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

Part 3: On-board transmitter simulation

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

Partie 3: Simulation des émetteurs embarqués

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document 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).

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

This fourth edition cancels and replaces the third edition (ISO 11451-3:2015), which has been technically revised.

The main changes are as follows:

— change of the frequency range from 1,8 MHz – 5,85 GHz to 1,8 MHz – 6 GHz;

— suppression of test methodology with commercial transmitters;

— use of modulation from ISO 11451-1;

— 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 D on function performance status classification (FPSC).

A list of all parts in the ISO 11451 series can be found on the ISO website.

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

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

Part 3:
On-board transmitter simulation

1 Scope

This document specifies methods for testing the immunity of passenger cars and commercial vehicles to electromagnetic disturbances from on-board transmitters connected to an external antenna and portable transmitters with integral antennas, regardless of the vehicle propulsion system (e.g. spark ignition engine, diesel engine, electric motor).

2 Normative references

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

ISO 11451-1, *Road vehicles — Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy — Part 1: General principles and terminology*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11451-1 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
integral antenna
permanent fixed antenna which may be built-in, designed as an indispensable part of the portable transmitting device

3.2
peak power sensor
power sensor that allows direct measurement of the peak power of the modulated carrier signal

3.3
average power sensor
power sensor that allows direct measurement of the average power of the modulated carrier signal

4 Test conditions

The applicable frequency range of the test method is 1,8 MHz to 6 GHz.

The user shall specify the test severity level(s) over the frequency range. Suggested test levels are included in Annex D. Typical on-board transmitter characteristics (frequency bands, power level and modulation) are given in Annex B.

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

— test temperature;

— supply voltage;

— dwell time;

— frequency step;

— modulation;

— test signal quality.

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

5.1 General

This test should typically be performed in an absorber lined shielded enclosure (ALSE). Where national regulations permit, the test can also be performed at an outdoor test site.

5.2 Absorber lined shielded enclosure (ALSE)

An absorber lined shielded enclosure with the characteristics specified in ISO 11451-2 should be used for this test.

NOTE At frequencies where absorbers are not effective, the reflections in the chamber can affect the exposure of the vehicle.

5.3 Outdoor test site

Where national regulations permit the use of an outdoor test site, the outdoor test site should have an area with a radius of 10 m free from large metal structures or objects. When performing outdoor test-site tests, it is important to be aware of harmonic suppression regulations.

6 Test instrumentation

6.1 General

The following test instrumentation is used:

— 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;

— direct current charging artificial network (DC- charging AN), and/or artificial mains networks (AMN), and/or asymmetric artificial networks (AAN).

6.2 Signal sources

6.2.1 Transmitters with antenna outside the vehicle

Signal sources for transmitters with antenna outside the vehicle should be simulated on-board transmitters (use of a signal generator and broadband power amplifier located external to the vehicle capable of generating radio frequency (RF) power in their operational frequency ranges with specific output power delivered to a test antenna or original equipment manufacturer (OEM) antenna fitted to the vehicle).

When using simulated on-board transmitters located external to the vehicle, it is advisable to place an RF choke (ferrite or powdered iron toroid) around the coaxial cable to the antenna to produce a minimum lossy impedance of 200 ohms. This reduces the cable shield skin currents and more closely simulate a transmitter installed in the vehicle.

6.2.2 Transmitters with antenna inside the vehicle

Signal sources for transmitters with antenna inside the vehicle should be simulated portable transmitters (use of a signal generator and broadband power amplifier located external to the vehicle capable of generating radio frequency (RF) power in their operational frequency ranges with specific output power). The power is delivered to a small passive antenna within the vehicle. Antennas used for this testing are described in Annex C.

6.3 Power monitoring

6.3.1 General

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 power sensor or a peak power sensor (peak conservation may be applied for AM per ISO 11451-1);

— pulsed power modulation shall be measured with a peak power sensor;

— when applying broadband test signal, power measurement instrumentation shall be capable of measuring average and peak values of the channel power;

— power sensors should be connected directly to the coupler ports;

— power sensors shall exhibit a VSWR < 1,2 and 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.

6.3.2 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,

— power rating compatible with testing needs.

6.3.3 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 < 6 dB. Verification shall be performed in accordance with Annex A.

6.4 Vector network analyser (VNA)

The VNA shall exhibit the following characteristics:

— frequency range: 1,8 MHz to 6 GHz,

— dynamic range: > 60 dB (IF bandwidth < 3 kHz),

— return loss: > 32 dB,

— transmission loss accuracy: < 0,1 dB,

— minimum number of points: 401,

— 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°,

  — termination match: return loss > 40 dB.

The following characteristics are recommended:

— frequency step: specified by the manufacturer (logarithmic step recommended),

— power level: 0 dBm (recommended value),

— averaging capability (optional),

— it is recommended to use the same connector type to match that of the interconnecting cable assembly and transmit antenna (avoid using adaptors).

6.5 Antennas

6.5.1 Simulated on-board transmitters

When an OEM antenna is not installed on the vehicle, the antenna(s) described below shall be used.

— For frequency ranges ≤ 30 MHz, loaded antennas shall be used. Loaded antennas employ lumped or distributed reactive components with a radiating element physically shorter than quarter wave at resonance. It is recommended to use a “screw-driver” antenna which allows use of a single antenna thus reducing installation time. Use of this antenna also facilitates automation techniques.

— For frequency ranges > 30 MHz, for example, for the very high frequency (VHF) and ultra-high frequency (UHF) bands, quarter wave antennas should be given preference over 5/8 wave antennas, since there are higher skin currents created by quarter wave antennas.

NOTE A screwdriver antenna is a vertical antenna for mobile operation in amateur HF band. It can cover from 10 m to 160 m band according to adjust a centre loading coil remotely. It is named from an electric screwdriver, because of its tuning method by a reversible DC electric motor.

All antennas shall be tuned on the vehicle for minimum voltage standing wave ratio (VSWR, typically less than 2:1) unless otherwise specified in the test plan. As a minimum, the VSWR value shall be measured and recorded with the antenna on the vehicle at the lower and upper band edge and at a middle frequency. See Annex A for procedures to make these measurements.

6.5.2 Simulated portable transmitter

Unless otherwise specified, the simulated portable transmitter antenna shall be a passive antenna. For characteristics of a passive antenna, see Annex C.

6.6 Stimulation and monitoring of the vehicle

If remote stimulation and monitoring are required in the test plan, the vehicle shall be operated by actuators which have a minimum effect on the electromagnetic characteristics, e.g. plastic blocks on the push-buttons, pneumatic actuators with plastic tubes.

Connections to monitoring equipment can be accomplished by using fibre-optics or high resistance leads. Other types of leads can be used, but they require extreme care to minimize interactions. The orientation, length and location of such leads shall be carefully documented to ensure repeatability of test results.

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

7 Test set-up

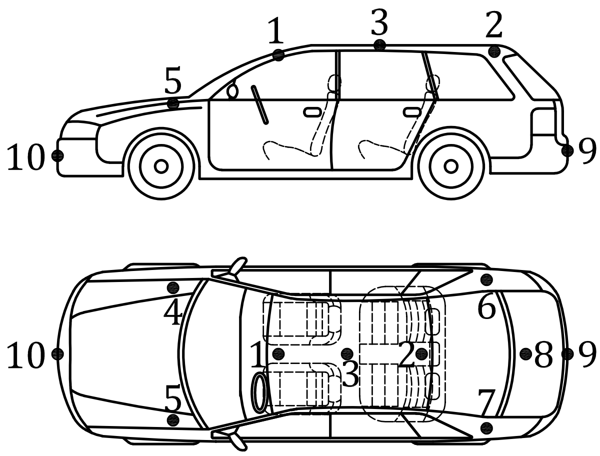
7.1 Transmitters with antenna outside the vehicle

The test can be performed with test antenna(s) or with the vehicle's OEM antenna, as defined in 6.5.1.

When a test antenna is used, the location(s) of the antenna on the vehicle shall be defined in the test plan. If no specific location(s) are agreed between the users of this document, the following location (s) are recommended, as illustrated in Figure 1:

— locations 1 (vehicle roof, front) and 2 (vehicle roof, rear) are the default locations for frequencies ≥ 30 MHz. Locations 3 through 8 are optional.

— location 9 (bumper) is the default location for frequencies < 30 MHz. Location 10 is optional.



Key

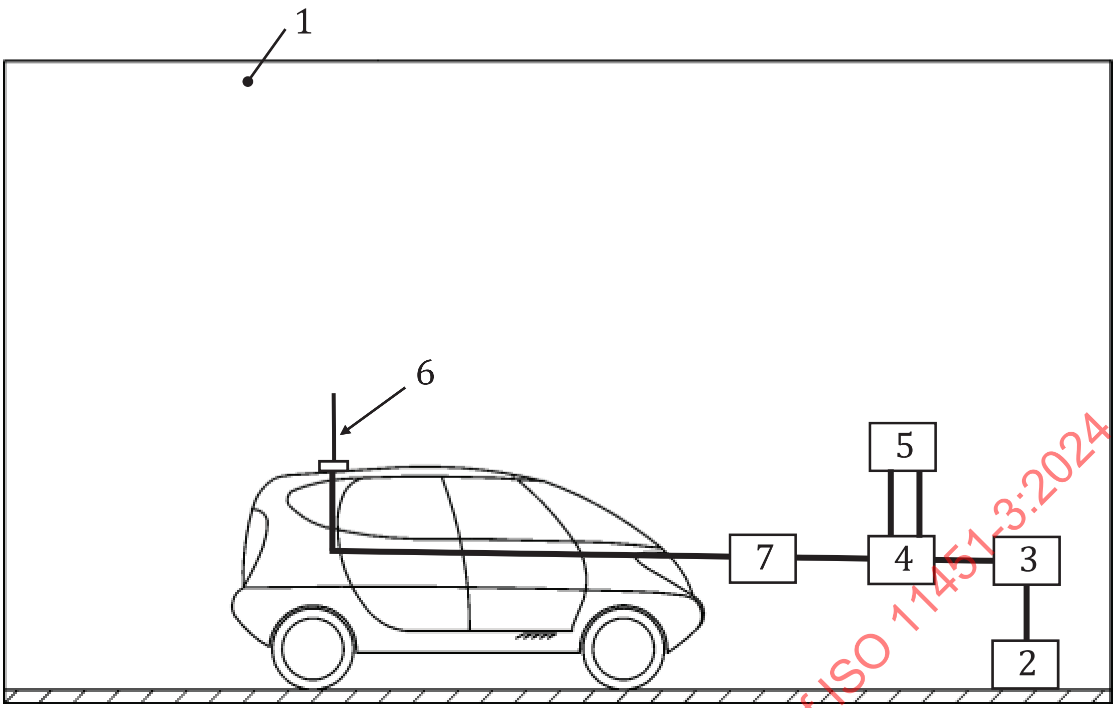
1 vehicle roof (front)
2 vehicle roof (rear)
3 vehicle roof (middle)
4 fender (front, right)
5 fender (front, left)
6 fender (rear, right)
7 fender (rear, left)
8 trunk lid (middle)
9 bumper (middle) < 30 MHz only
10 front bumper < 30 MHz only

Figure 1 — Recommended locations for antennas outside the vehicle

Examples of test set-up for simulated on-board transmitters are shown in Figure 2 (use of test antenna) and Figure 3 (use of vehicle OEM antenna).

When the vehicle OEM antenna is used, it should be used as it is installed in the vehicle without any change of antenna characteristics (location, VSWR, etc.).

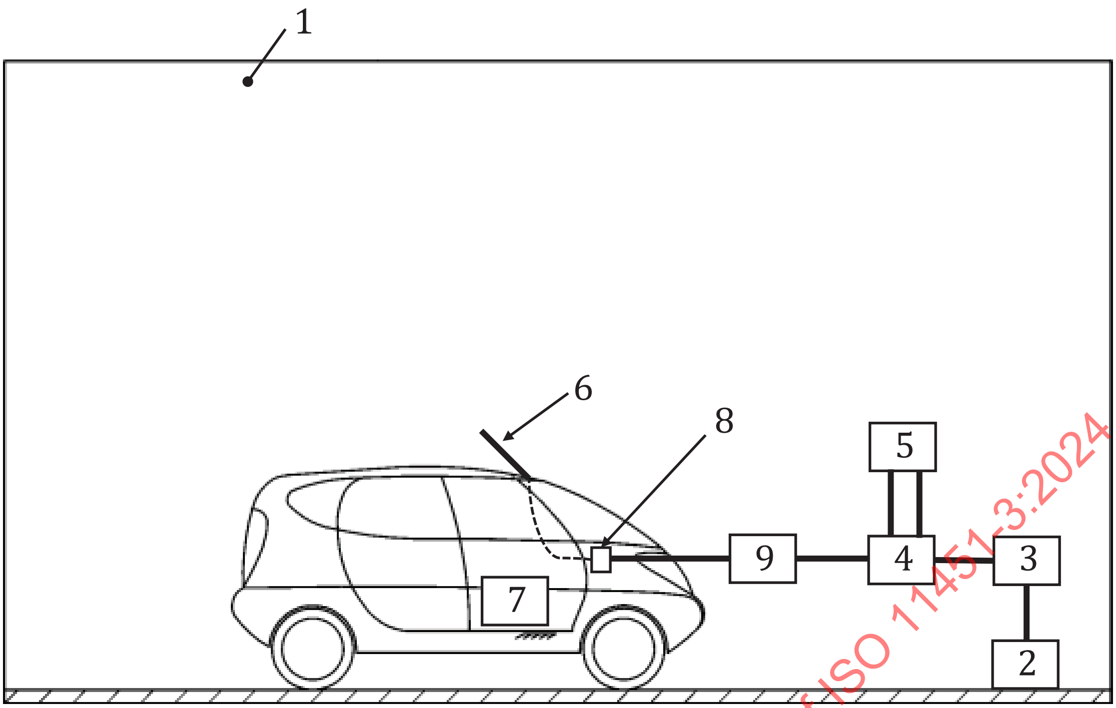
When the vehicle OEM antenna is used for multiple transmitters/receivers frequency, it is advisable not to use a simulated on-board transmitter (with "broadband" amplifier). The amplifier noise level can be sufficient to degrade some vehicle functions, like GPS satellite reception. The validation of such functions (relative to vehicle on-board-transmitter immunity) can only be performed with the vehicle OEM on-board transmitter. In this case, it might be necessary to operate the on-board vehicle transmitter in real conditions. This can be performed by using specific equipment, like a GSM base station simulator.



Key

1 ALSE
2 RF signal generator (can be outside test facility)
3 power amplifier (can be outside test facility)
4 dual directional coupler (can be outside test facility)
5 power meter (can be outside test facility)
6 test antenna (positions defined in test plan)
7 RF choke (see 6.2.1)

Figure 2 — Example of test set-up for simulated on-board transmitter and test antenna



Key

1 ALSE
2 RF signal generator (can be outside test facility)
3 power amplifier (can be outside test facility)
4 dual directional coupler (can be outside test facility)
5 power meter (can be outside test facility)
6 vehicle OEM antenna
7 on-board transmitter (disconnected from vehicle antenna)
8 vehicle antenna cable connector
9 RF choke (see 6.2.1)

Figure 3 — Example of test set-up for simulated on-board transmitter and vehicle OEM antenna

7.2 Transmitters with antenna inside the vehicle

7.2.1 General

The location(s) of a simulated portable transmitter in the vehicle shall be defined in the test plan. If no specific location(s) are agreed between the users of this document, it is recommended to specify places where the portable transmitter can be placed or used. Examples include:

— between front seats,

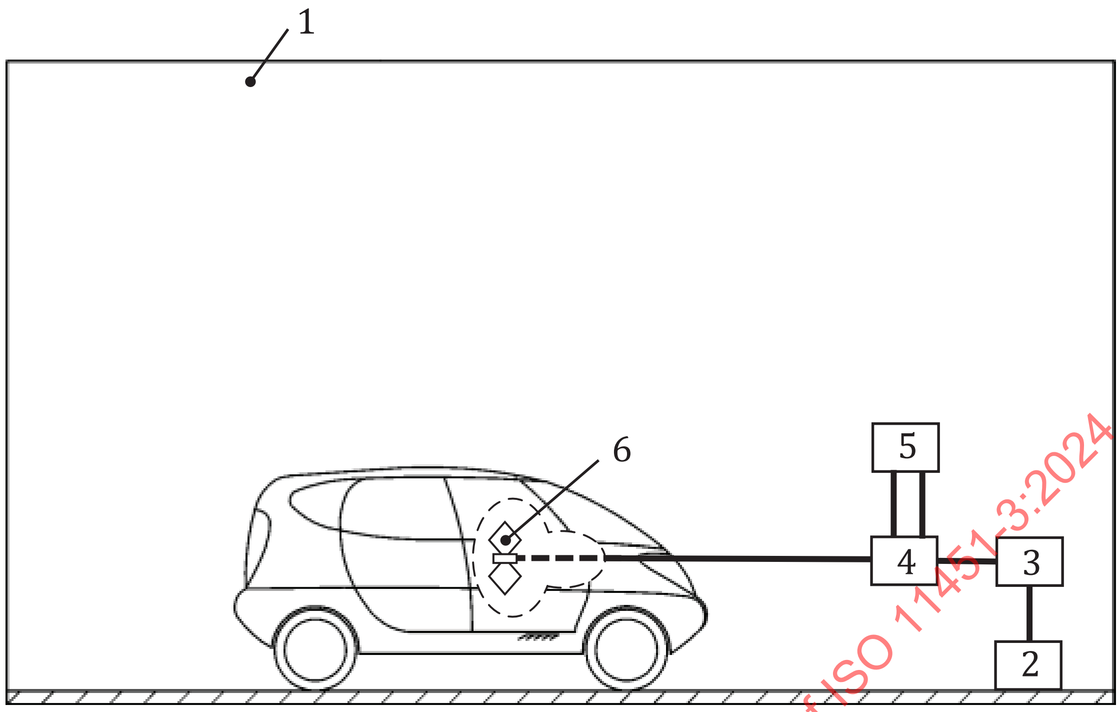
— on the vehicle's centre console,

— storage compartments,

— in any specified places where a portable transmitter can be placed or used.

7.2.2 Simulated portable transmitters

An example of test set-up for simulated portable transmitters is shown in Figure 4.



Key

1 ALSE
2 RF signal generator (can be outside test facility)
3 power amplifier (can be outside test facility)
4 dual directional coupler (can be outside test facility)
5 power meter (can be outside test facility)
6 test antenna (positions defined in test plan)

Figure 4 — Example of test set-up for simulated portable transmitters

8 Test procedure

8.1 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.

The general arrangement of vehicle, transmitter(s) and associated equipment represents a standardized test condition. Any deviations from the standard test configuration shall be agreed upon prior to testing and recorded in the test report.

The vehicle shall be made to operate under typical loading and operating conditions. These operating conditions shall be clearly defined in the test plan.

8.2 Test plan

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

— test set-up;

— frequency range(s) and associated modulation(s);

— duration of transmission;

- antenna location and polarization;
- routing of the coaxial cable to the antenna in the vehicle (for simulated on-board transmitters);
- vehicle mode of operation;
- vehicle monitoring conditions;
- vehicle acceptance criteria;
- simulated portable transmitter antenna location;
- definition of test severity levels;
- definition of signal modulation;
- maximum antenna VSWR value if necessary;
- test report content;
- any special instructions and changes from the standard test.

8.3 Test method

8.3.1 Transmitters with antenna outside the vehicle

8.3.1.1 General

The vehicle, antenna(s) and associated equipment are installed as described in 7.1.

Test severity levels are based on the antenna configuration used. This means that:

- when using an OEM antenna configuration, the reference parameter is the forward power delivered to the attached OEM antenna cable;
- when using test antennas, the reference parameter is the net power delivered directly to the antenna. See Annex A for procedures for net power characterization.

In either configuration, measurement of the reflected power serves only as a means to monitor the stability of the signal source during testing.

8.3.1.2 OEM antenna configuration

Testing is based on test setup shown in Figure 3. The test shall at least be performed with this configuration even if tests are also performed with test antenna(s).

Increase the forward power level until the predetermined forward power level is achieved. For modulated signals, the peak conservation principle shall be applied as defined in ISO 11451-1 or alternatively use of wideband peak power sensors (see 6.3). Perform the test at frequencies within the designed bandwidth of the OEM antenna (at least at the lower and upper band edge and at a middle frequency and at frequency steps not greater than those defined in ISO 11451-1).

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

When required in the test plan, the immunity threshold shall be determined.

8.3.1.3 Test antenna configuration

Testing is based on test setup shown in Figure 2.

Increase the forward power level until the predetermined net power level is achieved. For modulated signals, the peak conservation principle shall be applied as defined in ISO 11451-1 or alternatively use of peak power sensors (see 6.3). Perform the test at frequencies within the designed bandwidth of the test antenna (at least at the lower and upper band edge and at a middle frequency). The use of more than one test antenna can be necessary to cover an entire frequency band.

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

When required in the test plan, the immunity threshold shall be determined.

8.3.2 Transmitters with antenna inside the vehicle

8.3.2.1 Simulated portable transmitters

This method is performed in two phases:

— Phase 1: test level setting;

— Phase 2: test of the vehicle.

8.3.2.2 Test level setting

Testing is based on a specified net power applied to the transmit antenna. The net power level is derived from the forward power measured at the dual directional coupler, which is remotely connected to the transmit antenna via low loss coaxial cable. The measured reflected power serves as a means to monitor the stability of the test setup between characterizations. See Annex A for procedures for net power characterization.

The adjustment of the net power level shall be performed with the simulated portable transmitter antenna placed at a minimum distance of 1 m from any part of the vehicle, from the ground plane and from the test enclosure, and 0,5 m from any absorber, until the predetermined net power level is achieved (see Annex B).

For amplitude modulation (AM) and pulse modulation (PM) signals, the power level adjustment shall conform to the peak conservation principle given in ISO 11451-1 or direct measurement with peak power sensors (see 6.3). Alternative modulations including Broadband test signal may also be considered.

The forward power shall be adjusted within (−0/+0,5) dB from that recorded during the net power characterization (see Annex A).

8.3.2.3 Vehicle test

There are two alternative ways, either of which can be used, to expose the vehicle after the test level setting phase.

a) Approach the simulated portable transmitter at the various positions indicated in the test plan without switching off the power of the simulated portable transmitter.

b) Switch off the power of the simulated portable transmitter and approach the various positions indicated in the test plan, then switch on the power of the simulated portable transmitter.

The test on the vehicle shall be performed at the various positions indicated in the test plan, with either CW or modulated signals indicated in Annex B, or both.

The test on the vehicle shall be performed without any change in the forward power level recorded during net power characterization. See Annex A for net power characterization

Due to the position of the simulated portable transmitter antenna close to the vehicle, variation in transmitter net power can occur. Although changes in net power may occur when the transmitter antenna is close to the vehicle, the forward power shall not be changed.

If manual positioning of the antenna is required while the RF power is switched on, then care shall be taken, according to ICNIRP Guidelines,[2] 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.

Perform the test at frequencies within the designed bandwidth of the test antenna (at least at the lower and upper band edge and at a middle frequency).

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

NOTE Because it is not practical to perform the test at every possible location of a portable transmitter inside the vehicle, the test can be performed as a first step for limited defined locations with power levels higher than the typical one given in Annex B.

8.4 Test report

As required by the test plan, a test report shall be submitted, including a reference to this document (i.e. ISO 11451-3:2024) and detailing information regarding the test equipment, test site, test set-up, systems tested, frequencies, power levels, the antenna used, the portable transmitter used, VSWR values, system interactions, and any other information relevant to the test.

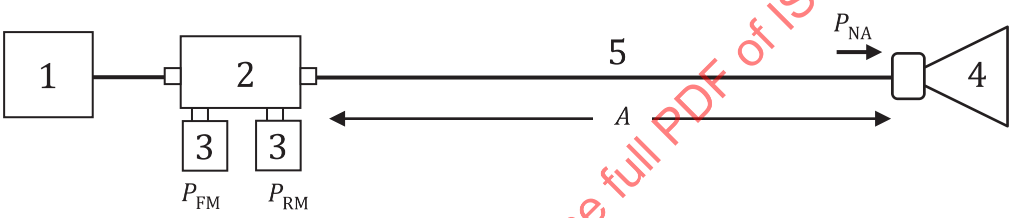
Annex A
(normative)

Net power characterization procedure

A.1 Introduction

The calibration procedure detailed herein facilitates accurate delivery of net power to the transmit antenna used for simulated on-board external transmitters or internal portable transmitters. Reflected power is not required for net power characterization. The 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 transmitter testing. In this setup, there is a single cable connecting the directional coupler directly to the transmit antenna. Also, power sensors (CW or Peak) 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
2 dual directional coupler
3 power sensor
4 transmit antenna
5 low loss coaxial cable with transmission loss A

P_{FM} measured forward power at the directional coupler
P_{RM} measured reverse power at the directional coupler
P_{NA} net power delivered to antenna

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).

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

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

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;

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

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

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

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

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

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

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

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

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

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

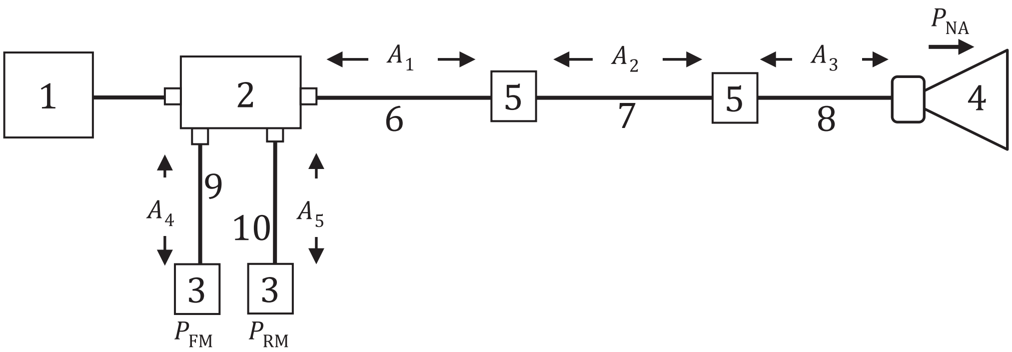
C_{FR} is the reflected coupling factor (< 1):

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

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

As stated above, 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
2 dual directional coupler
3 power sensor
4 transmit antenna
5 coaxial in-line connectors, adaptors, etc.
6 low loss coaxial cable with transmission loss A_1
7 low loss coaxial cable with transmission loss A_2
8 low loss coaxial cable with transmission loss A_3
9 low loss coaxial cable with transmission loss A_4
10 low loss coaxial cable with transmission loss A_5
P_{FM} measured forward power
P_{RM} measured reverse power
P_{NA} net power delivered to antenna

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).

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

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

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 input 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 input 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 output 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 losses 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 ensure 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.

Dimensions in millimetres

Key

1 vector network analyser (VNA)

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 in Formulae (A.5) to (A.7) (example given for reporting of S_{21}).

Linear-complex: $S_{21} = R_\mathrm{e} + jI_\mathrm{m}$ (A.5)

Linear-magnitude: $|S_{21}| = |R_\mathrm{e} + jI_\mathrm{m}| = \sqrt{{R_\mathrm{e}}^2 + {I_\mathrm{m}}^2}$ where $|S_{21}| < 1$ (A.6)

dB: $S_{21\mathrm{lg}} = 20 \cdot \log_{10} |S_{21}|$ (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:

$$T_\mathrm{N} = |S_{21}|^2 = 10^{\frac{S_{21\mathrm{lg}}}{10}} = ({R_\mathrm{e}}^2 + {I_\mathrm{m}}^2) \quad \text{(A.8)}$$

where $T_\mathrm{N} = T_1, T_2, T_3, T_4$.

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

A.3 Directional coupler parameter verification

A.3.1 General

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

A.3.2 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 (Formula A.9) and P2 (Formula A.10) is less than 1,3.

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

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

$$|S_{11}| = 10^{\frac{S_{11\mathrm{lg}}}{20}} \quad \text{(A.11)}$$

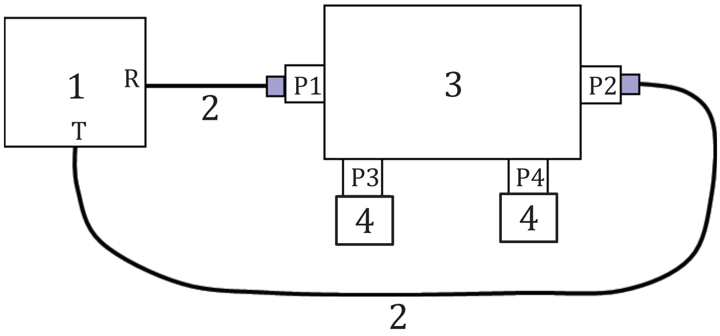
$$|S_{22}| = 10^{\frac{S_{22\mathrm{lg}}}{20}} \quad (|S_{11}| \text{ and } |S_{22}| < 1) \quad \text{(A.12)}$$

3) Measure and record $|S_{21}|$ over the test frequency range. Record the transmission loss A_{DC} (Formula A.13), where:

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

4) Verify $|A_{\mathrm{DClg}}|$ is less than 0,5 dB (Formula A.14), where:

$$A_{\mathrm{DClg}} = 20 \cdot \log_{10} |S_{21}| \quad \text{(A.14)}$$



Key

1 vector network analyser (VNA)
2 low loss 50 Ω coaxial cable
3 dual directional coupler
4 50 Ω termination (VSWR < 1,1)

T transmission port
R reflection port
P1 coupler input
P2 coupler output
P3 forward power measurement port
P4 reflected power measurement port

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

A.3.3 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.

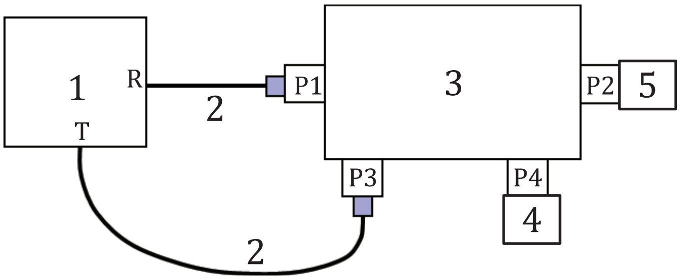
2) Measure and record $|S_{22}|$ at P3 over the test frequency range. Calculate and verify that the VSWR is less than 1,5.

3) Measure and record $|S_{21}|$ over the test frequency range. Record the forward coupling factor, C_{FF} (Formula A.15), where:

$$C_{FF} = |S_{21}|^2 \quad \text{(A.15)}$$

4) Verify $|C_{FFlg}|$ is greater than 20 dB (Formula A.16), where:

$$C_{FFlg} = 20 \cdot \log_{10} |S_{21}| \quad \text{(A.16)}$$



Key

1 vector network analyser (VNA)
2 low loss 50 Ω coaxial cable
3 dual directional coupler
4 50 Ω termination (VSWR < 1,1)
5 reference 50 Ω termination standard used for TOSM calibration (see Clause A.2)
T transmission port
R reflection port
P1 coupler input
P2 coupler output
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.3.4 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.

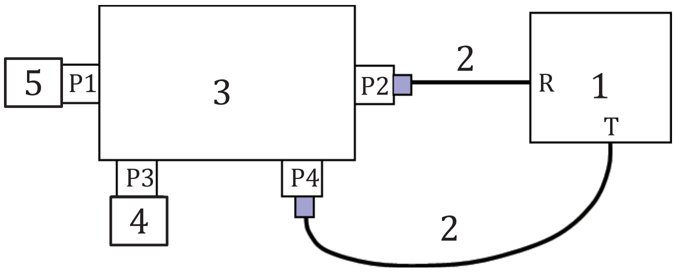
2) Measure and record S_{22} at P4 over the test frequency range. Calculate and verify that the VSWR is less than 1,5.

3) Measure and record $|S_{21}|$ over the test frequency range. Record the forward coupling factor, C_{FR} (Formula A.17), where:

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

4) Verify $|C_{FRlg}|$ is greater than 20 dB (Formula A.18), where:

$$C_{FRlg} = 20 \cdot \log_{10} |S_{21}| \tag{A.18}$$



Key

1 vector network analyser (VNA)
2 low loss 50 Ω coaxial cable
3 dual directional coupler
4 50 Ω termination (VSWR < 1,1)
5 reference 50 Ω termination standard used for TOSM calibration (see Clause A.2)

T transmission port
R reflection port
P1 coupler input
P2 coupler output
P3 forward power measurement port
P4 reflected power measurement port

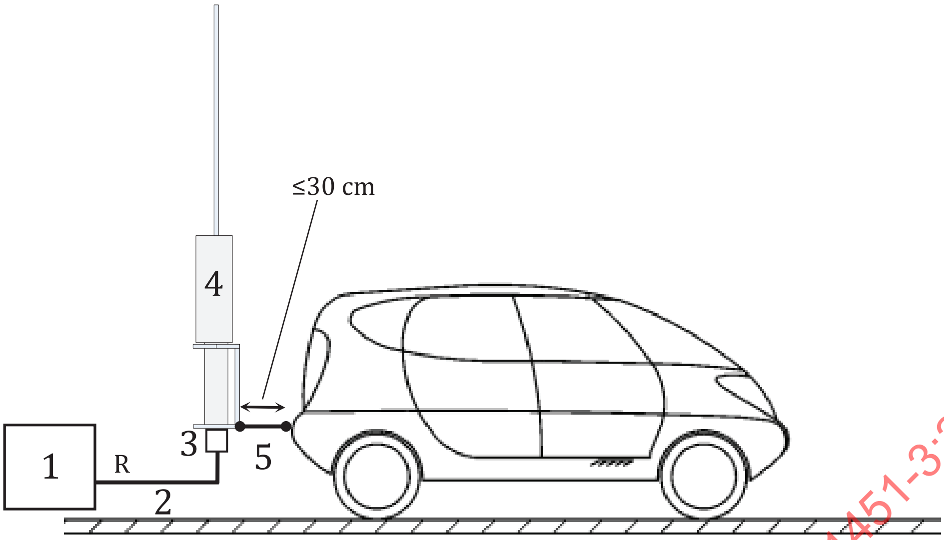
Figure A.6 — Setup for reflected coupling factor (C_{FR}) and P4 VSWR verification

A.4 Transmit antenna reflection coefficient measurement

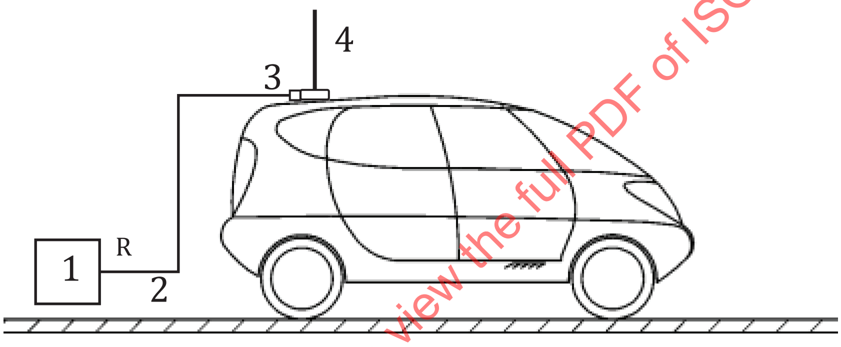
A.4.1 External transmitter antennas

Install the external antenna on the vehicle in any of the recommended positions illustrated in Figure 1. Connect the VNA to base input to the antenna using the cables that were part of the VNA characterization. This is illustrated in Figure A.7. Figure A.7 a) illustrates an example for position 9 where the transmit antenna is mounted to the bumper to facilitate testing ≤ 30 MHz. Conversely Figure A.7 b) illustrates an example for position 2 where the transmit antenna is mounted to the vehicle roof to facilitate testing > 30 MHz. The VNA, which was calibrated according to Clause A.2, is connected to the base of the transmit antenna. In both cases the antenna is tuned to achieve VSWR typically less than 3:1 unless otherwise specified in the test plan. VSWR value shall be recorded with the antenna at the lower and upper band edge and at a middle frequency.

When using transmit antennas for testing ≤ 30 MHz, grounding the base of the antenna to the vehicle body is critical toward achieving the lowest possible VSWR. As an example, a ground strap no longer than ≤ 30 cm in length with a width ≥ 20 cm in width can be used.



a) Transmitter antenna configuration for testing ≤ 30 MHz



b) Transmitter antenna configuration for testing > 30 MHz

Key

1 vector network analyser (VNA)

2 same low loss 50 Ω coaxial cable (≤ 3 000 mm in length) as shown in Figure A.3

3 measurement reference plane per TOSM calibration (see Figure A.3)

4 transmit antenna

5 vehicle ground connection for antenna (≤ 30 MHz) (length ≤ 30 cm, width ≥ 20 cm)

R VNA that facilitates measurement of S_{11}

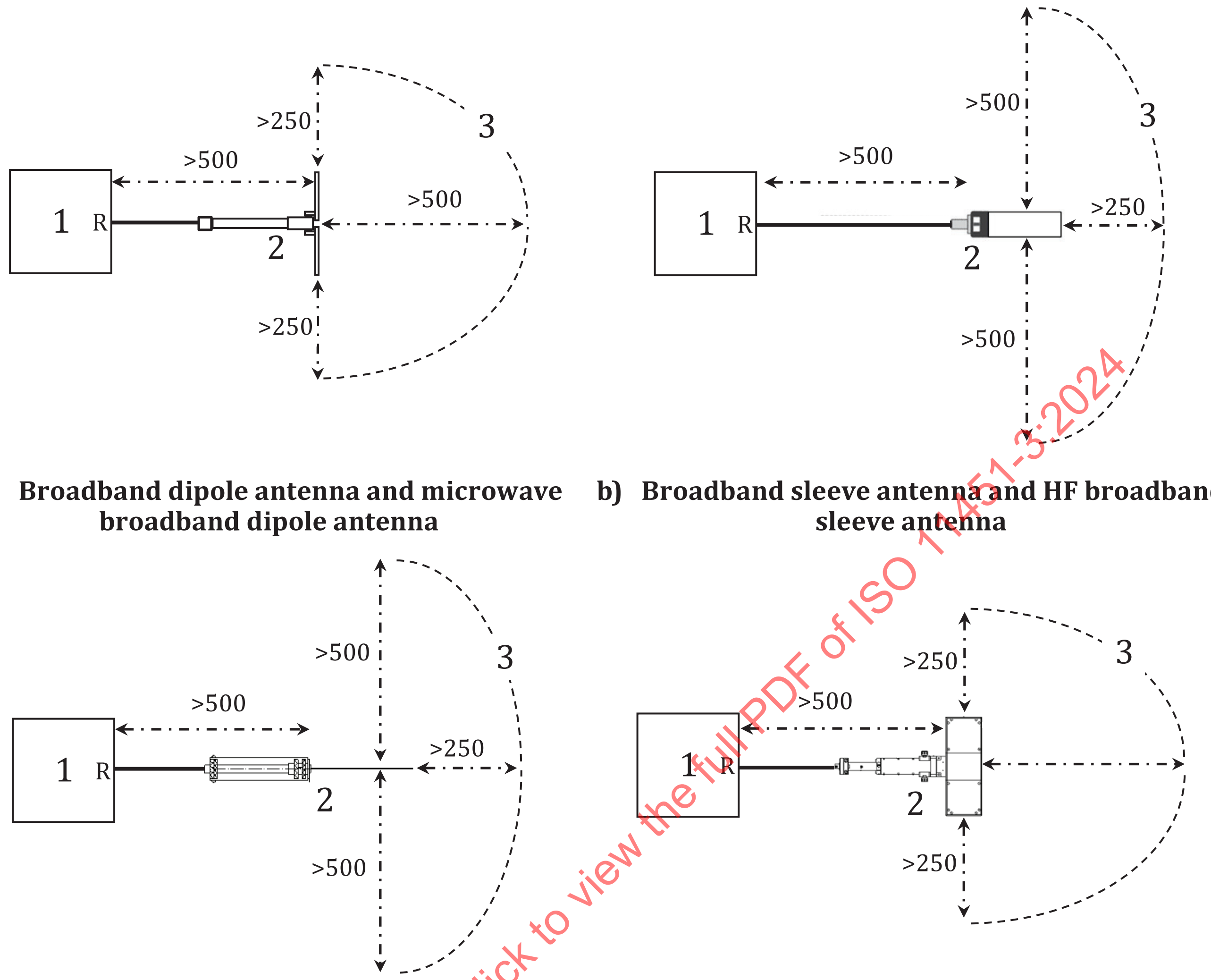
Figure A.7 — Example of VNA connection to external transmitter antenna

A.4.2 Internal portable transmitter antennas

Connect the VNA to any of the transmit antennas as shown in Figure A.8 (see 6.5.2 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.8. Measure and record the reflection coefficient “ρ” (i.e. magnitude of S_{11}) of antenna over at all test frequencies (Formula A.19).

$$\rho = |S_{11}| = 10^{\frac{S_{11\text{lg}}}{20}} \qquad \text{(A.19)}$$

Dimensions in millimetres



a) **Broadband dipole antenna and microwave broadband dipole antenna**

b) **Broadband sleeve antenna and HF broadband sleeve antenna**

c) **Sleeve antenna**

d) **Folded dipole antenna**

Key

1 vector network analyser (VNA)

2 low loss 50 Ω coaxial cable

3 boundary for location of any conductive surface

R reflection port

Figure A.8 — 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.9. 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.

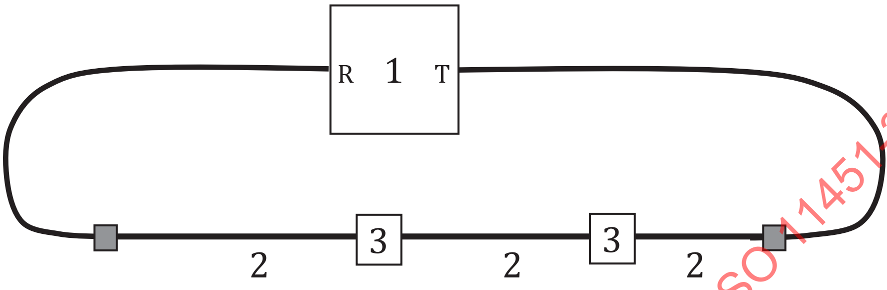
3) Measure and record $|S_{21}|$ over the test frequency range. Record the transmission loss T_1 (Formula A.20), where:

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

4) Verify that $|T_{1lg}|$ is less than 4 dB (Formula A.21), where:

$$T_{1lg} = 20 \cdot \log_{10} |S_{21}| \qquad (A.21)$$

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 (VNA)

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.9 — 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.

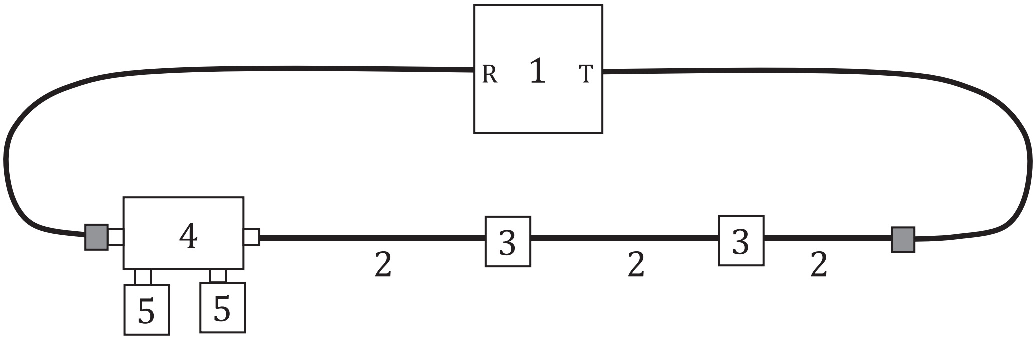
1) Attach the directional coupler to the interconnect cable assembly. Connect the VNA as illustrated in Figure A.10. The other ports of the coupler shall be terminated with a 50 Ω load with a VSWR less than 1,3.

2) Measure and record $|S_{21}|$ over the test frequency range. Record the transmission loss T_2 (Formula A.22), where:

$$T_2 = |S_{21}|^2 \qquad (A.22)$$

3) Verify that $|T_{2lg}|$ is less than 4 dB (Formula A.23), where:

$$T_{2lg} = 20 \cdot \log_{10} |S_{21}| \qquad (A.23)$$



Key

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

See Figure A.2 for component references.

Figure A.10 — 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 on 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.11 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.11 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.11 a), measure and record $|S_{21}|$ over the test frequency range. Record the transmission loss T_3 (Formula A.24), where:

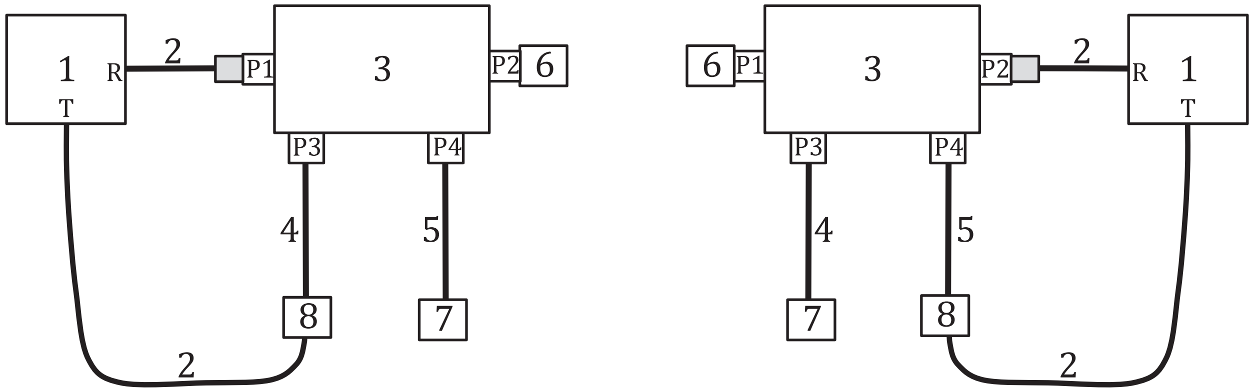
$$T_3 = |S_{21}|^2 \quad \text{(A.24)}$$

4) Connect the VNA to the directional coupler output and the reflected power measurement point as illustrated in Figure A.11 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.11 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.11b, measure and record $|S_{21}|$ over the test frequency range. Record the transmission loss T_4 (Formula A.25), where:

$$T_4 = |S_{21}|^2 \quad \text{(A.25)}$$



a) **Measurement of T_3**

b) **Measurement of T_4**

Key

1 vector network analyser (VNA)

2 low loss 50 Ω coaxial cable

3 dual directional coupler

4 50 Ω coaxial cable assembly (connects to forward power sensor)

5 50 Ω coaxial cable assembly (connects to reflected power sensor)

6 reference 50 Ω termination standard used for TOSM calibration (see Clause A.2)

7 50 Ω termination (VSWR < 1,1)

8 measurement point (S_{22}, S_{21})

P1 coupler input

P2 coupler output

P3 forward power measurement port

P4 reflected power measurement port

R reflection port

T transmission port

Figure A.11 — Measurement of T_3 and T_4

Annex B
(informative)

Typical characteristics and use of 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 transmitters with antenna outside vehicle and 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 can be different from one region to another, use of power levels greater than those indicated can be expected.

Table B.1 — Typical characteristics for transmitters with antenna outside vehicle and for portable transmitters

Transmitter designation	Frequency band[a] MHz	Power for antenna outside vehicle W	Power for portable transmitters W	Typical transmitter modulation	Test modulation (see ISO 11451-1)
short wave	1,8 to 30	100 (RMS)	Not applicable	Telegraphy, AM, SSB, FM	AM 1 kHz, 80 %
CB	26 to 28	Not applicable	4 (RMS)	Telegraphy, AM, SSB FM	AM 1 kHz, 80 %
8 m	30 to 50	120 (RMS)	Not applicable	FM	CW
6 m	50 to 54	120 (RMS)	Not applicable	Telegraphy, AM, SSB, FM	AM 1 kHz, 80 %
4 m	68 to 87,5	120 (RMS)	Not applicable	FM	CW
2 m	144 to 148	120 (RMS)	10 (RMS)	Telegraphy, AM, SSB, FM	CW
LAND MOBILE	146 to 174 216 to 223	Not applicable	10 (Peak)	FM, FSK	CW
1,25 m	220 to 225	Not applicable	10 (RMS)	Telegraphy, AM, SSB FM	CW
70 cm	420 to 450	120 (RMS)	10 (RMS)	Telegraphy, AM, SSB, FM	CW
TETRA/ TETRAPOL	380 to 390 410 to 420 450 to 460 806 to 825 870 to 876	20 (Peak)	10 (Peak)	TDMA/ FDMA, Tetra: π/4 DQPSK	PM3 1 kHz 50 % duty cycle
CDMA 800 (cellular)	815 to 849	Not applicable	0,25 (Peak)	QPSK	PM3 1 kHz 50 % duty cycle
GSM 850	824 to 849	20 (Peak)	2 (Peak)	GMSK, PSK, DS	PM3 1 kHz 50 % duty cycle
GSM 900	876 to 915	20 (Peak) or 8 (Peak)	2 (Peak)	GMSK	PM3 1 kHz 50 % duty cycle
23 cm	1 200 to 1 300	25 (RMS.)	Not applicable	Telegraphy, AM, SSB, FM	CW

[a] The addition of the 5G frequency band (5 925 to 7 125) MHz is currently under study due to lack of antenna for covering this frequency range.

Table B.1 *(continued)*

Transmitter designation	Frequency band[a] MHz	Power for antenna outside vehicle W	Power for portable transmitters W	Typical transmitter modulation	Test modulation (see ISO 11451-1)
PCS, GSM 1800/1900	1 710 to 1 785 1 850 to 1 910	2 (Peak) or 1 (Peak)	1 (Peak)	GMSK	PM3 1 kHz 50 % duty cycle
CDMA 1900 (PCS)	1 850 to 1 910	0,25 (Peak)	0,25 (Peak)	QPSK	PM3 1 kHz 50 % duty cycle
UMTS (mobile phone WCDMA and TD/CDMA)	824 to 849 880 to 915 1 850 to 2 025	0,25 (Peak)	0,25 (Peak)	HPSK QAM	PM3 1 kHz 50 % duty cycle
Bluetooth, WLAN (data) WIFI	2 400 to 2 500	0,10 (Peak)	0,10 (Peak)	QPSK	PM3 1 kHz 50 % duty cycle Or broadband noise
LTE (mobile phone OFDMA and SC-FDMA)	450 to 458 / 663 to 915 / 1 427 to 1 517 / 1 626 to 1 785 / 1 850 to 2 025 / 2 300 to 2 400 / 2 483 to 2 690 / 3 300 to 3 800	0,25 (Peak)	0,25 (Peak)	OFDM - PSK	PM3 1 kHz 50 % duty cycle Or broadband noise
IEEE 802.11a/h/j/n/ac/ax (5G WIFI)	5 150 to 5 350 5 725 to 5 850	0,5 (Peak)	0,5 (Peak)	OFDM - PSK	PM3 1 kHz 50 % duty cycle Or broadband noise
5G NR1 (mobile phone CP-OFDM and DFTS-OFDM)	3 300 to 4 200 4 400 to 5 000	0,25 (Peak)	0,25 (Peak)	OFDM - QPSK	PM3 1 kHz 50 % duty cycle Or broadband noise

[a] The addition of the 5G frequency band (5 925 to 7 125) MHz is currently under study due to lack of antenna for covering this frequency range.

Table B.2 — Abbreviated terms

Modulation/ Access system	Description	Example for use
AM	Amplitude modulation	Broadcast
BT	Bluetooth	-
CB	Citizens band	-
CDMA	Code division multiple access	-
DQPSK	Differential quadrature phase shift keying	Iridium satellite telephone
FDMA	Frequency division multiplex access	-
FM	Frequency modulation	Broadcast
FSK	Frequency shift keying	-
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
LTE	Long term evolution	-
OFDM	Orthogonal frequency division multiplexing	LTE
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	-
2 m/1,25 m/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 MHz to 2 700 MHz

— Radiating element dimensions: 240 mm × 109 mm

— Maximum power input: 20 W

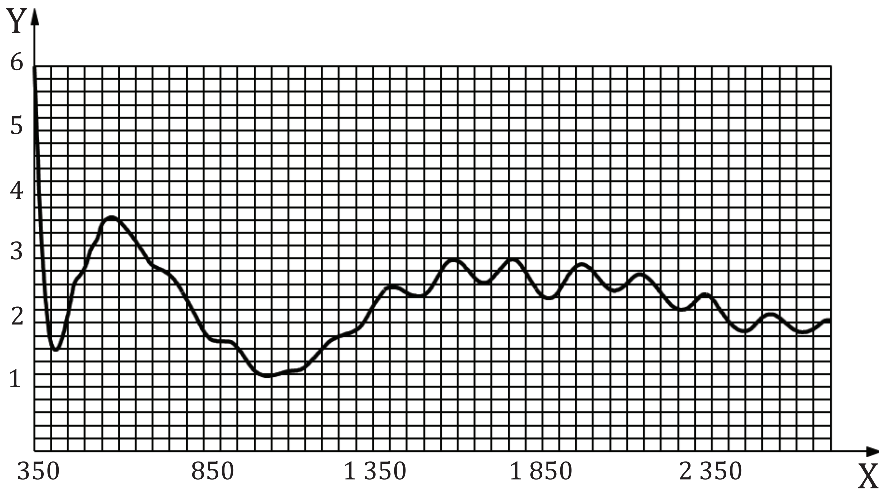
— Connector: type-N female

— 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 × 100 mm test zones where field uniformity is better than ±3 dB. In the frequency range (360 to 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.



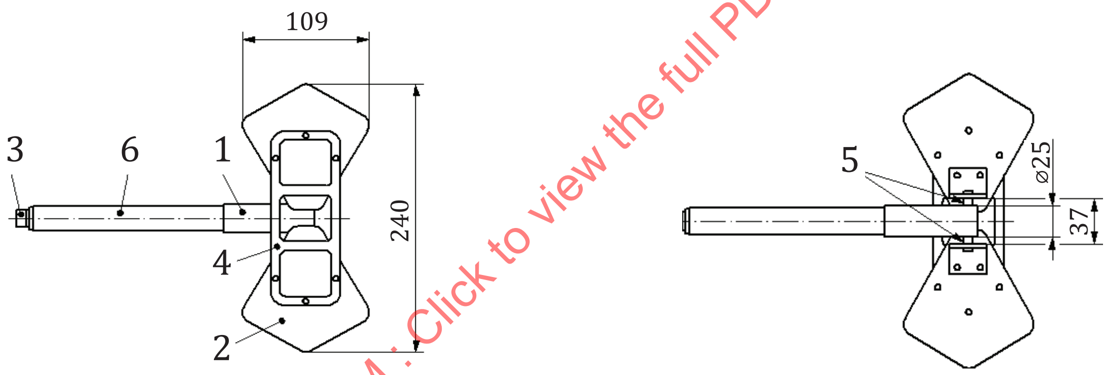
Key

X frequency (MHz)

Y VSWR

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

Dimensions in millimetres



Key

1 broadband low loss balun 1:1

2 flat antenna elements

3 N-female connector

4 element fixture and spacing frame (5 mm, non-metallic)

5 symmetrical terminals, M4

6 22 mm tube for handling or fixture

Figure C.2 — Construction details of broadband dipole antenna

Dimensions X and Y in millimetres

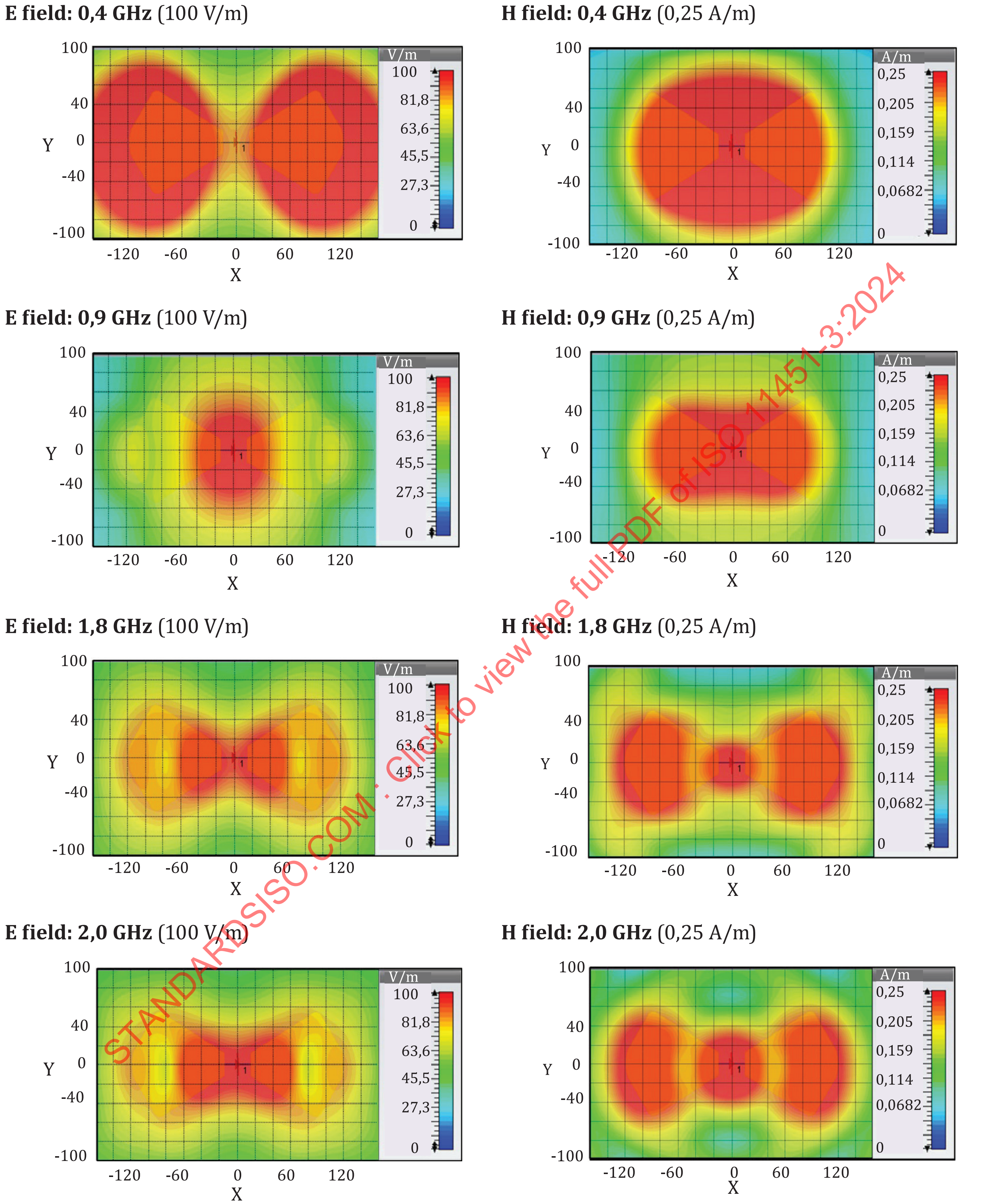


Figure C.3 — E and H field patterns for the broadband dipole antenna (0,4 to 2,0) GHz

C.3 Broadband sleeve antenna

— Input impedance: 50 Ω

— Frequency range: 700 MHz to 3 200 MHz

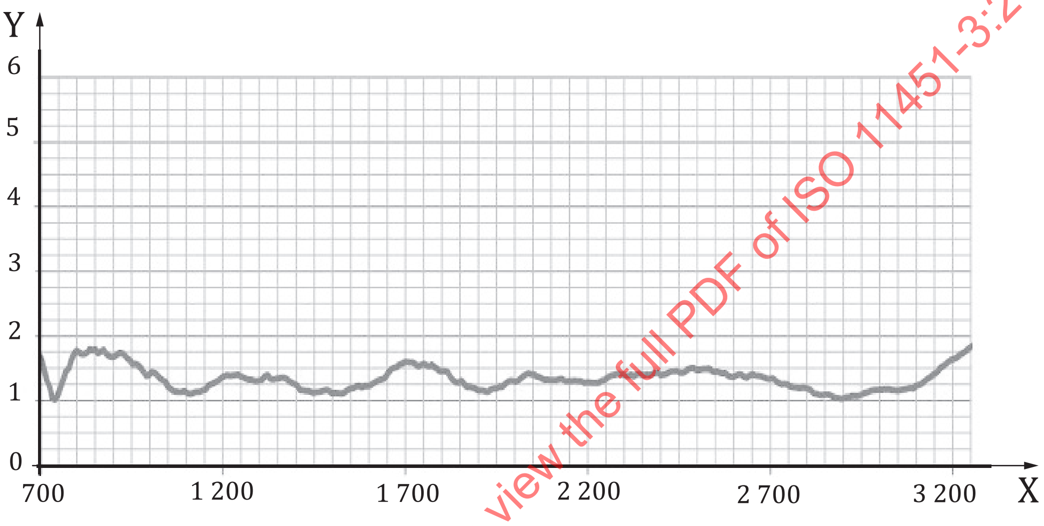
— Radiating element dimensions: 186 mm × 50 mm

— Maximum power input: 20 W (700 MHz to 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.



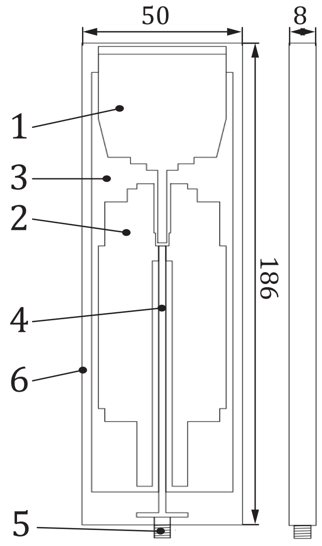
Key

X frequency (MHz)

Y VSWR

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

Dimensions in millimetres



Key

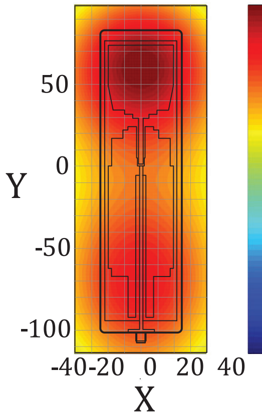
1 radiation element
2 ground element
3 PCB
4 semi-rigid cable
5 SMA-female connector
6 dielectric case

Figure C.5 — Construction details of broadband sleeve antenna

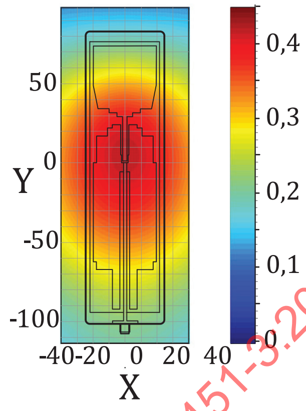
The broadband sleeve antenna has a test zone along the radiation element, where electric fields are effectively generated. Figures C.6 and C.7 show distribution and peak amplitude of electric field strengths (V/m) and magnetic field strengths (A/m) for a 1 W net power input at a 50 mm distance from antenna elements.

Dimensions X and Y in millimetres

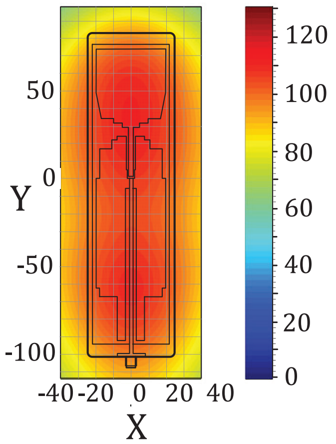
E field: 0,7 GHz (133 V/m)



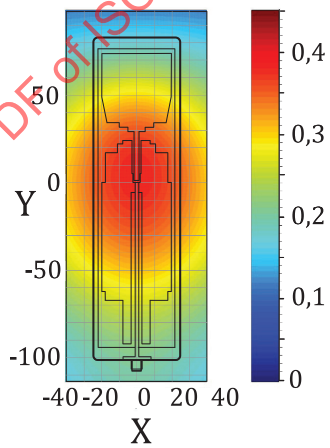
H field: 0,7 GHz (0,43 A/m)



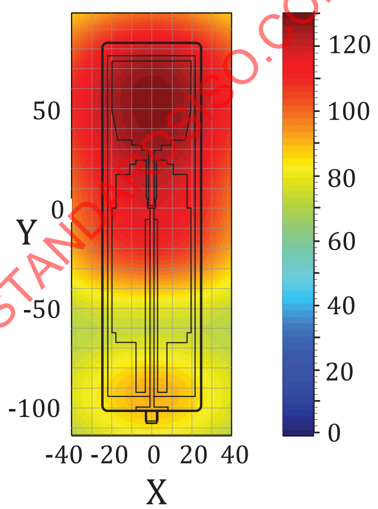
E field: 0,9 GHz (113 V/m)



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)

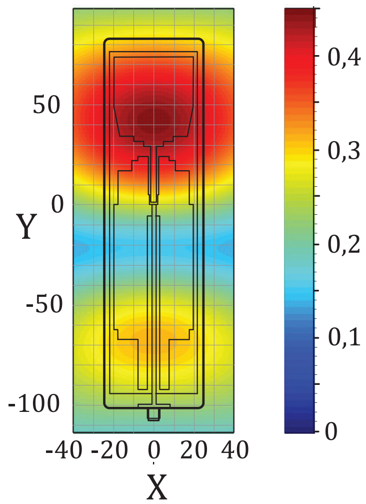


Figure C.6 — E and H field patterns for the broadband sleeve antenna (0,7 to 1,8) GHz

Dimensions X and Y in millimetres

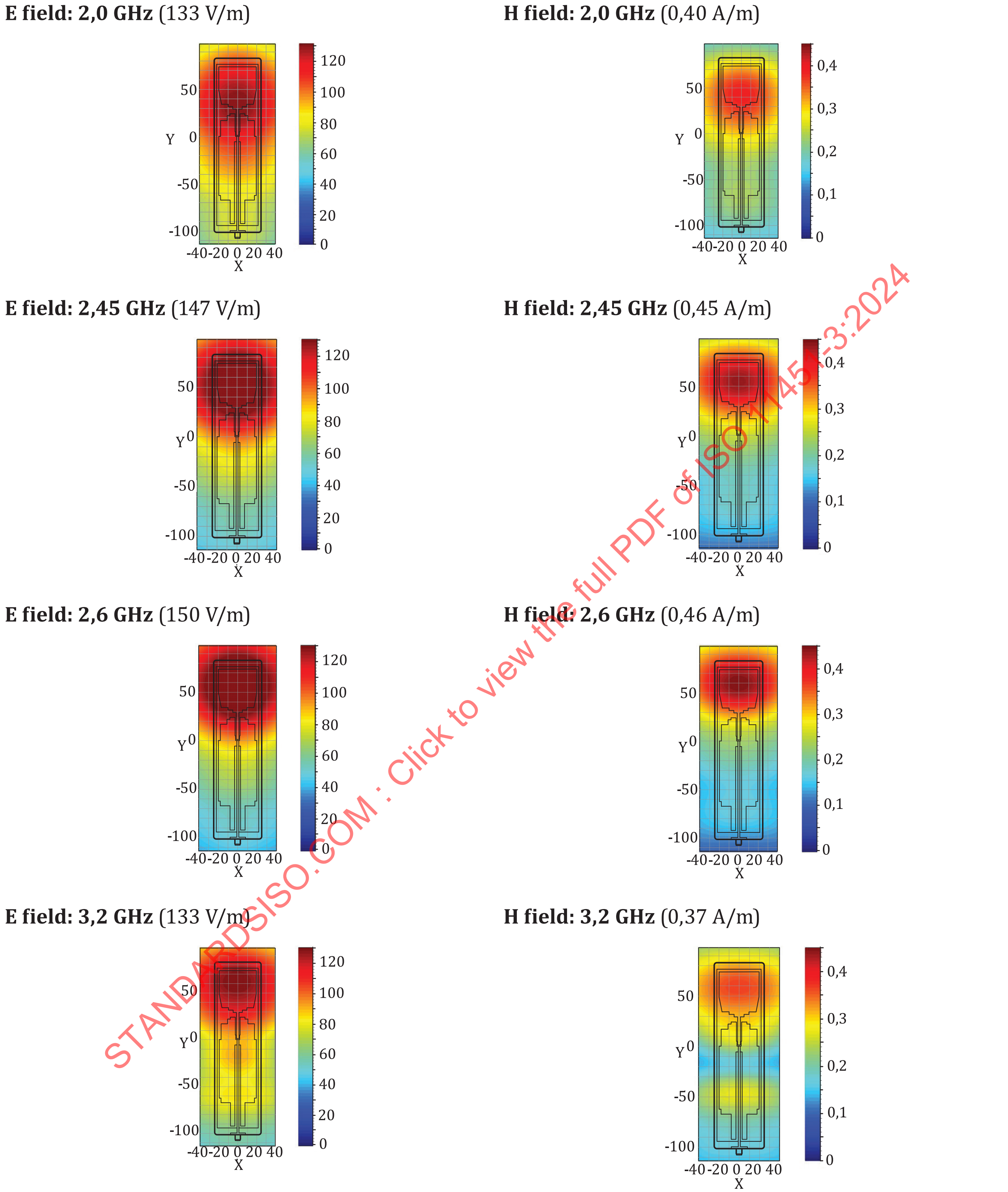


Figure C.7 — E and H field patterns for the broadband sleeve antenna (2,0 to 3,2) GHz

C.4 Sleeve antenna

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

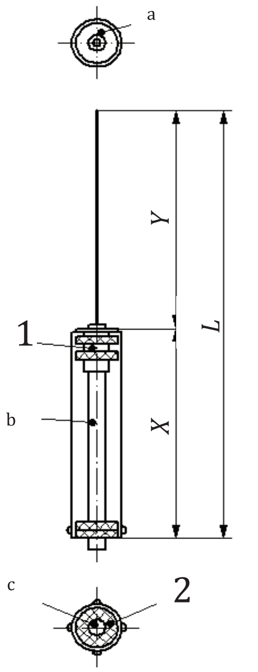
An explanation of the antenna and sleeve length for each frequency band is given in Table C.1. These characteristics are for information only. An example of geometrical characteristics of a sleeve antenna for simulated portable transmitters is shown in Figure C.8.

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

Frequency band MHz	Centre frequency MHz	*X* Antenna element length[a] Tolerance: *X* ± 5 % mm	*Y* Sleeve length Tolerance: *Y* ± 5 % mm
380 to 390	385	198 ± 9	162 ± 8
410 to 420	415	189 ± 9	155 ± 8
420 to 450	435	180 ± 9	147 ± 7
450 to 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 $\lambda/4$ 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 wavelength 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 $\lambda/4$ 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 X and Y in millimetres

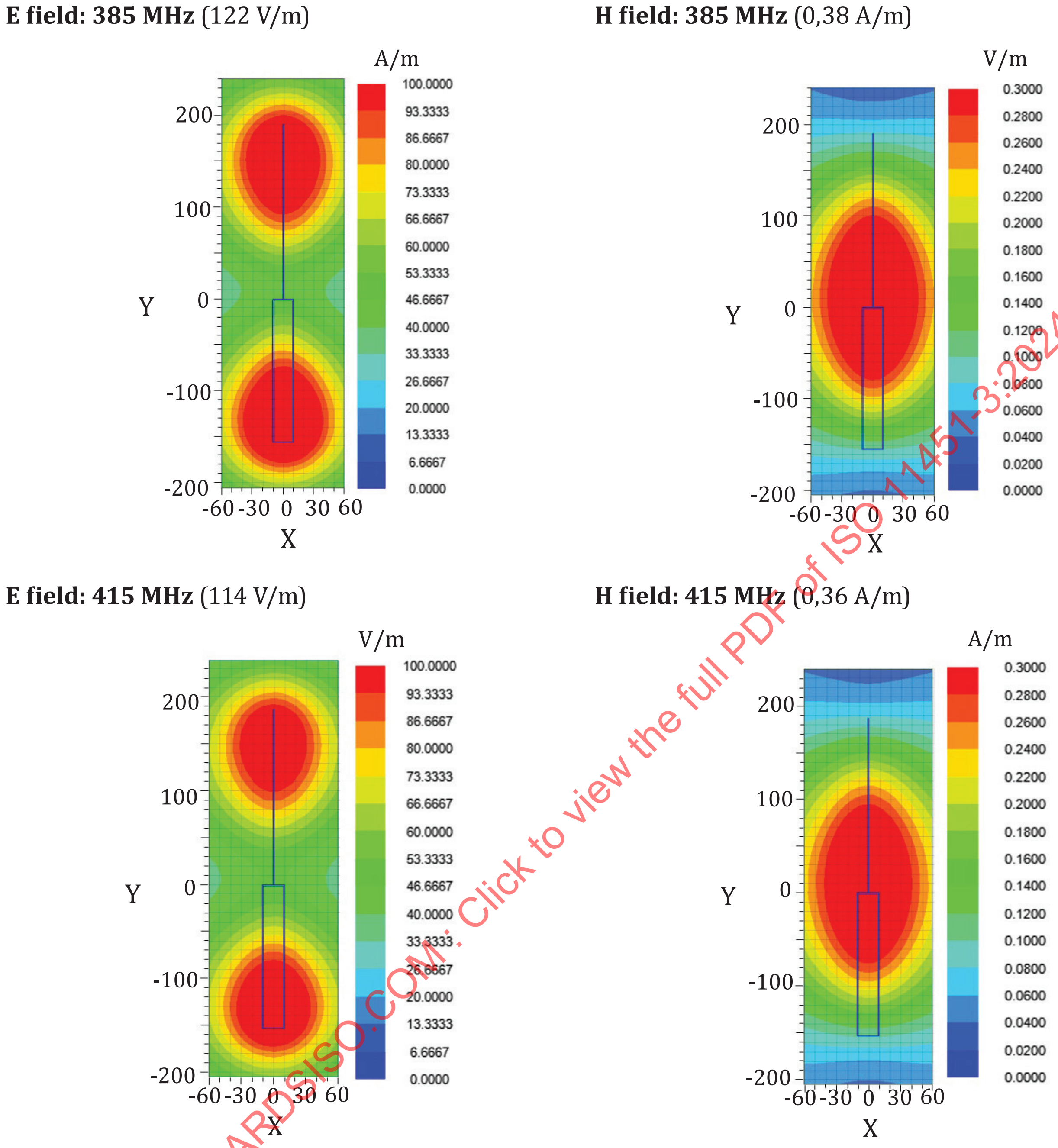


Figure C.9 — E and H field patterns for the sleeve antenna (385, 415) MHz

Dimensions X and Y in millimetres

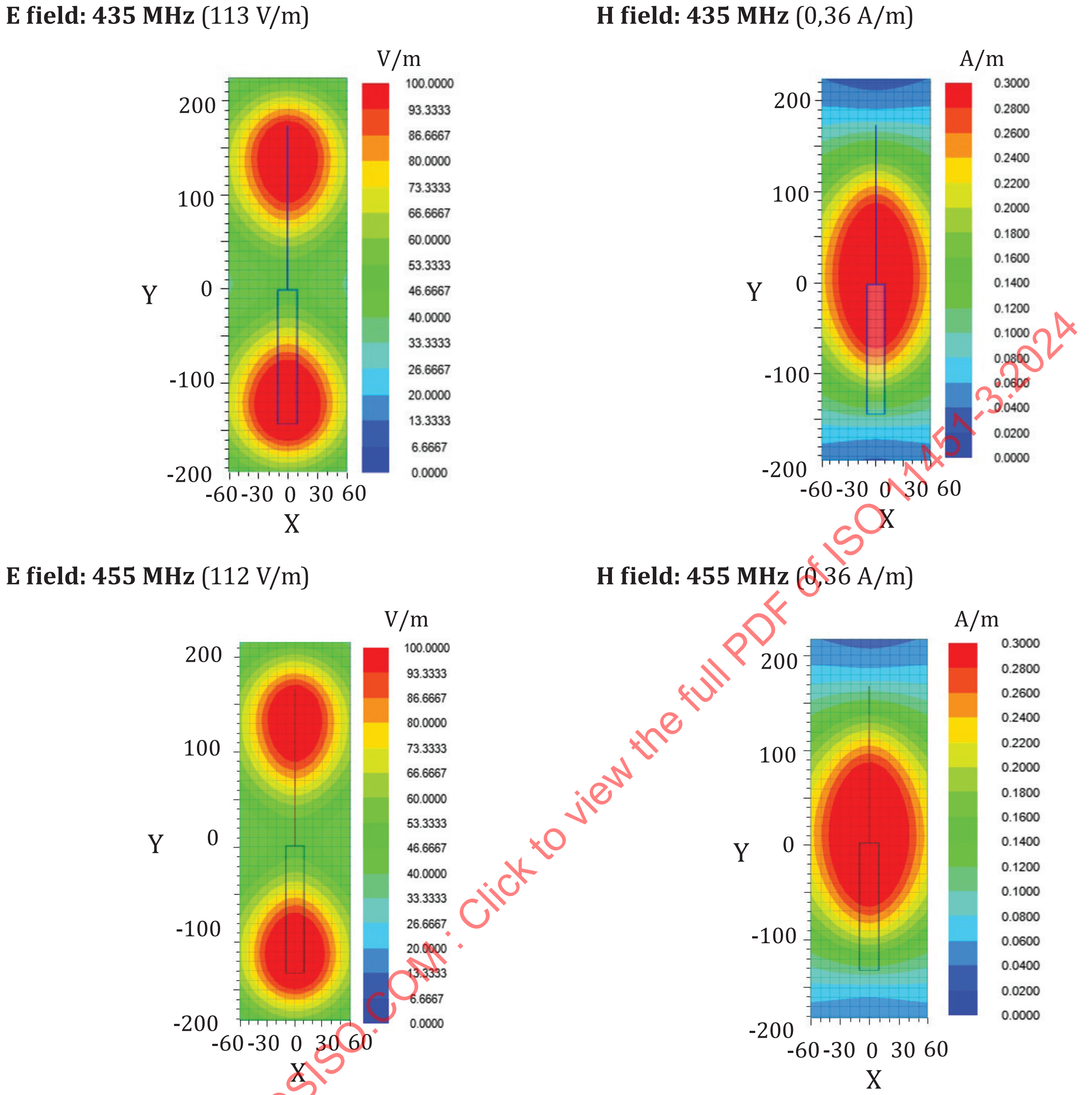


Figure C.10 — E and H field patterns for the sleeve antenna (435, 455) MHz

C.5 Folded dipole antenna

— Input impedance: 50 Ω

— Balun transformation ratio: 1:1

— Frequency range: 142 MHz to 246 MHz

— Radiating element dimensions: 89 mm × 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 and 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.