects, adaptors, coaxial switches, etc. Presence of these additional items can increase the VSWR of the interconnection which introduces uncertainty to the net power delivered to the transmit antenna.



Key

- 1 vector network analyser
- 2 low loss 50 Ω coaxial cable
- 3 coaxial connectors/adaptors
- T transmission port
- R reflection port

See [Figure A.2](#) for component references.

Figure A.8 — Measurement of VSWR and T_1 for coupler/antenna interconnect

A.6 Characterization of transmission loss for the coupler/antenna interconnect

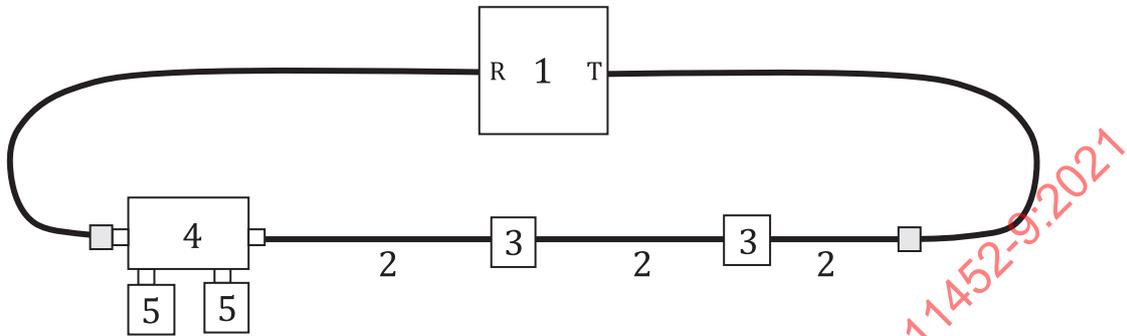
Characterization requires in-situ measurement of the transmission loss for the combination of the directional coupler and antenna interconnect cable.

- 1) Attach the directional coupler to the interconnect cable assembly. Connect the VNA as illustrated in [Figure A.9](#). The other ports of the coupler shall be terminated with a 50 Ω load with a VSWR less than 1,3.
- 2) Measure and record $|S_{21}|$ over the test frequency range. Record the transmission loss T_2 , where:

$$T_2 = |S_{21}|^2 \tag{A.22}$$

3) Verify that T_{2dB} is less than 4 dB, where:

$$T_{2dB} = |20 \cdot \log(S_{21})| \tag{A.23}$$



Key

- | | | | |
|---|-----------------------------|---|-------------------------------|
| 1 | vector network analyser () | 5 | 50 Ω termination (VSWR < 1,1) |
| 2 | low loss 50 Ω coaxial cable | T | transmission port |
| 3 | coaxial connectors/adaptors | R | reflection port |
| 4 | dual directional coupler | | |

See [Figure A.2](#) for component references.

Figure A.9 — Measurement of T_2

A.7 Characterization of VSWR and transmission loss for the coupler/power sensor interconnect

Connect all of the elements that comprise the directional coupler and interconnect between it and the connection point of the power sensors or measurement receiver. Characterization requires in-situ measurements of the VSWR and transmission loss of the interconnections between the directional coupler and power sensors. [Figure A.2](#) is used as a reference to provide guidance of how to carry out these in-situ measurements for laboratory specific equipment test setups. Alternative methods (e.g. separate component measurements) are not permitted.

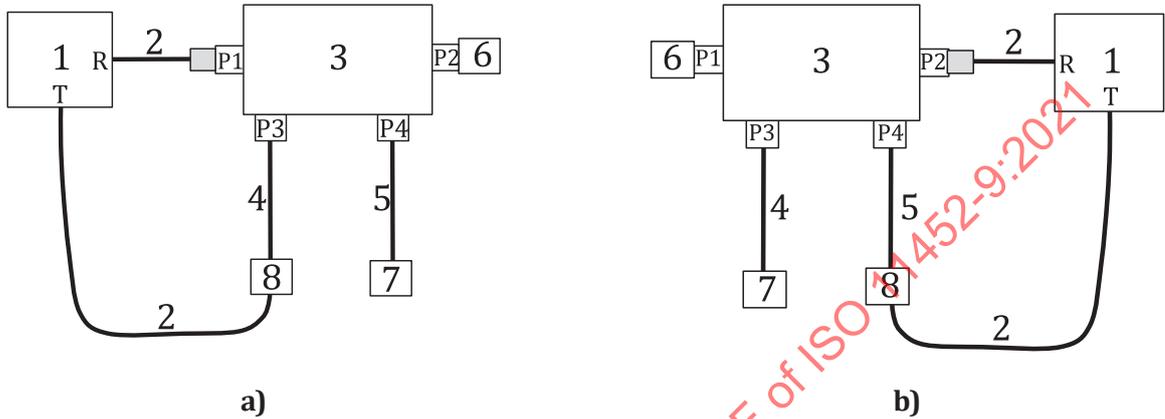
- 1) Connect the VNA to the directional coupler input and the forward power measurement point as illustrated in [Figure A.10 a](#)). Connect a reference “matched” termination on the output of the coupler. The reflected power measurement point shall be terminated with a 50 Ω load with a VSWR less than 1,1.
- 2) Measure and record $|S_{22}|$ at the forward power measurement point [see [Figure A.10 a](#))] over the test frequency range. Calculate and verify that the VSWR is less than 1,5.
- 3) With the VNA remaining connected as illustrated in [Figure A.10 a](#)), measure and record $|S_{21}|$ over the test frequency range. Record the transmission loss T_3 , where:

$$T_3 = |S_{21}|^2 \tag{A.24}$$

- 4) Connect the VNA to the directional coupler output and the reflected power measurement point as illustrated in [Figure A.10 b](#)). Connect a reference “matched” termination on the input of the coupler. The forward power measurement point shall be terminated with a 50 Ω load with a VSWR less than 1,1.

- 5) Measure and record $|S_{22}|$ at the reflected power measurement point, see [Figure A.10 b\)](#) over the test frequency range. Calculate and verify that the VSWR is less than 1,5.
- 6) With the VNA remaining connected as illustrated in [Figure A.10b](#), measure and record $|S_{21}|$ over the test frequency range. Record the transmission loss T_4 , where:

$$T_4 = |S_{21}|^2 \tag{A.25}$$



Key

- | | | | |
|---|---|----|---|
| 1 | vector network analyser (VNA) | 7 | 50 Ω termination (VSWR < 1,1) |
| 2 | low loss 50 Ω coaxial cable | 8 | measurement point (S_{22} , S_{21}) |
| 3 | dual directional coupler | P1 | coupler input |
| 4 | 50 Ω coaxial cable assembly (connects to forward power sensor) | P2 | coupler output |
| 5 | 50 Ω coaxial cable assembly (connects to reflected power sensor) | P3 | forward power measurement port |
| 6 | reference 50 Ω termination standard used for TOSM calibration (see A.2) | P4 | reflected power measurement port |

Figure A.10 — Measurement of T_2 and T_3

Annex B (informative)

Typical characteristics and use of portable transmitters

Additional tests with unmodified commercial portable transmitter may be performed. The detailed test method should be defined in the test plan.

Examples of typical characteristics for portable transmitters are given in [Table B.1](#), an explanation of terms used in [Table B.1](#) is given in [Table B.2](#). These characteristics are for information only; frequency bands may be different from one region to another, use of power levels greater than those indicated can be expected.

Table B.1 — Typical characteristics for portable transmitters

Transmitter designation	Frequency [MHz]	Power ^a [W]	Typical transmitter modulation	Test modulation
10 m	26 to 30	10(RMS)	Telegraphy, AM, SSB FM	AM 1 kHz, 80 %
2 m	144 to 148	10(RMS)	Telegraphy, AM, SSB FM	CW
1,25 m	220 to 225	10(RMS)	Telegraphy, AM, SSB FM	CW
70 cm	420 to 450	10(RMS)	Telegraphy, AM, SSB FM	CW
LAND MOBILE	146 to 174 216 to 223	10(Peak)	FM, FSK	CW
TETRA/TETRAPOL	380 to 390 410 to 420 / 450 to 460 806 to 825 / 870 to 876	10(Peak)	$\pi/4$ DQPSK	PM 18 Hz 50 % duty cycle
CDMA 800 (cellular)	815 to 849	0,25(Peak)	QPSK	PM 1 600 Hz 50 % duty cycle
GSM 850 (mobile) GSM 900 (mobile)	824 to 849 876 to 915	2(Peak)	GMSK	PM 217 Hz 50 % duty cycle
GSM 1800/1900 (mobile phone)	1 710 to 1 785 1 850 to 1 910	1(Peak)	GMSK	PM 217 Hz 50 % duty cycle
CDMA 1900 (PCS)	1 850 to 1 910	0,25(Peak)	QPSK	PM 1 600 Hz 50 % duty cycle
UMTS (mobile phone WCDMA & TD/CDMA)	824 to 849 880 to 915 1 850 to 1 980 1 885 to 2 025 1 920 to 1 980	0,25(Peak)	HPSK QAM	PM 1 600 Hz 50 % duty cycle

^a Power levels listed are typical of commercial equipment. However, power levels used during testing with simulated portable transmitters will be dependent on the test antenna used (see [Annex C](#)). Typically, the power levels using the simulated portable transmitter antenna will be higher (see [Annex D](#)).

Table B.1 (continued)

Transmitter designation	Frequency [MHz]	Power ^a [W]	Typical transmitter modulation	Test modulation
Bluetooth, WLAN (data) WIFI	2 400 to 2 500	0,10(Peak)	QPSK	PM 1 600 Hz 50 % duty cycle Or broadband noise of 20MHz by AWG See Annex F
LTE (mobile phone OFDMA & SC-FDMA)	452 to 458 698 to 803 / 807 to 862 / 880 to 915 / 1 427 to 1 463 1 625 to 1 661 / 1 710 to 1 785 1 850 to 2 025 / 2 300 to 2 400 2 496 to 2 690 3 400 to 3 800	0,25(Peak)	OFDM - PSK	PM 1 000 Hz 10 % duty cycle Or broadband noise of 20MHz by AWG See Annex F
IEEE 802.11a (5G WIFI)	5 150 to 5 350 5 725 to 5 850	0,5(Peak)	OFDM - PSK	PM 1 600 Hz 50 % duty cycle Or broadband noise of 20MHz by AWG See Annex F

^a Power levels listed are typical of commercial equipment. However, power levels used during testing with simulated portable transmitters will be dependent on the test antenna used (see [Annex C](#)). Typically, the power levels using the simulated portable transmitter antenna will be higher (see [Annex D](#)).

Table B.2 — Abbreviated terms

Modulation/ Access system	Description	Example for use
AM	Amplitude modulation	Broadcast
BT	Bluetooth	-
CDMA	Code division multiple access	
DQPSK	Differential quadrature phase shift keying	Iridium satellite telephone
FDMA	Frequency division multiplex access	-
FM	Frequency modulation	Broadcast
GMSK	Gaussian minimum shift keying	GSM
GSM 850	Global system of mobile phones 850 MHz band	-
GSM 900	Global system of mobile phones 900 MHz band	-
GSM 1800/1900	Global system of mobile phones 1 800/1 900 MHz band	-
HPSK	Hybrid phase shift keying	
IEEE 802.11a	802.11 refers to a family of specifications developed by the IEEE for wireless LAN technology	WLAN
IMT-2000	International mobile telecommunications 2000	UMTS
LTE	Long term evolution	
OFDM	Orthogonal frequency division multiplexing	LTE

Table B.2 (continued)

Modulation/ Access system	Description	Example for use
OFDMA	Orthogonal frequency division multiplexing access	
PCS	Personal communications service	-
PM	Pulse modulation	GSM
PSK	Phase shift keying	CDMA
QAM	Quadrature amplitude modulation	WCDMA
QPSK	Quadrature phase shift keying	UMTS, W-LAN
SC-FDMA	Single carrier-frequency division multiple access	
SSB	Single side band	Military, ham radio
Telegraphy	Morse telegraphy coded work	-
TDMA	Time division multiple access	Tetra 25, DECT, GSM
TETRA	Terrestrial trunked radio	-
TETRAPOL	Terrestrial trunked radio police	-
UMTS	Universal mobile telecommunication system	
WCDMA	Wideband code division multiplex access	
WIFI	Wireless fidelity	
WLAN	Wireless local area network	-
10m/2m/1,25m/70 cm	HAM radio band as wavelength	-

Annex C (informative)

Characteristics of simulated portable transmitter antenna

C.1 Introduction

This annex provides details of the transmitter antenna, together with examples of other simulated portable transmitter antennas, which can be used to perform the tests according to this document:

- broadband dipole antenna;
- broadband sleeve antenna;
- sleeve antennas;
- folded dipole antennas;
- microwave broadband dipole antenna;
- HF broadband sleeve antenna.

All dimensions indicated in the figures of this annex are in millimetres.

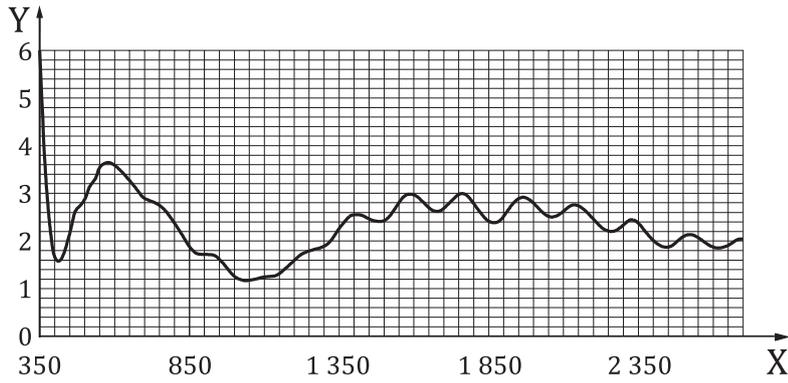
C.2 Broadband dipole antenna

- Input impedance: 50 Ω
- Balun transformation ratio: 1:1
- Frequency range: 360–2 700 MHz
- Radiating element dimensions: 240 mm \times 109 mm
- Maximum power input 20 W
- Connector: type-N female
- VSWR characteristic: see [Figure C.1](#)

The geometrical characteristics of the broadband dipole antenna for simulated portable transmitters are indicated in [Figure C.2](#).

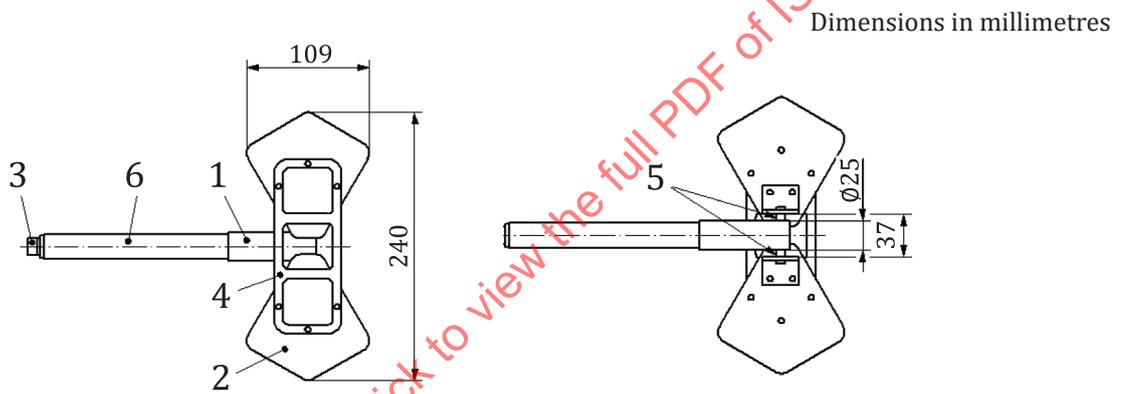
The broadband dipole antenna has three 100 mm \times 100 mm test zones where field uniformity is better than ± 3 dB. In the frequency range (360–480) MHz, the E field is concentrated under the elements of the antenna and moves to the centre after 800 MHz. The average field severity is calculated by averaging the field in these zones.

[Figure C.3](#) shows field distribution and peak amplitudes in volts per metre (V/m) for a 1 W net input at a 50 mm distance from the antenna elements. The greenest areas (the mid-grey areas toward the grid edges when viewed in monochrome) show a greater than 6 dB field degradation from the maximum field.



Key
 X frequency [MHz]
 Y VSWR

Figure C.1 — Typical VSWR characteristics of broadband dipole antenna



Key

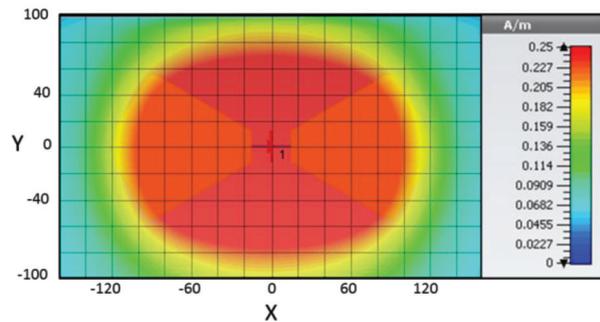
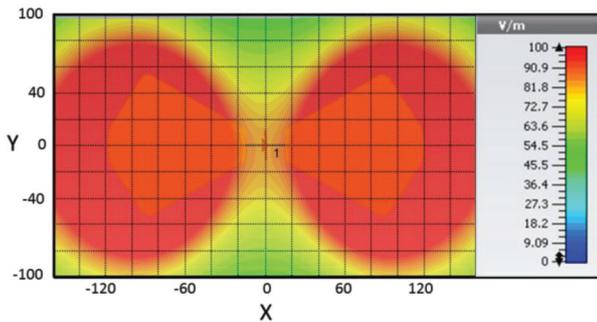
1 broadband low loss balun 1:1	4 element fixture and spacing frame (5 mm, non-metallic)
2 flat antenna elements	5 symmetrical terminals, M4
3 N-female connector	6 22 mm tube for handling or fixture

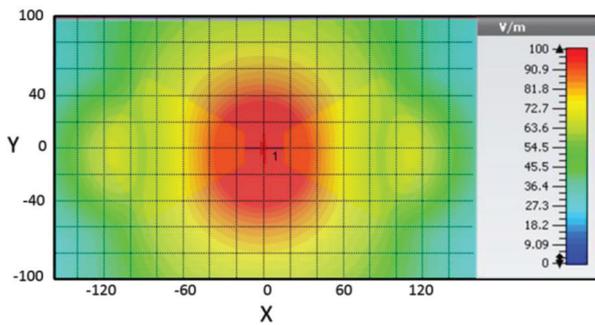
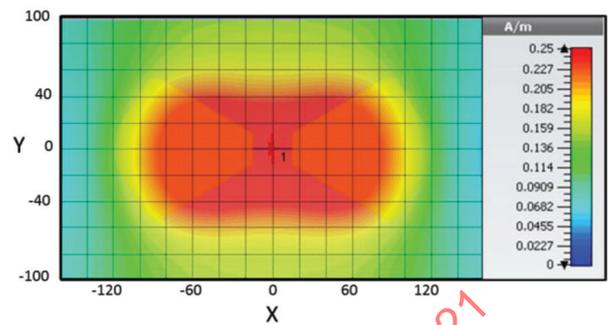
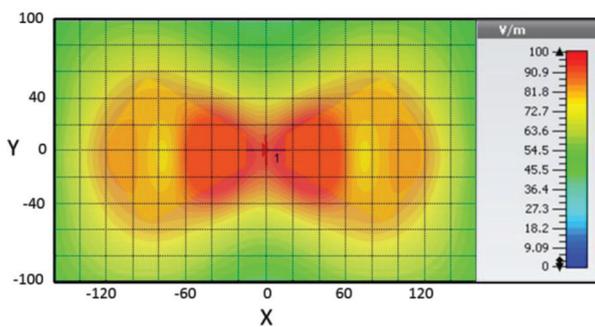
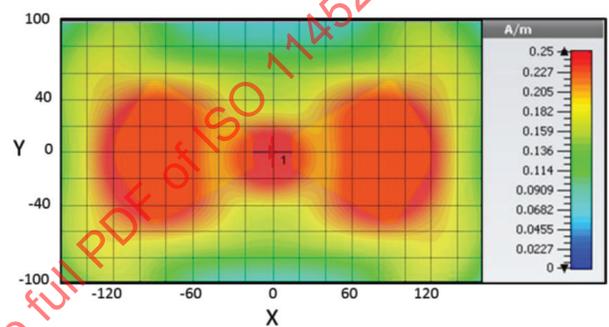
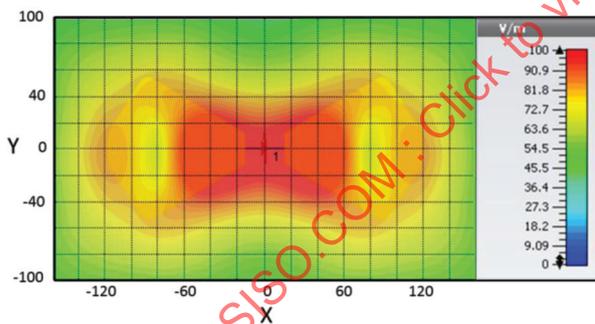
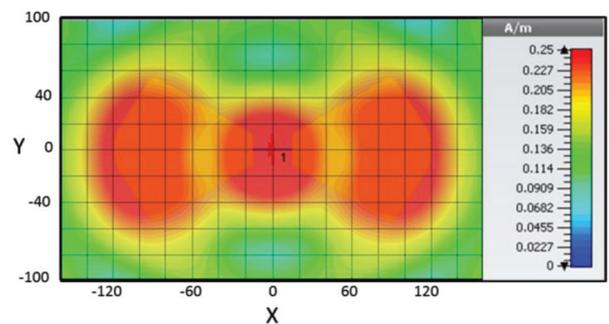
Figure C.2 — Construction details of broadband dipole antenna

Dimensions X and Y in millimetres

E field: 0,4 GHz (100 V/m)

H field: 0,4 GHz (0,25 A/m)

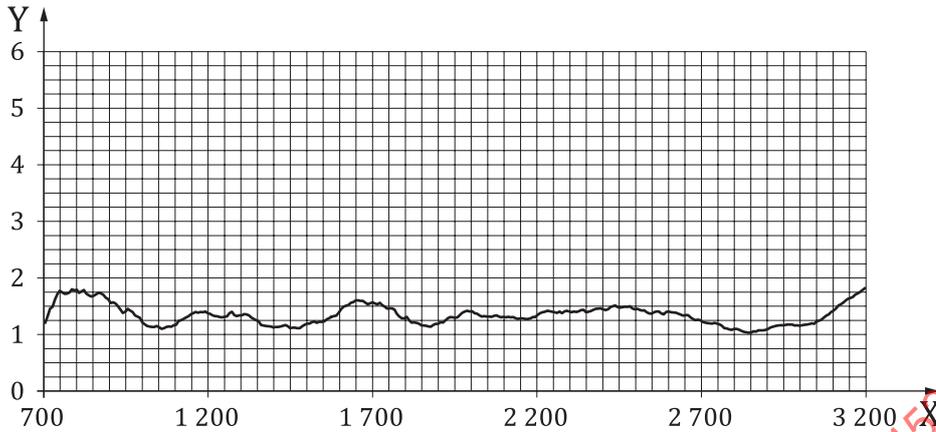


E field: 0,9 GHz (100 V/m)**H field: 0,9 GHz (0,25 A/m)****E field: 1,8 GHz (100 V/m)****H field: 1,8 GHz (0,25 A/m)****E field: 2,0 GHz (100 V/m)****H field: 2,0 GHz (0,25 A/m)****Figure C.3 — E and H field patterns for the broadband dipole antenna (0,4 – 2,0) GHz**

C.3 Broadband sleeve antenna

- Input impedance: 50 Ω
- Frequency range: 700 MHz – 3 200 MHz
- Radiating element dimensions: 186 mm \times 50 mm
- Maximum power input 20 W (700 MHz - 3 200 MHz)
- Connector: type-SMA female
- VSWR characteristic: see [Figure C.4](#)

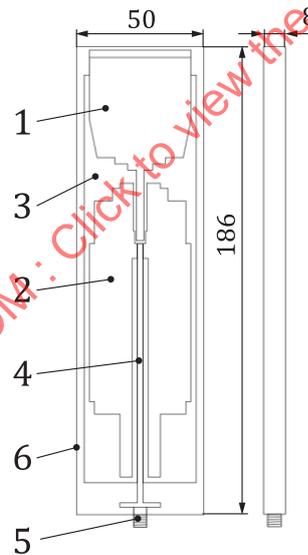
The geometrical characteristics of the broadband sleeve antenna for simulated portable transmitters are indicated in [Figure C.5](#).



Key
 X frequency [MHz]
 Y VSWR

Figure C.4 — Typical VSWR characteristics of broadband sleeve antenna

Dimensions in millimetres



Key
 1 radiation element
 2 ground element
 3 PCB
 4 semi-rigid cable
 5 SMA-female connector
 6 dielectric case

Figure C.5 — Construction details of broadband sleeve antenna

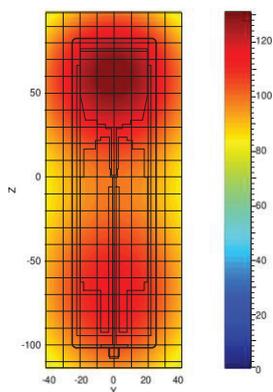
The broadband sleeve antenna has a test zone along the radiation element, where electric fields are effectively generated. [Figures C.6](#) through [C.7](#) show distribution and peak amplitude of electric field

strengths (V/m) and magnetic field strengths (A/m) for a 1 W net power input at a 50 mm distance from antenna elements.

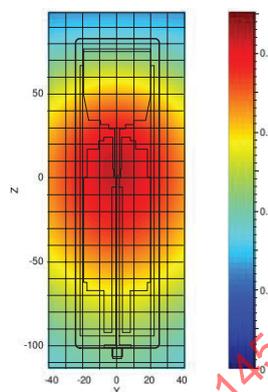
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Dimensions Y and Z in millimetres

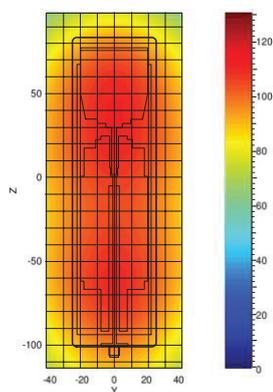
E field: 0,7 GHz (133 V/m)



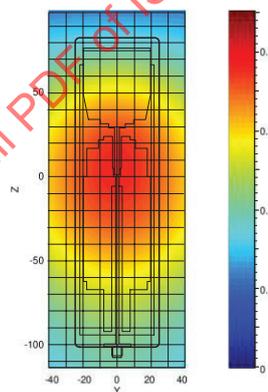
H field: 0,7 GHz (0,43 A/m)



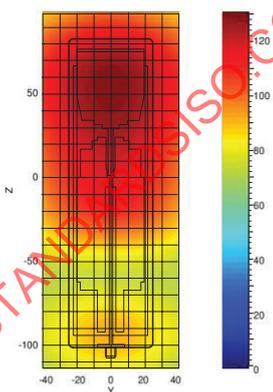
E field: 0,9 GHz (113 V/m)



H field: 0,9 GHz (0,39 A/m)



E field: 1,8 GHz (131 V/m)



H field: 1,8 GHz (0,45 A/m)

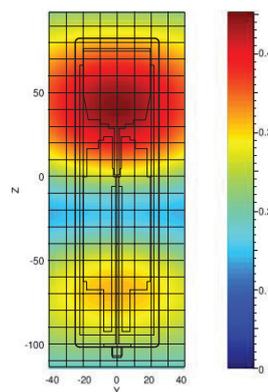


Figure C.6 — E and H field patterns for the broadband sleeve antenna (0,7 – 1,8) GHz

Dimensions Y and Z in millimetres

E field: 2,0 GHz (133 V/m)

H field: 2,0 GHz (0,40 A/m)

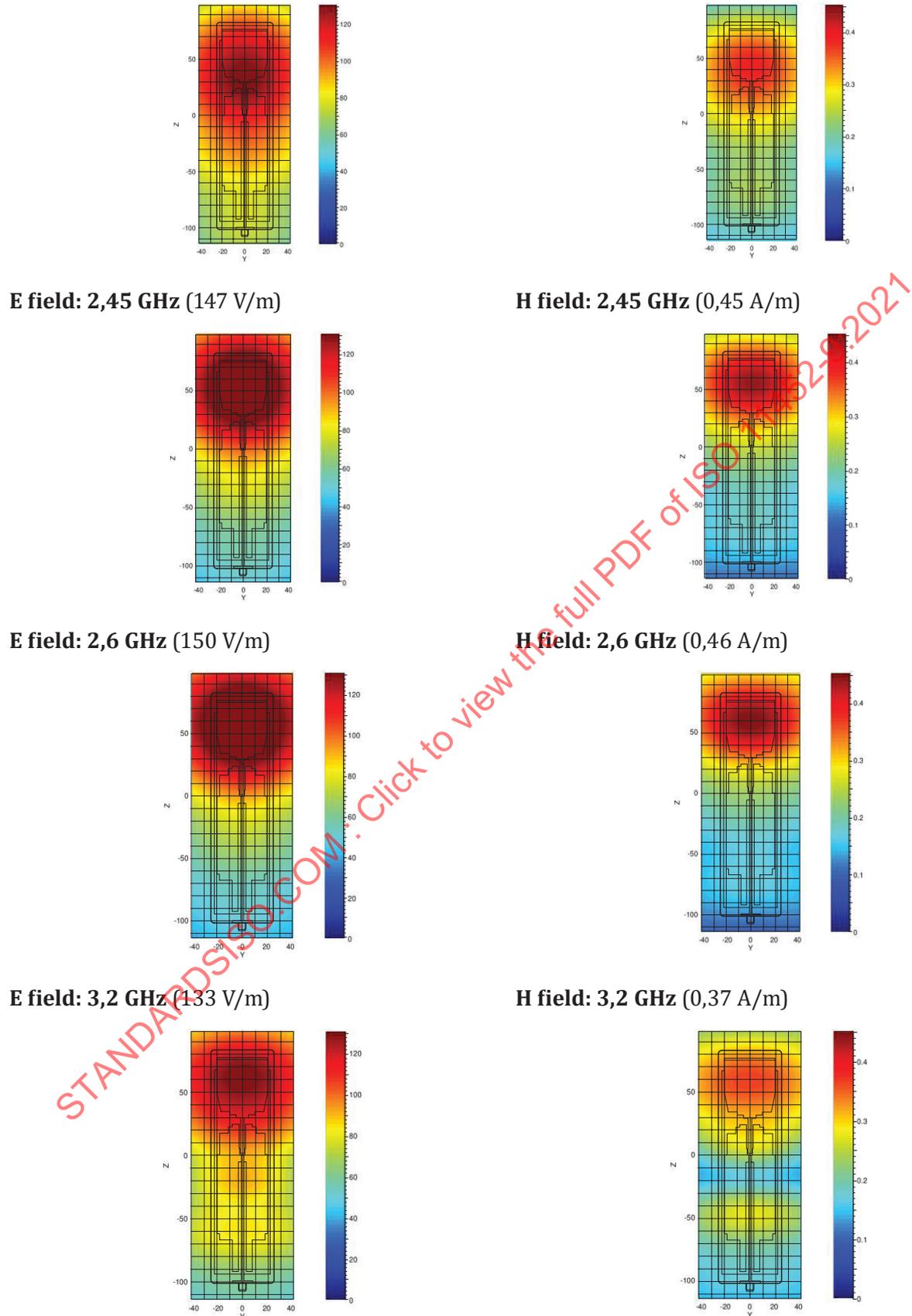


Figure C.7 — E and H field patterns for the broadband sleeve antenna (2,0 – 3,2) GHz

C.4 Sleeve antenna

- Input impedance: 50 Ω
- Permissible power: 30 W
- Connector: type-BNC
- Gain: 2,15 dB ± 1 dB
- VSWR: < 2:1

An explanation of the antenna and sleeve length for each frequency band is given in [Table C.1](#). These characteristics are for information only. An example of geometrical characteristics of a sleeve antenna for simulated portable transmitters is shown in [Figure C.8](#).

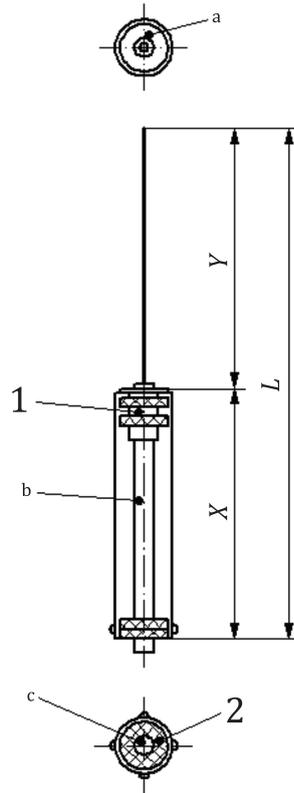
Table C.1 — Example of antenna and sleeve element length for each band

Dimensions in millimetres

Frequency band	Centre frequency	X Antenna element length ^a	Y Sleeve length
MHz	MHz	Tolerance: $X \pm 5\%$	Tolerance: $Y \pm 5\%$
380–390	385	198 ± 9	162 ± 8
410–420	415	189 ± 9	155 ± 8
420–450	435	180 ± 9	147 ± 7
450–460	455	172 ± 8	141 ± 7

^a Antenna element and sleeve lengths shall be tuned to attain the specific VSWR.

The antennas are designed as typical $1/4 \lambda$ sleeve antennas. Each band antenna utilizes a cable, a BNC connector, a brass rod as the antenna element and a steel pipe as the sleeve element. For keeping a constant cross section along the sleeve and cable, a cable fixing plastic screw and four polycarbonate screws may be applied at the bottom of sleeve element.



$$L = X + Y = \lambda/2 \times 0,95$$

$X: Y = 55: 45$ (based on the configuration samples)
 where λ , in millimetres, is the wave length of centre frequency.

Fractional shortening: 95 %

Sleeve outer diameter: 20 mm (equivalent to S45RP)

Antenna diameter: 2 mm (brass rod)

Sleeve inner diameter: 18,5 mm (equivalent to S45RP)

Connector: BNC (UG-625/U, BNC-P-3)

Key

- 1 BNC connector
- 2 polycarbonate screw: M3
- a Tightening with a 14,9 mm diameter nut.
- b Cable.
- c Cable-fixing plastic screw: material, nylon MC; outer diameter, 13 mm; inner diameter, 6 mm; thickness, 6 mm; screw hole, M3.

The surfaces of the antenna element and sleeve are recommended to be of a rust-resistant metallic material (e.g. Ni).

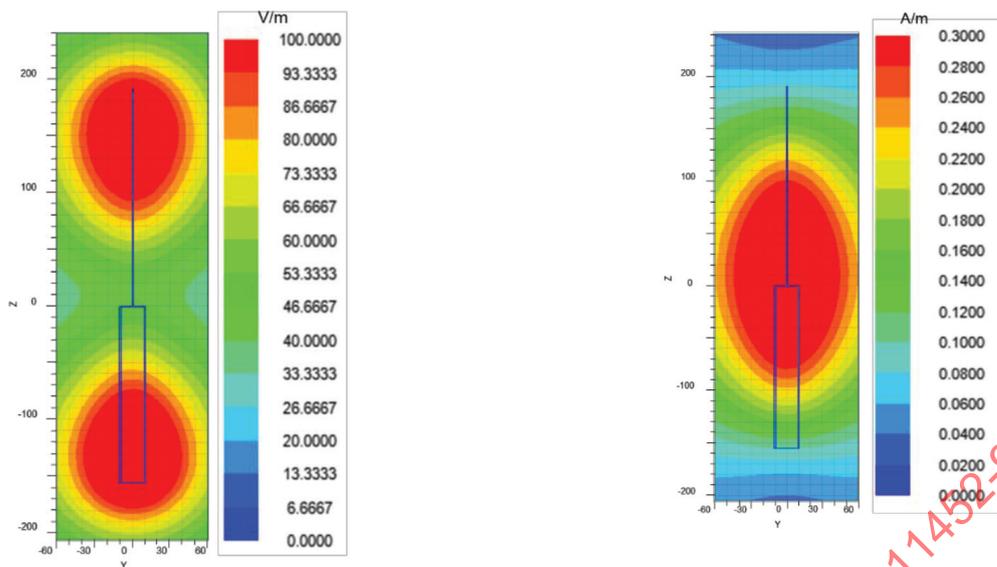
Figure C.8 — Example of $1/4\lambda$ sleeve antenna configuration

The sleeve antenna has a test zone along the radiation element, where electric fields are effectively generated. [Figures C.9](#) and [C.10](#) shows distribution and peak amplitude of electric field strengths (V/m) and magnetic field strengths (A/m) for a 1 W net power input at a 50 mm distance from antenna elements.

Dimensions Y and Z in millimetres

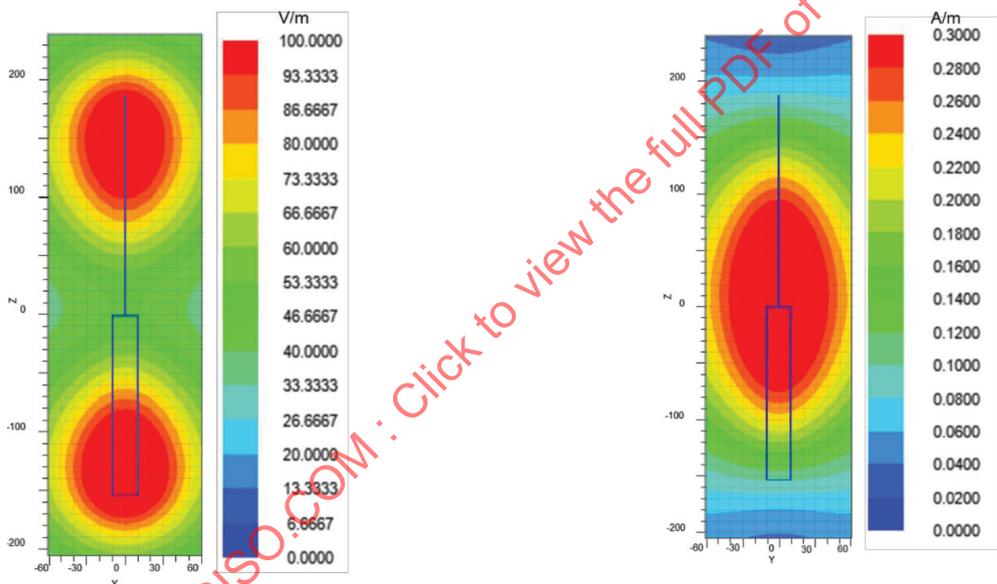
E field: 385 MHz (122 V/m)

H field: 385 MHz (0,38 A/m)



E field: 415 MHz (114 V/m)

H field: 415 MHz (0,36 A/m)

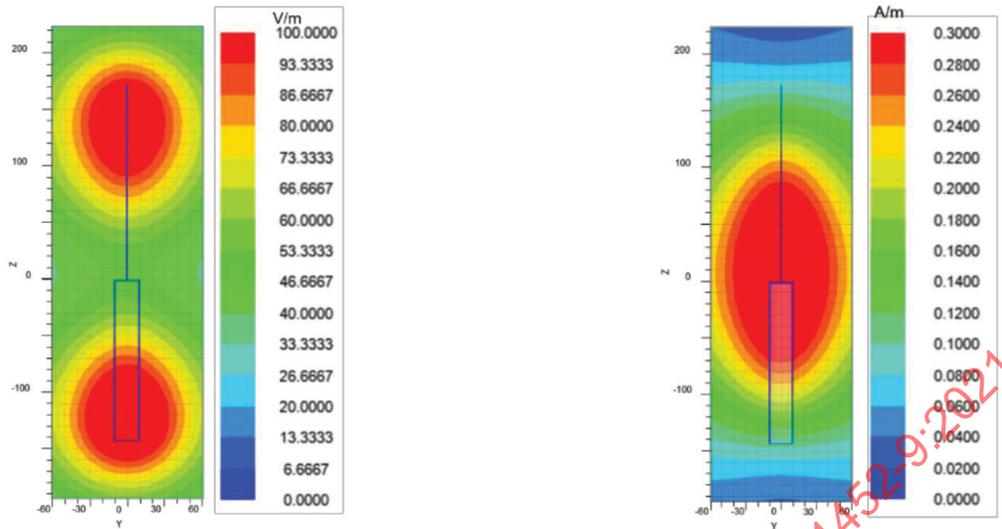


E field: 435 MHz (113 V/m)

H field: 435 MHz (0,36 A/m)

Figure C.9 — E and H field patterns for the sleeve antenna (385, 415) MHz

Dimensions Y and Z in millimetres



E field: 455 MHz (112 V/m)

H field: 455 MHz (0,36 A/m)

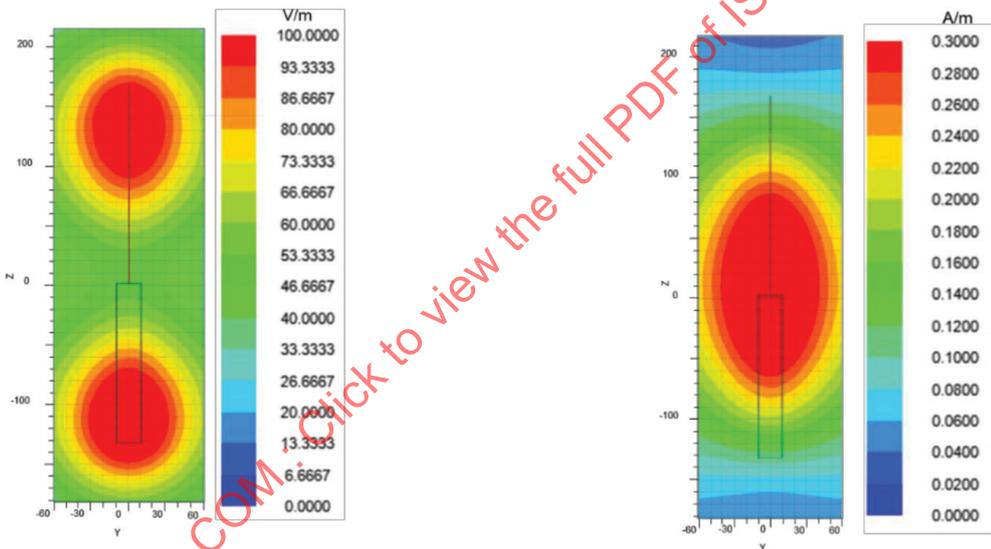


Figure C.10 — E and H field patterns for the sleeve antenna (435, 455) MHz

C.5 Folded dipole antenna

- Input impedance: 50 Ω
- Balun transformation ratio: 1:1
- Frequency range: 142 MHz – 246 MHz
- Radiating element dimensions: 89 mm \times 240 mm
- Maximum power input 30 W
- Connector: type-N female
- VSWR characteristic: see [Table C.2](#)

The antennas are designed as folded dipole antenna. An explanation of the antenna for each frequency band is given in [Table C.2](#). The structural characteristics common to all antennas in this case are shown in [Figures C.11](#) and [C.12](#).

The folded dipole antenna has a test zone along the radiation element, where electric fields are effectively generated. [Figures C.13](#) through [C.14](#) show distribution and peak amplitude of electric field strengths (V/m) and magnetic field strengths (A/m) for a 1 W net power input at a 50 mm distance from antenna elements.

Table C.2 — Typical VSWR characteristics of folded dipole antenna for 142 – 246 MHz

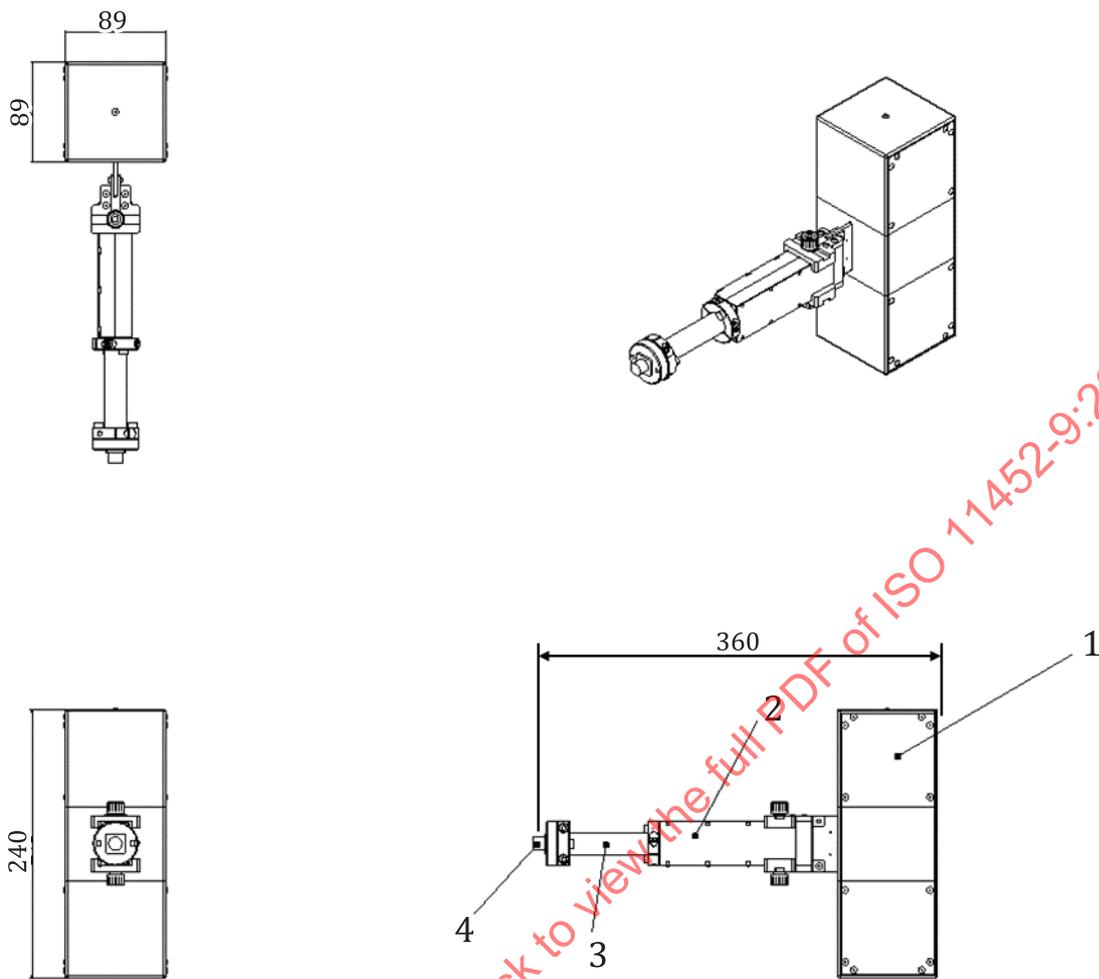
Frequency band (MHz)	VSWR
142-150	
151-161	
162-174	
172-180	
<p>Key</p> <p>X Frequency [MHz]</p> <p>Y VSWR</p> <p>1 146 MHz_test</p> <p>2 155 MHz_test</p> <p>3 165 MHz_test</p> <p>4 174 MHz_test</p> <p>5 222 MHz_test</p>	

Table C.2 (continued)

Frequency band (MHz)	VSWR
215-246	
<p>Key</p> <p>X Frequency [MHz]</p> <p>Y VSWR</p> <p>1 146 MHz_test</p> <p>2 155 MHz_test</p> <p>3 165 MHz_test</p> <p>4 174 MHz_test</p> <p>5 222 MHz_test</p>	

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Dimensions in millimetres



Key

- 1 radiation elements
- 2 low loss balun 1:1
- 3 20 mm tube for handling or fixture
- 4 N-female connector

Figure C.11 — Construction details of folded dipole antenna