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BSI Standards Publication

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

Part 11: Reverberation chamber

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National foreword

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

Part 11: Reverberation chamber

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

Partie 11: Chambre réverbérante

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Foreword

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

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 11452-11 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 3, *Electrical and electronic equipment*.

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

— *Part 1: General principles and terminology*

— *Part 2: Absorber-lined shielded enclosure*

— *Part 3: Transverse electromagnetic mode (TEM) cell*

— *Part 4: Harness excitation methods*

— *Part 5: Stripline*

— *Part 7: Direct radio frequency (RF) power injection*

— *Part 8: Immunity to magnetic fields*

— *Part 9: Portable transmitters*

— *Part 10: Immunity to conducted disturbances in the extended audio frequency range*

— *Part 11: Reverberation chamber*

Introduction

Immunity measurements of complete road vehicles can generally only be carried out by the vehicle manufacturer, owing to, for example, high costs of absorber-lined shielded enclosures, the desire to preserve the secrecy of prototypes or a large number of different vehicle models.

For research, development and quality control, a laboratory measuring method can be used by both vehicle manufacturers and equipment suppliers to test electronic components.

This test method is based on parts of IEC 61000-4-21 and RTCA/DO-160E.

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

Part 11: **Reverberation chamber**

1 Scope

This part of ISO 11452 specifies a reverberation chamber method for testing the immunity (off-vehicle radiation source) of electronic components for passenger cars and commercial vehicles, regardless of the propulsion system (i.e. 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 inside the reverberation chamber, with peripheral devices either inside or outside the chamber. It is applicable to disturbances from continuous narrowband electromagnetic fields.

The test is performed using the tuned mode method.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 11452-1, *Road vehicles — Component test methods for electrical disturbances from narrowband radiated electromagnetic energy — Part 1: General principles and terminology*

3 Terms and definitions

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

3.1
antenna characterization factor
ACF
ratio of the average received power to forward power obtained in the antenna characterization

NOTE See Clause B.5.

3.2
chamber characterization factor
CCF
normalized average received power over one tuner rotation with the DUT and supporting equipment present

NOTE See Clause C.3.

3.3
chamber loading factor
CLF
ratio of the antenna characterization factor to the chamber characterization factor

NOTE 1 See Clause C.4.

NOTE 2 It is a measure for the additional loading of the chamber due to the test setup including, for example, the DUT and the support equipment.

3.4
lowest usable frequency
LUF
lowest frequency for which the field uniformity requirements are met

NOTE The LUF is determined during the characterization of the chamber in accordance with Annex B.

3.5
maximum chamber loading factor
MLF
maximum chamber loading factor for which the field uniformity has been demonstrated using the procedure defined in Clause B.7

3.6
reverberation chamber
high Q shielded room (cavity) whose boundary conditions are changed via one or several stepped rotating tuners

NOTE This results in a statistically uniform electromagnetic field.

3.7
support equipment
equipment associated with performing an EMC test on a DUT including (but not all inclusive) load simulator, wiring harnesses, power supply (or batteries), DUT monitoring equipment including fibre optic interface modules and TV camera

3.8
test bench
polystyrene block(s) with a minimum height above the ground floor of $\lambda/4$ at the lowest frequency

NOTE Typically a 1 m high support is used.

3.9
tuner
large metallic reflector capable of changing the electromagnetic boundary conditions in a reverberation chamber as it rotates or moves

NOTE As the tuner moves, the nulls and maximums in the field change location, ensuring the device under test (DUT) is exposed to a statistically uniform field.

3.10
working volume
volume within the reverberation chamber that contains the test bench, the DUT, the harness, the support equipment that is located on the test bench, and the receiving antenna

4 Test conditions

The applicable frequency range of the test method is from LUF (see Clause B.6) to 18 GHz.

The user of this part of ISO 11452 shall specify the test severity level or levels over the frequency bands. Typical test levels are suggested in Annex A.

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

— test temperature;

— supply voltage;

— modulation;

— dwell time;

— test signal quality.

5 Test location

5.1 General

The test shall be performed in a reverberation chamber.

5.2 Reverberation chamber

The chamber shall be large enough to test the DUT including the test bench, the support equipment, and the receiving antenna within the chamber's working volume.

NOTE 1 The chamber size will influence the lowest useable frequency (LUF).

This working volume typically has a cuboid shape, but this is not a requirement.

The reverberation chamber shall contain at least one mechanical tuner to stir the electromagnetic fields inside the chamber. The mechanical tuner(s) should be as large as possible with respect to overall chamber size and working volume considerations. In addition each tuner should be shaped such that a non-repetitive field pattern is obtained over one revolution of the tuner.

NOTE 2 The number, size and shape of the tuners will influence the lowest useable frequency (LUF).

After initial construction, the reverberation chamber shall be characterized in accordance with Annex B, and fulfil the field uniformity requirements of Table B.2. The LUF of the reverberation chamber is determined during this initial characterization. Following any major modifications, a new chamber characterization shall be carried out again. Changes to the tuners shall be considered a major modification.

6 Test apparatus and instrumentation

6.1 Isotropic E-field probe

The field probe shall be capable of measuring electric field strength in three orthogonal axes.

6.2 RF signal generator

The RF signal generator shall be capable of covering the specified frequency bands and modulations.

6.3 Transmitting and receiving antennas

Linearly polarized antennas capable of satisfying the frequency requirements shall be used for transmitting and receiving, respectively. The antenna efficiency should be at least 75 % (log periodic and horn antennas typically fulfil this requirement). The use of multiple antennas to cover the complete frequency range of the reverberation chamber is allowed.

6.4 Power amplifiers

The power amplifiers are used to amplify the RF signal and provide the necessary power to the transmitting antenna to produce the specified field strengths.

6.5 Spectrum analyser

The spectrum analyser shall be capable of covering the specified frequency bands. The spectrum analyser is used in conjunction with the receiving antenna during the chamber characterization with and without the DUT.

6.6 Directional coupler

The directional coupler shall be capable of covering the specified frequency bands. It shall be capable of handling the RF output of the power amplifier without damage. The directional coupler is used in conjunction with the power meter to measure the forward power delivered to the transmitting antenna.

6.7 Power meter

The power meter shall be capable of covering the specified frequency bands. The power meter is used in conjunction with the directional coupler to measure the forward power delivered to the transmitting antenna.

6.8 Computer control

Specialized software used in conjunction with a computer and the RF test equipment should be utilized to characterize the chamber performance in accordance with Annex B, prior to any DUT testing. The software should store the characterization information for use during testing. The computer and software will then be used to control the RF test equipment and tuner during DUT testing. The software shall be capable of performing the tests as described in Clause 8.

6.9 Stimulation and monitoring of the DUT

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

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

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

7 Test set-up

7.1 General

A general layout of the reverberation chamber is shown in Figure 1.

At the LUF, the working volume shall be at least $\lambda/4$ from any chamber surface, field generating antenna or tuner assembly. The DUT and wiring harness shall be located within the chamber working volume.

The volume of the DUT, test bench and support equipment should not occupy more than 8 % of the total chamber volume.

All unnecessary RF absorbing material shall be removed from the room (e.g. wooden tables, carpeting, extra equipment, etc.).

The equipment placed in the chamber (DUT, wiring harness, support equipment, ground plane) may load the chamber beyond that of the maximum loading verification. Prior to collecting data a check shall be performed to determine if the DUT, or its support equipment, or both the DUT and its support equipment, have adversely loaded the chamber. This check shall be performed as outlined in Annex C.

7.2 Ground plane and DUT grounding

If the DUT outer case is not grounded to the vehicle metal structure, the DUT and harness shall be placed either

— directly on the test bench (without ground plane), or

— insulated from a ground plane placed on the test bench.

If the outer case of the DUT is intended to be grounded to the vehicle metal structure, the DUT case should be grounded to a ground plane during testing (either to the ground floor or through a ground plane placed on the test bench). Grounding of the DUT case shall simulate the actual vehicle configuration.

The test bench ground plane (if used) shall be constructed from either copper, brass or galvanized steel. The minimum size of the ground plane depends upon the size of the system under test and shall allow for complete harness and system component placement. The ground plane (excluding the grounding connection) shall be placed within the chamber working volume and at least $\lambda/4$ from any wall and tuner at the lowest frequency of use. The ground plane shall be bonded to the chamber with bonding straps such that the d.c. resistance shall not exceed 2,5 mΩ. In addition, the bond straps shall be placed at a distance no greater than 0,3 m apart edge to edge.

NOTE Using the ground floor as ground plane is an alternative method that is currently being studied.

7.3 Power supply and AN

When a d.c. power supply is needed to maintain battery voltage, the d.c. power supply shall be located outside the test chamber. All power lines entering the chamber shall be filtered. The d.c. power leads used for battery maintenance within the chamber may be shielded from the chamber filter to the battery connection point. The d.c. power leads within the chamber should be routed along the wall and chamber floor in order to minimize field coupling to these leads.

If no ground plane is used, then artificial networks shall not be used. The power feeds to the DUT shall be connected directly to the battery terminals.

If a ground plane is used, then each power supply lead shall be connected to the power supply through an AN. Power shall be applied to the DUT via a 5 µH/50 Ω AN (see Annex D for the schematic). The number of ANs required depends upon the intended DUT installation in the vehicle.

— For a remotely grounded DUT (vehicle power return line longer than 200 mm), two ANs are required: one for the positive supply line and another for the power return line. The power supply negative terminal shall be connected to the ground plane on the source (input) side of the return line AN.

— For a locally grounded DUT (vehicle power return line 200 mm or shorter), only one AN is required for the positive supply line. The DUT power return line shall be no longer than 200 mm and connected directly to the ground plane. The power supply negative terminal shall be connected to the ground plane near the AN case ground.

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

The measuring port of each AN shall be terminated with a 50 Ω load.

7.4 Location of DUT and wiring harness

A $\left(1700^{+300}_{0}\right)$ mm wiring harness shall be used, unless otherwise specified in the test plan. The wiring harness should be representative of the actual installation (shielded, unshielded, twisted pair, etc.). The length of the wiring harness shall be documented in the test report.

The wiring harness shall be placed in a "U-shaped" configuration to allow a straight harness length of (1 500 ± 75) mm between the DUT and the load simulator. Harness bends shall be $\left(90^{+45}_{0}\right)$°.

If a ground plane is used, the DUT and harness shall be elevated (50 ± 5) mm above the ground plane with a non-conductive, low permittivity (dielectric-constant) material (relative permittivity, $\varepsilon_r \leqslant 1,4$).

7.5 Location of load simulator

Preferably, the load simulator shall be placed directly on the ground plane (if used). If the load simulator has a metallic case, this case shall be bonded to the ground plane.

Alternatively, the load simulator may be located adjacent to the ground plane (with the case of the load simulator bonded to the ground plane) or outside of the test chamber, provided the test harness from the DUT passes through an RF boundary bonded to the ground plane.

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

7.6 Location of transmitting antenna

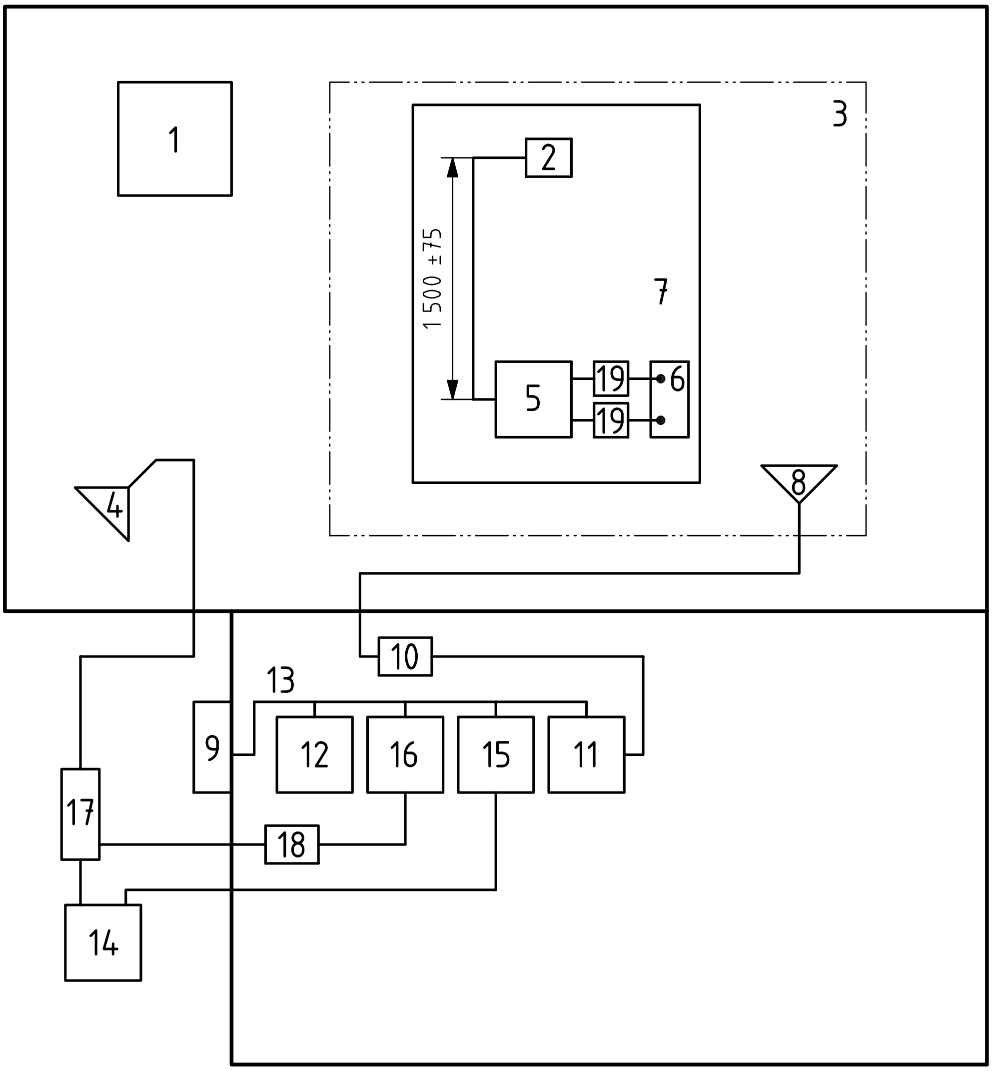
The location of the transmitting (Tx) antenna shall be the same for both characterization and testing. The transmitting antenna shall not directly illuminate the working volume. The transmitting antenna should be directed into a corner of the chamber if possible (see Figure 1 for location of transmitting antenna). Directing the antenna into the tuner is also acceptable. The transmitting antenna should be supported by a non-conductive stand (e.g. non-conductive tripod or polystyrene fixture) and should be placed at a distance not less than $\lambda/4$ (at lowest frequency) from the chamber walls and corners.

NOTE An upward tilt of the antenna is advisable to avoid direct incident wave illumination of the chamber wall resulting in a potentially high VSWR situation.

7.7 Location of receiving antenna

The receiving (Rx) antenna may be placed at an arbitrary position within the chamber working volume and should be placed on a polystyrene support. The receiving antenna shall avoid pointing at the transmitting antenna and centre of the working volume.

Dimensions in millimetres



Key

1 tuner
2 DUT
3 chamber working volume
4 Tx antenna
5 load simulator
6 battery
7 test bench (with ground plane if required)
8 Rx antenna
9 tuner controller
10 attenuator
11 spectrum analyser
12 computer system with software
13 computer interface
14 RF amplifier
15 RF signal generator
16 power meter
17 directional coupler
18 power sensor
19 AN(s) (used with ground plane setup)

Figure 1 — Example of suitable test facility (top view)

8 Test method

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

8.1 Test plan

Prior to performing the tests, a test plan shall be generated which shall include the following, as well as any special instructions and changes from the standard test:

— test set-up;

— frequency range;

— test frequencies or step sizes;

— DUT mode of operation;

— DUT acceptance criteria;

— test severity levels;

— DUT monitoring conditions;

— test report content.

Every DUT shall be tested under the most significant conditions, i.e. at least in stand-by mode and in a mode where all the actuators can be excited.

8.2 Test procedure

8.2.1 Setting Up the DUT

Install the DUT, harness and associated equipment in the chamber working volume in accordance with Clause 7.

8.2.2 Determining chamber loading effects

Prior to the actual testing, determine the loading effects of the reverberation chamber in accordance with Annex C for each test frequency, including the calculation of the chamber loading factor F_{CLF} and the minimum pulse width $T_{\text{p,min}}$ that can be sustained by the chamber.

To determine the loading effects, the field strength may be lower than for the actual testing.

8.2.3 Determining chamber forward power requirements

Calculate for each test frequency the necessary forward power $P_{\text{Forw,Test}}$ into the transmitting antenna for the required electric field strength using Equation (1):

$$P_{\text{Forw,Test}} = F_{\text{CLF}} \left(\frac{E_{\text{Test}}}{G_{\text{RC}}} \right)^2 \quad (1)$$

where

E_{Test} is the required field strength, in V/m;

F_{CLF} is the chamber loading factor from Annex C;

G_{RC} is the chamber gain from the empty chamber characterization from Annex B.

Interpolation between the frequency points used for the chamber characterization in accordance with Annex B is allowed.

8.2.4 Selecting frequency step intervals and tuner dwell time

Frequency step intervals and tuner dwell times shall be selected with consideration of DUT response time, DUT susceptibility bandwidths, and monitoring test equipment response time. The frequency steps intervals and tuner dwell times shall be documented in the test report.

At a minimum, the frequency steps of ISO 11452-1 shall be used.

The dwell time at each test frequency tuner position shall be at least 2 s, exclusive of test equipment response time and the time required to rotate the tuner (to a full stop). Additional dwell time at each test frequency may be necessary to allow the DUT to be exercised in appropriate operating modes and to allow for the “off time” during low frequency modulation.

8.2.5 Pulse test signal considerations

The chamber loading determines the minimum pulse width that can be sustained in a given chamber for pulse modulation testing.

If the required pulse width is shorter than the minimum test pulse width $T_{\mathrm{p,min}}$ in accordance with Annex C for more than 10 % of the test frequencies, absorbers shall be added or the pulse width increased. If absorbers are added, repeat the measurements and the calculations of the chamber loading effects in accordance with Annex C, until the time constant requirement is satisfied with the least possible absorbers.

8.2.6 DUT Test

Apply for each test frequency the calculated necessary forward power $P_{\mathrm{Forw,Test}}$ to achieve the test field strength.

The number of tuner steps for testing shall be at least the number of tuner steps used for the chamber characterization in accordance with Annex B. The tuner should be rotated in evenly spaced steps so that one complete revolution is obtained per frequency. Assure that the DUT is exposed to the field level for the appropriate dwell time.

Monitor and record the maximum and average values of the received power $P_{\mathrm{Rec,Test}}$ (i.e. $P_{\mathrm{Rec,Test,max}}$ and $P_{\mathrm{Rec,Test,avg}}$) with the receiving antenna used in the characterization of each frequency band to ensure that the required field strength is being generated. Use $P_{\mathrm{Rec,Test,avg}}$ to ensure that the chamber loading has not changed from the chamber loading factor determination. Differences greater than 3 dB in $P_{\mathrm{Rec,Test,avg}}$ shall be resolved.

Monitor the forward power $P_{\mathrm{Forw,Test}}$ into the transmitting antenna and record the average value $P_{\mathrm{Forw,Test,avg}}$ over a tuner rotation. Variations in $P_{\mathrm{Forw,Test}}$ over a tuner rotation greater than 3 dB shall be noted in the test report.

Modulate the carrier as specified in the test plan. Unless otherwise specified, peak power conservation shall be utilized in accordance with ISO 11452-1.

Monitor any deviations of the DUT.

Scan the frequency range to the upper frequency limit using the appropriate antennas and modulations.

8.3 Test report

As required in the test plan, a test report shall be submitted detailing information regarding the test equipment, test set-up, systems tested, test frequencies, power levels, system interactions, and any other relevant information regarding the test.

The test report should include the following parameters for each test frequency, in addition to the reporting requirements related to the DUT:

— curves of maximum and average received power, $P_{\text{Rec,Test,max}}$ and $P_{\text{Rec,Test,avg}}$, from the receiving antenna used to monitor the field in the chamber;

— curve of average forward power, $P_{\text{Forw,Test,avg}}$, delivered to the transmitting antenna;

— variations in forward power, $P_{\text{Forw,Test}}$, during the data collection period greater than 3 dB;

— curves of the chamber loading factor, F_{CLF}, and maximum loading factor, F_{MLF};

— number of tuner steps.

Any deviation from the test plan shall be specified in the test report.

Annex A
(informative)

Function performance status classifications (FPSC)

A.1 General

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

A.2 Classification of test severity levels

The suggested severity levels are given in Tables A.1 and A.2.

Table A.1 — Example severity levels for CW and AM modulated tests

Test severity levels	Category 1 V/m	Category 2 V/m	Category 3 V/m
L_{4i}	100	100	100
L_{3i}	100	100	100
L_{2i}	40	60	80
L_{1i}	25	40	60

Table A.2 — Example severity levels for pulse modulated tests

Test severity levels	Category 1 V/m	Category 2 V/m	Category 3 V/m
L_{4i}	100	100	150
L_{3i}	100	100	100
L_{2i}	100	100	100
L_{1i}	70	70	100

Annex B
(normative)

Mode tuning chamber characterization

B.1 General

As an initial guide to chamber performance and forward power requirements, perform a “one-time” empty chamber characterization (no DUT present) using the procedures of Clause B.2. Prior to each test a characterization shall be performed using the procedures of Clause C.2. A chamber can be used to perform tests at and above the frequency at which the chamber meets the field uniformity requirements in Table B.2.

Once a chamber has been modified (e.g. absorber added, antennas changed, etc.) or the characterization procedure modified (e.g. changed number of tuner steps, etc.) to obtain a desired characteristic, that configuration and/or procedure shall remain the same for the duration of the test for that characterization to remain valid.

Characterization of the fields inside the reverberation chamber shall consist of eight probe locations for cuboid working volumes. For other shapes it may be necessary to add more probe locations in order to properly define the working volume.

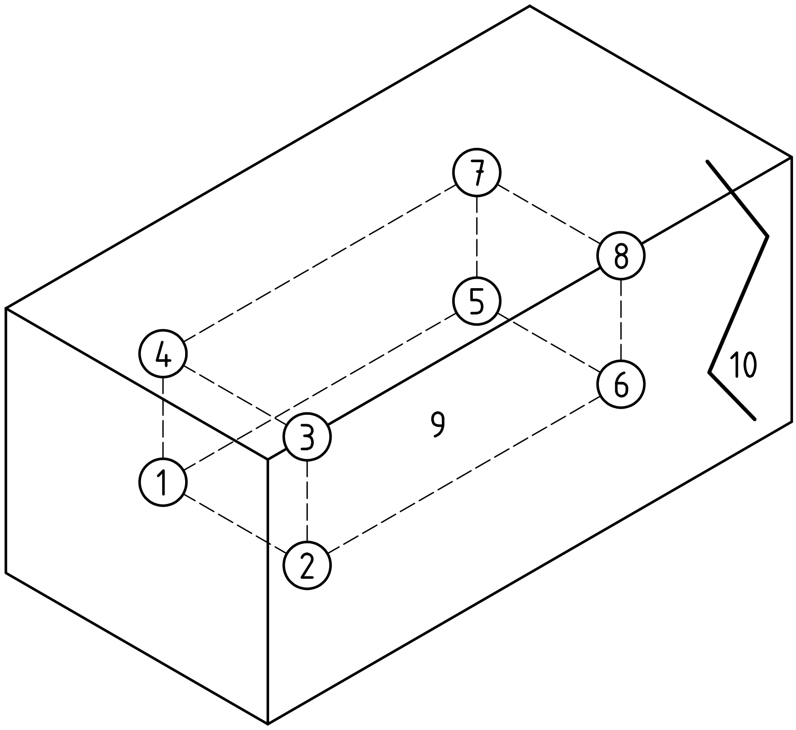
The minimum separation distance between different probe locations shall be at least $\lambda/4$ for the lowest characterization frequency.

The probe locations shall enclose the working volume as shown in Figure B.1. It is recommended that the surfaces bounding the working volume not be located closer than $\lambda/4$ for the lowest characterization frequency from any chamber surface, transmitting antenna or tuner assembly.

It is recommended that the working volume for chamber characterization be sized to suit the maximum working volume of the chamber since a second characterization will be required if larger items are to be tested.

An isotropic E-field probe, which provides access to each of the three axes shall be used to perform characterizations. A calibrated electrically short dipole antenna (i.e. less than $\lambda/3$) may be substituted, provided that the dipole antenna is positioned at three mutually perpendicular orientations for each probe location. Care should be taken to ensure that the dipole is not influenced by its connecting cable. An optically isolated measurement system (isotropic E-field probe or dipole) is recommended. The probe does not necessarily need to be oriented along the chamber axes during characterization.

The receiving antenna may be located at any location within the working volume. The receiving antenna shall be moved to a new location within the working volume of the chamber for each change in probe location. Each location should be at least $\lambda/4$ at the lowest characterization frequency from any previous location. The receiving antenna should also be placed in a new orientation relative to the chamber axis at each location (at least 20° in each axis). Care should be taken to ensure that the proper separation distance between the receiving antenna and probe are maintained. If the receiving antenna is to be mounted in a fixed position during routine testing, it is suggested that one of the locations should be the intended permanent location of the receiving antenna.



Key

1, 2, 3, 4, 5, 6, 7, 8 probe locations for characterization

9 working volume

10 tuner

Figure B.1 — Probe locations for chamber characterization

The minimum number of frequency steps and tuner positions for the chamber characterization are given in Table B.1. Table B.1 also gives the recommended number of tuner steps for characterization and test. The lowest frequency for chamber characterization, f_S, may be identical to the lowest usable frequency of the chamber f_{LUF}, but not necessarily. It is during this procedure that f_{LUF} is to be determined, which implies that iterations might become necessary to fulfil the requirements of Table B.1 for the very first characterization of the chamber until f_{LUF} is known at least approximately. If the field uniformity requirements of Table B.2 are already met for f_S, then f_S and f_{LUF} become identical.

Table B.1 — Tuner position and frequency step requirements

Frequency range[a]	Recommended number of tuner positions for characterization and test[b]	Minimum number of tuner positions for characterization and test[b]	Minimum number of frequencies for characterization[c]
f_S to $3f_S$	50	12	20
$3f_{LUF}$ to $6f_{LUF}$	18	6	15
$6f_{LUF}$ to $10f_{LUF}$	12	6	10
$> 10f_{LUF}$	12	6	20 per decade

[a] f_S = lowest frequency for chamber characterization; f_{LUF} = lowest usable frequency of the chamber.

[b] Independent tuner positions.

[c] Logarithmically spaced.

B.2 Measurement procedure

Before starting the measurements for the chamber characterization, clear the working volume (i.e. remove test bench).

For each of the probe locations, of which there are at least eight, and each of the characterization frequencies, perform the measurement procedure described below.

— Place the isotropic E-field probe at the location on the perimeter of the chamber working volume as shown in Figure B.1.

— Place the receiving antenna at the corresponding receiving antenna location within the chamber working volume. See Clause B.1 for restrictions of receiving antenna locations.

— Adjust the RF source to inject an appropriate forward power P_{Forw} into the transmitting antenna such that the received power P_{Rec} is large enough (see below). Make sure that the frequency is in band for both transmitting and receiving antennas that are used. Care shall be taken to ensure that the harmonics of the RF input to the chamber are at least 15 dB below the fundamental. Set the amplitude measurement instrument to monitor the receiving antenna on the correct frequency.

— Step the tuner through 360° in discrete steps so that the power measurement instruments and isotropic E-field probe capture the minimum number of samples as outlined in Table B.1 over one complete tuner rotation. Care shall be taken to ensure that the dwell time is sufficiently long enough that the amplitude measurement instrumentation and isotropic E-field probe have time to respond properly.

— For each tuner position, record the received power P_{Rec} from the receiving antenna, the field strength for each axis of the E-field probe (i.e. E_X, E_Y, and E_Z) and the forward power P_{Forw} into the transmitting antenna.

— From these values compute the maximum received power, $P_{\text{Rec, max}}$, average received power, $P_{\text{Rec,avg}}$, the maximum field strength for each axis of the E-field probe ($E_{X,\text{max}}$, $E_{Y,\text{max}}$, $E_{Z,\text{max}}$) and the average forward power, $P_{\text{Forw,avg}}$, over the tuner rotation. All calculations shall be done using linear units [i.e. W and V/m, not dBm or dB(μV/m)]. Ensure that the noise floor of the power measuring instrument for the received power is at least a factor of 100 (i.e. 20dB) below the maximum received power, $P_{\text{Rec, max}}$, for proper average data collection. If this is not the case, increase the forward power appropriately or modify instrumentation. Large variations in forward power (i.e. 3 dB or more) are an indication of poor source/amplifier performance.

— Normalize each of the maximum isotropic E-field measurements (i.e. each of the three rectangular components) to the square-root of the average forward power (i is the index for the probe position):

$$e_{X,i} = \frac{E_{X,\text{max}}}{\sqrt{P_{\text{Forw,avg}}}} \quad \text{(B.1)}$$

$$e_{Y,i} = \frac{E_{Y,\text{max}}}{\sqrt{P_{\text{Forw,avg}}}} \quad \text{(B.2)}$$

$$e_{Z,i} = \frac{E_{Z,\text{max}}}{\sqrt{P_{\text{Forw,avg}}}} \quad \text{(B.3)}$$

— Calculate the chamber characterization factor $A_{\text{CCF},i}$ using Equation (B.4) (i is the index for the probe position):

$$A_{\text{CCF},i} = \frac{P_{\text{Rec,avg}}}{P_{\text{Forw,avg}}} \quad \text{(B.4)}$$

NOTE The measurement iterations over the frequency steps and the tuner steps can be interchanged if desired, i.e. step through the frequencies at each step of the tuner.

B.3 Chamber gain

For each characterization frequency, calculate the average of the normalized maximum of all the isotropic E-field measurements over all N probe locations (usually $N = 8$) giving equal weight to each axis (i.e. each rectangular component). This defines the chamber gain and is used to calculate the necessary forward power for the required test level:

$$G_{\text{RC}} = e_{\text{avg}} = \frac{\left(e_{X,1},\ldots,e_{X,N},e_{Y,1},\ldots,e_{Y,N},e_{Z,1},\ldots,e_{Z,N}\right)}{3N} = \frac{1}{3N}\sum_{i=1}^{N}\left(e_{X,i}+e_{Y,i}+e_{Z,i}\right) \tag{B.5}$$

B.4 Field uniformity

The field uniformity is specified as a standard deviation from the mean value of the maximum values obtained at each of the probe locations during one rotation of the tuner. The standard deviation is calculated using data from each probe axis independently and the total data set.

For each characterization frequency, calculate for each probe axis the average of the normalized maxima of the E-field measurements over all N probe locations (usually $N = 8$):

$$e_{X,\text{avg}} = \frac{1}{N}\sum_{i=1}^{N} e_{X,i} \tag{B.6}$$

$$e_{Y,\text{avg}} = \frac{1}{N}\sum_{i=1}^{N} e_{Y,i} \tag{B.7}$$

$$e_{Z,\text{avg}} = \frac{1}{N}\sum_{i=1}^{N} e_{Z,i} \tag{B.8}$$

The standard deviations shall be calculated using Equations (B.9) to (B.12) (usually $N = 8$):

$$\sigma_X = 1{,}06\sqrt{\frac{\sum_{i=1}^{N}\left(e_{X,i}-e_{X,\text{avg}}\right)^2}{N-1}} \tag{B.9}$$

$$\sigma_Y = 1{,}06\sqrt{\frac{\sum_{i=1}^{N}\left(e_{Y,i}-e_{Y,\text{avg}}\right)^2}{N-1}} \tag{B.10}$$

$$\sigma_Z = 1{,}06\sqrt{\frac{\sum_{i=1}^{N}\left(e_{Z,i}-e_{Z,\text{avg}}\right)^2}{N-1}} \tag{B.11}$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}\left(\left(e_{X,i}-e_{\text{avg}}\right)^2+\left(e_{Y,i}-e_{\text{avg}}\right)^2+\left(e_{Z,i}-e_{\text{avg}}\right)^2\right)}{3N-1}} \tag{B.12}$$

The standard deviations relative to the mean, expressed in terms of dB, shall be calculated using Equations (B.13) to (B.16):

$$\sigma_X = 20\log_{10}\left(\frac{\sigma_X + e_{X,\text{avg}}}{e_{X,\text{avg}}}\right) \quad \text{(B.13)}$$

$$\sigma_Y = 20\log_{10}\left(\frac{\sigma_Y + e_{Y,\text{avg}}}{e_{Y,\text{avg}}}\right) \quad \text{(B.14)}$$

$$\sigma_Z = 20\log_{10}\left(\frac{\sigma_Z + e_{Z,\text{avg}}}{e_{Z,\text{avg}}}\right) \quad \text{(B.15)}$$

$$\sigma = 20\log_{10}\left(\frac{\sigma + e_{\text{avg}}}{e_{\text{avg}}}\right) \quad \text{(B.16)}$$

The chamber passes the field uniformity requirements, provided that the standard deviations for the three individual field components and for the total data set are within the tolerance requirements given in Table B.2.

Table B.2 — Standard deviation requirements

Frequency range	Tolerance requirements for standard deviation[a]
Below 100 MHz	6 dB[b]
100 MHz to 400 MHz	6 dB[b] at 100 MHz decreasing linearly to 3 dB at 400 MHz
Above 400 MHz	3 dB

[a] A maximum of three frequencies per octave may exceed the allowed standard deviation by an amount not to exceed 1 dB of the required tolerance.

[b] The standard deviation requirement of IEC 61000-4-21 (4 dB at frequencies $\leqslant$ 100 MHz) may be necessary if required by the test plan. Additional tuner steps may be necessary to achieve this more stringent standard deviation requirement.

If the chamber fails to meet the uniformity requirement, it may not be possible for the chamber to operate at the desired lower frequency. If the margin by which the chamber fails to meet the uniformity requirement is small, it may be possible to obtain the desired uniformity by

a) increasing the number of samples (i.e. tuner steps) for chamber characterization and test,

b) normalizing the data to the net power ($P_{\text{Net}} = P_{\text{Forw}} - P_{\text{Reverse}}$), or

c) reducing the size of the working volume.

If the chamber exceeds the required field uniformity, the number of samples required may be reduced, but not below the minimum requirement of Table B.1. This offers the ability to optimize each chamber for the minimum number of samples and therefore minimum test time.

If the tuner fails to provide the required uniformity then the uniformity may be improved by increasing the number of tuners, making the tuner(s) larger, or lowering the Q by adding absorber. The chamber characteristics (size, construction method, wall materials) should also be evaluated to determine if the chamber is likely to pass the requirement. Chambers with no more than 60 to 100 modes at the lowest test frequency or very high Qs (such as those encountered in welded aluminium chambers) are likely to encounter difficulty in meeting the required uniformity.

B.5 Receiving antenna characterization factor (ACF)

The receiving antenna characterization factor (ACF) for an empty chamber is determined to provide a baseline for comparison with a loaded chamber (Annex C). The characterization factor is necessary to correct the antenna measurements for several effects including antenna efficiency.

Calculate the receiving antenna characterization factor (ACF) for each frequency by calculating the average value of the collected chamber characterization factors [from Equation (B.4)] over the (at least) eight probe locations:

$$A_{\mathrm{ACF}} = A_{\mathrm{CCF},i,\mathrm{avg}} \tag{B.17}$$

B.6 Lowest usable frequency (LUF)

The lowest usable frequency f_{LUF} of the chamber is the minimum frequency for which the field uniformity requirements of Table B.2 are met.

B.7 Maximum chamber loading factor (MLF)

In order to determine if the chamber is adversely affected by a DUT which “loads” the chamber, perform a one time check of the chamber field uniformity under simulated loading conditions. It is suggested the “loaded” chamber characterization be carried out only once in the life of the chamber or after major modification to the chamber. Prior to each test a characterization shall be performed using the procedures of Annex C.

In the working volume of the chamber, install a sufficient amount of absorber to load the chamber to at least the level expected during normal testing [a factor of sixteen change in ACF (12 dB) should be considered as a nominal amount of loading].

NOTE Each chamber is unique. The easiest way to determine the amount of absorber necessary is by trial and error.

Repeat the characterization outlined in Clauses B.2 to B.5 using (at least) the eight locations of the E-field probe. Care should be taken to ensure that the E-field probe and receiving antenna maintain a distance of greater than $\lambda/4$ from any absorber.

Repeat the calculation of the field uniformity using the data from the (at least) eight locations of the E-field probe. If the chamber loading results in a rectangular component of the fields exceeding the allowed standard deviation, or if the standard deviation for all vectors (i.e. σ) exceeds the allowed standard deviation (see Table B.2) then the chamber has been loaded to the point where field uniformity is unacceptable. In this case, the amount of chamber loading shall be reduced and the loading effects evaluation shall be repeated.

Determine the maximum chamber loading factor by comparing the antenna characterization factor (ACF) from the empty chamber to that obtained from the “loaded” chamber (see Clause B.5):

$$F_{\mathrm{MLF}} = \frac{A_{\mathrm{ACF,empty}}}{A_{\mathrm{ACF,loaded}}} \tag{B.18}$$

Annex C
(normative)

Determination of chamber loading effects

C.1 General

This annex describes a procedure to determine the effects of loading of a reverberation chamber due to the DUT, the wiring harness, the support equipment, the test bench, etc. The effects are characterized by the chamber loading factor A_{CLF} and the minimum test pulse width $T_{\text{p,min}}$.

This procedure shall be carried out prior to each test, unless the test is performed with an already used test setup (identical or similar type). In this case a new determination of the loading effects is not necessary.

C.2 Measurement procedure

Place the receiving antenna at a location within the working volume of the chamber and maintain $\lambda/4$ separation from the DUT, support equipment, etc. (at the lowest test frequency).

Measure the maximum and the average values of the output power P_{Rec} of the receiving antenna, and the average value of the forward power P_{Forw} into the transmitting antenna for all test frequencies using the following procedure:

— Adjust the RF source level to inject an appropriate forward power P_{Forw} into the transmitting antenna. Care shall be taken to ensure that the harmonics of the RF input to the chamber are at least 15 dB below the fundamental.

— Set the amplitude measurement instrumentation to monitor the receiving antenna on the correct frequency.

— Operate the chamber and the tuner taking into account the possible additional features defined in Clause B.1 that have been required to meet the homogeneity criterion. Care shall be taken to ensure that the dwell time is sufficiently long enough to ensure that the amplitude measurement has time to respond properly.

— Record the maximum and the average of the received power P_{Rec} of the receiving antenna, and the average value of the forward power P_{Forw} into the transmitting antenna. The instrument for measuring P_{Rec} should have a noise floor at least 20 dB below the maximum of the received power P_{Rec} in order to collect accurate average data.

C.3 Chamber characterization factor

Calculate the chamber characterization factor A_{CCF} for each test frequency using Equation (C.1):

$$A_{\text{CCF}} = \frac{P_{\text{Rec,avg}}}{P_{\text{Forw,avg}}} \tag{C.1}$$

where

$P_{\text{Rec,avg}}$ is the received power averaged over one tuner rotation;

$P_{\text{Forw,avg}}$ is the forward power averaged over one tuner rotation.

To improve the estimation of A_{CCF}, it is possible to repeat the measurement procedure of Clause C.2 with one of the methods described below.

— Use of different receiving antenna locations and using the average value as defined in Equation (C.2).

$$A_{CCF} = A_{CCF,i,avg} = \frac{1}{n}\sum_{i=1}^{n} A_{CCF,i} \qquad (C.2)$$

where

n is the number of antenna locations;

i is the index of the probe position.

NOTE The same averaging idea is used for the estimation of the receiving antenna characterization factor A_{CCF} (see Clause B.5).

— Perform an A_{CCF} estimation with the stirring mode method, in order to get more values of $P_{Rec,avg}$ and $P_{Forw,avg}$ over the tuner rotation for the averaging using Equation (C.1).

— Use a second order polynomial regression smoothing technique using the values obtained from Equation (C.1).

C.4 Chamber loading factor

If the average value of the received power $\langle P_{Rec} \rangle$ measured in Clause C.2 is within (i.e. not greater than or less than) the values recorded for all receiving antenna locations during the chamber characterization in accordance with Annex B, calculation of the chamber loading factor is not necessary and the value of the chamber loading factor is set to be one.

$$F_{CLF} = 1 \qquad (C.3)$$

Otherwise calculate for all test frequencies the chamber loading factor F_{CLF} using Equation (C.4):

$$F_{CLF} = \frac{A_{ACF,empty}}{A_{CCF}} \qquad (C.4)$$

where

A_{CCF} is the chamber characterization factor obtained in Clause C.3, and

$A_{ACF,\ empty}$ is the antenna characterization factor obtained during the chamber characterization for the empty chamber (see Clause B.5).

Interpolation might be required to obtain the ACF at the test frequencies.

If the chamber loading factor F_{CLF} is greater than the maximum loading factor F_{MLF} determined during the chamber characterization in accordance with Annex B for more than 10 % of the frequencies, the chamber may be loaded to a point where field uniformity could be affected. In such case the field uniformity measurements for the loaded chamber in accordance with Annex B shall be repeated with the DUT in place or with a simulated loading equivalent to the DUT.

If the dynamic range of the measurement system was insufficient to get accurate average received power measurements, the antenna characterization factor A_{ACF} and the chamber characterization factor A_{CCF} may be recalculated using maximum received power and then used to calculate the chamber loading factor F_{CLF}. If maximum received power is used, it shall be used to recalculate both A_{ACF} and A_{CCF}.

CAUTION — This applies only to the calculation of F_{CLF}. Do not use A_{ACF} or A_{CCF} based on maximum to determine any other parameters.

C.5 Minimum test pulse width

Calculate for all test frequencies the minimum test pulse width that the loaded reverberation chamber can sustain:

$$T_{p,min} = \frac{20\pi V f^2}{\eta_{Tx}\eta_{Rx} c_0^3} A_{CCF} \qquad \text{(C.5)}$$

where

V is the chamber volume,

f is the test frequency, and

η_{Rx} are the antenna efficiency factors for the transmitting and receiving antenna respectively and can conservatively be assumed to be 75 % for a log periodic antenna and 90 % for a horn antenna, $c_0 \approx 2{,}998 \cdot 10^8 \frac{m}{s}$ is the propagation speed of electromagnetic waves in free space, and A_{CCF} is the chamber characterization factor calculated in accordance with Clause C.3.

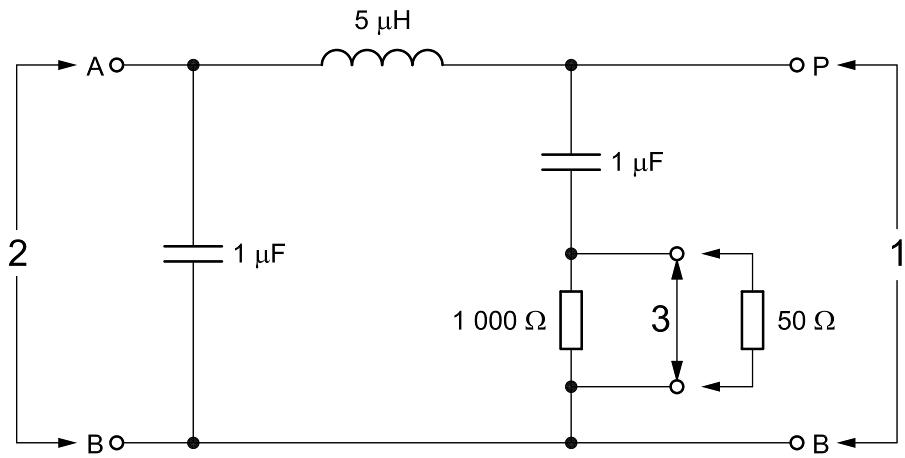
Annex D
(normative)

Artificial network

D.1 General

The AN is used as a reference standard in the laboratory in place of the impedance of the vehicle wiring harness in order to determine the behaviour of electrical equipment and electronic devices. It shall be able to withstand continuous load corresponding to the requirements of the DUT.

An example AN schematic is shown in Figure D.1 (see also Clause D.2).



Key

1 port for the DUT

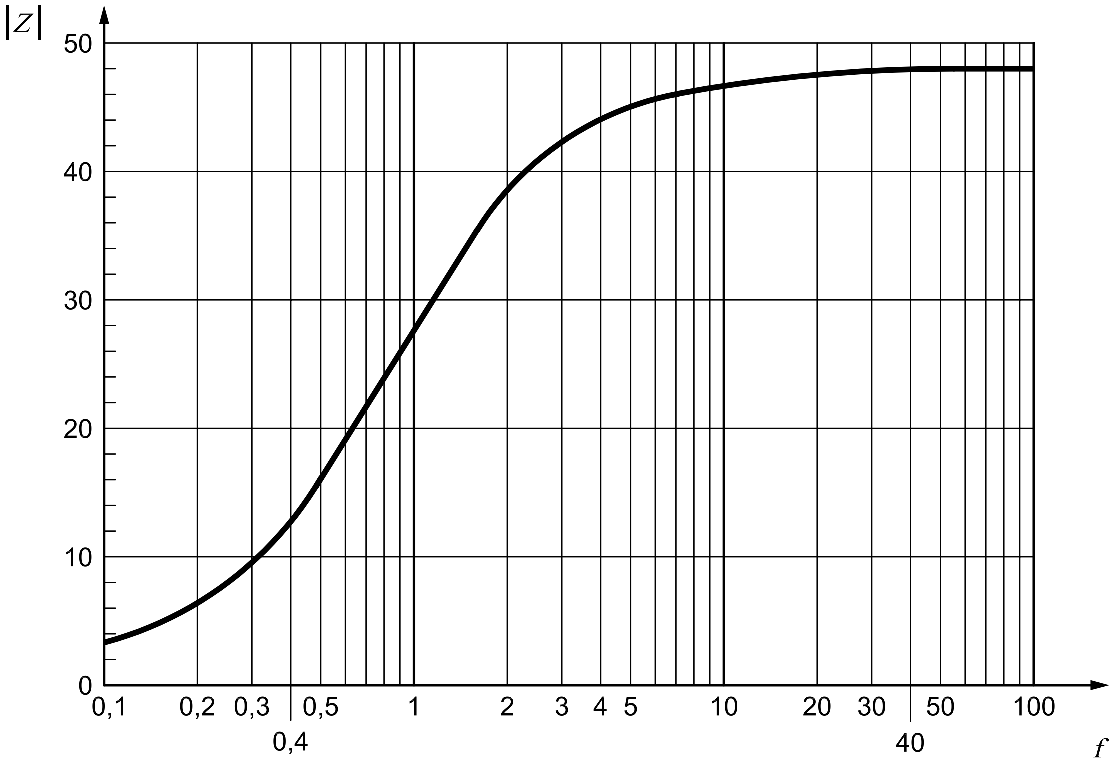
2 power supply port

3 measurement port

Figure D.1 — Example AN schematic

D.2 AN impedance

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



Key

|Z| impedance, Ω

f frequency, MHz

Figure D.2 — Characteristics on AN impedance $|Z_{\mathrm{PB}}|$ as function of frequency, *f*, 0,1 MHz to 100 MHz

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[1] ISO 11452-1:2005, *Road vehicles — Component test methods for electrical disturbances from narrowband radiated electromagnetic energy — Part 1: General principles and terminology*

[2] IEC 61000-4-21, *Electromagnetic compatibility (EMC) — Part 4-21: Testing and measurement techniques — Reverberation chamber test methods*

[3] RTCA/DO-160E, *Environmental Conditions and Test Procedures for Airborne Equipment*

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