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INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE
COMITÉ INTERNATIONAL SPÉCIAL DES PERTURBATIONS RADIOÉLECTRIQUES

BASIC EMC PUBLICATION
PUBLICATION FONDAMENTALE EN CEM

**Specification for radio disturbance and immunity measuring apparatus and methods –
Part 1-4: Radio disturbance and immunity measuring apparatus – Antennas
and test sites for radiated disturbance measurements**

**Spécifications des méthodes et des appareils de mesure des perturbations
radioélectriques et de l'immunité aux perturbations radioélectriques –
Partie 1-4: Appareils de mesure des perturbations radioélectriques et de
l'immunité aux perturbations radioélectriques – Antennes et emplacements
d'essai pour les mesures des perturbations rayonnées**



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INTERNATIONAL ELECTROTECHNICAL COMMISSION
INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE

**SPECIFICATION FOR RADIO DISTURBANCE AND IMMUNITY
MEASURING APPARATUS AND METHODS –**

**Part 1-4: Radio disturbance and immunity measuring apparatus –
Antennas and test sites for radiated disturbance measurements**

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International Standard CISPR 16-1-4 has been prepared by CISPR subcommittee A: Radio-interference measurements and statistical methods.

This third edition of CISPR 16-1-4 cancels and replaces the second edition published in 2007 and its Amendments 1 (2007) and 2 (2008). It is a technical revision.

This edition includes the following significant technical change with respect to the previous edition: provisions are added to address evaluation of a set-up table in the frequency range above 1 GHz.

It has the status of a basic EMC publication in accordance with IEC Guide 107, *Electromagnetic compatibility – Guide to the drafting of electromagnetic compatibility publications*.

The text of this standard is based on the following documents:

FDIS	Report on voting
CISPR/A/885/FDIS	CISPR/A/891/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of CISPR 16 series, under the general title *Specification for radio disturbance and immunity measuring apparatus and methods*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

The contents of the corrigendum of December 2010 have been included in this copy.

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SPECIFICATION FOR RADIO DISTURBANCE AND IMMUNITY MEASURING APPARATUS AND METHODS –

Part 1-4: Radio disturbance and immunity measuring apparatus – Antennas and test sites for radiated disturbance measurements

1 Scope

This part of CISPR 16 specifies the characteristics and performance of equipment for the measurement of radiated disturbances in the frequency range 9 kHz to 18 GHz. Specifications for antennas and test sites are included.

NOTE In accordance with IEC Guide 107, CISPR 16-1-4 is a basic EMC publication for use by product committees of the IEC. As stated in Guide 107, product committees are responsible for determining the applicability of the EMC standard. CISPR and its sub-committees are prepared to co-operate with product committees in the evaluation of the value of particular EMC tests for specific products.

The requirements of this publication apply at all frequencies and for all levels of radiated disturbances within the CISPR indicating range of the measuring equipment.

Methods of measurement are covered in Part 2-3, and further information on radio disturbance is given in Part 3 of CISPR 16. Uncertainties, statistics and limit modelling are covered in Part 4 of CISPR 16.

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.

CISPR 16-1-1, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-1: Radio disturbance and immunity measuring apparatus – Measuring apparatus*

CISPR 16-1-5:2003, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-5: Radio disturbance and immunity measuring apparatus – Antenna calibration test sites for 30 MHz to 1 000 MHz*

CISPR 16-2-3, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 2-3: Methods of measurement of disturbances and immunity – Radiated disturbance measurements*

CISPR/TR 16-3:2003, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 3: CISPR technical reports*
Amendment 1(2005)
Amendment 2(2006)

CISPR 16-4-2, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 4-2: Uncertainties, statistics and limit modelling – Uncertainty in EMC measurements*

IEC 60050-161, *International Electrotechnical Vocabulary (IEV) – Chapter 161: Electromagnetic compatibility*

IEC 61000-4-20, *Electromagnetic compatibility (EMC) – Part 4-20: Testing and measurement techniques – Emission and immunity testing in transverse electromagnetic (TEM) waveguides*

3 Terms, definitions and abbreviations

For the purposes of this document, the following terms, definitions and abbreviations apply, as well as those of CISPR 16-1-1, CISPR 16-1-5, and IEC 60050-161.

3.1 Terms and definitions

3.1.1

antenna

that part of a transmitting or receiving system that is designed to radiate or to receive electromagnetic waves in a specified way

NOTE 1 In the context of this standard, the balun is a part of the antenna.

NOTE 2 This term covers various devices such as the wire antenna, free space-resonant dipole, hybrid antenna and horn antenna.

3.1.2

balun

passive electrical network for the transformation from a balanced to an unbalanced transmission line or device or vice versa

3.1.3

calibration test site

CALTS

open area test site with metallic ground plane and tightly specified site attenuation performance in horizontal and vertical *E*-field (electric field) polarization

NOTE 1 A CALTS is used for determining the free-space antenna factor of an antenna.

NOTE 2 Site attenuation measurements of a CALTS are used for comparison to corresponding site attenuation measurements of a compliance test site, in order to evaluate the performance of the compliance test site.

3.1.4

common mode absorption device

CMAD

device that may be applied on cables leaving the test volume in radiated emission measurements to reduce the compliance uncertainty

3.1.5

compliance test site

COMTS

environment that assures valid, repeatable measurement results of the disturbance field strength from equipment under test for comparison to a compliance limit

3.1.6

cross-polar response

measure of the rejection by the antenna of the cross-polarized field, when the antenna is rotated in a linearly polarized electromagnetic field that is uniform in phase and amplitude over the aperture of the antenna under test

3.1.7

fully-anechoic room

FAR

shielded enclosure, the internal surfaces of which are lined with radio-frequency-energy absorbing material (i.e. RF absorber) that absorbs electromagnetic energy in the frequency range of interest

3.1.8

free-space-resonant dipole

wire antenna consisting of two straight colinear conductors of equal length, placed end to end, separated by a small gap, with each conductor approximately a quarter-wavelength long such that at the specified frequency, the input impedance of the wire antenna measured across the gap is pure real when the dipole is located in the free space

NOTE 1 In the context of this standard, this wire antenna connected to the balun is also called the "test antenna".

NOTE 2 This wire antenna is also referred to as "tuned dipole".

3.1.9

hybrid antenna

conventional wire-element log-periodic dipole array (LPDA) antenna with boom lengthened at the open-circuit end to add one broadband dipole (e.g. biconical or bow-tie), such that the infinite balun (boom) of the LPDA serves as a voltage source for the broadband dipole

Typically a common-mode choke is used at this end of the boom to minimize parasitic (unintended) RF currents on the outer conductor of the coaxial cable flowing into the receiver.

3.1.10

insertion loss

loss arising from the insertion of a device into a transmission line, expressed as the ratio of voltages immediately before and after the point of insertion of a device under test, before and after the insertion

It is equal to the inverse of the transmission S -parameter, $|1/S_{21}|$.

3.1.11

low-uncertainty antenna

robust biconical or LPDA antenna that meets the balance and cross-polar performance requirements of this standard, and whose antenna factor has an uncertainty of less than $\pm 0,5$ dB, used for the measurement of E -field strength at a defined point in space

NOTE It is further described in A.2.3.

3.1.12

quasi-free space test-site

facility for radiated emission measurements, or antenna calibration, that is intended to achieve free-space conditions

Unwanted reflections from the surroundings are kept to a minimum in order to satisfy the site acceptance criterion applicable to the radiated emission measurement or antenna calibration procedure being considered.

3.1.13

reflection coefficient

ratio of a common quantity to both the reflected and incident travelling waves

Hence, the voltage reflection coefficient is defined as the ratio of the complex voltage of the reflected wave to the complex voltage of the incident wave. The voltage reflection coefficient is equal to the scattering parameter S_{11} .

3.1.14**scattering parameters (*S*-parameters)**

set of four parameters used to describe the properties of a two-port network inserted into a transmission line

3.1.15**semi-anechoic chamber****SAC**

shielded enclosure, in which five of the six internal surfaces are lined with radio-frequency-energy absorbing material (i.e. RF absorber) that absorbs electromagnetic energy in the frequency range of interest, and the bottom horizontal surface is a conducting ground plane for use with OATS test set-ups

3.1.16**short-open-load-through calibration method****SOLT**

through-open-short-match calibration method

TOSM

calibration method for a vector network analyzer using three known impedance standards – short, open, and match/load, and a single transmission standard – through

The SOLT method is widely used, and the necessary calibration kits with 50 Ω characteristic impedance components are commonly available. A full two-port error model includes six error terms for each of the forward and reverse directions, for a total of twelve separate error terms, and requires twelve reference measurements to perform the calibration.

3.1.17**site attenuation**

minimum site insertion loss measured between two polarization-matched antennas located on a test site when one antenna is moved vertically over a specified height range and the other is set at a fixed height

3.1.18**site insertion loss**

loss between a pair of antennas placed at specified positions on a test site, when a direct electrical connection between the generator output and receiver input is replaced by transmitting and receiving antennas placed at the specified positions

3.1.19**test volume**

volume in the FAR in which the EUT is positioned

NOTE In this volume, the quasi-free space condition is met and this volume is typically 0,5 m or more from the absorbing material of the FAR.

3.1.20**through-reflect-line (TRL) calibration**

calibration method for a vector network analyzer using three known impedance standards “through”, “reflect” and “line” for the internal or external calibration of the VNA

Four reference measurements are needed for this calibration.

3.1.21**vector network analyzer****VNA**

network analyzer capable of measuring complex values of the four *S*-parameters S_{11} , S_{12} , S_{21} , S_{22}

3.2 Abbreviations

EUT	Equipment under test
FSOATS	Free-space OATS
LAS	Loop antenna system
LLA	Large-loop antenna
LPDA	Log-periodic dipole array
NSA	Normalised site attenuation
OATS	Open-area test site
SA	Site attenuation
SAC	Semi-anechoic chamber
S_{VSWR}	Site voltage standing wave ratio
VSWR	Voltage standing wave ratio

4 Antennas for measurement of radiated radio disturbance

4.1 General

Antennas of the type that are used for radiated emission measurements, having been calibrated, shall be used to measure the field strength, taking into account their radiation patterns and mutual coupling with their surroundings. The antenna and the circuits inserted between it and the measuring receiver shall not appreciably affect the overall characteristics of the measuring receiver. When the antenna is connected to the measuring receiver, the measuring system shall comply with the bandwidth requirements of CISPR 16-1-1 appropriate to the frequency band concerned.

The antenna shall be linearly polarized. It shall be orientable so that all polarizations of incident radiation can be measured. The height of the centre of the antenna above ground or above the absorber in a FAR may have to be adjustable according to a specific test procedure.

The accuracy of field-strength measurement of a uniform field of a sine-wave signal shall be better than ± 3 dB when an antenna meeting the requirements of this subclause is used with a measuring receiver meeting the requirements of CISPR 16-1-1.

NOTE This requirement does not include the effect due to a test site.

For additional information about the parameters of broadband antennas, see Annex A.

4.2 Physical parameter for radiated emission measurements

The physical parameter for radiated emission measurements made against an emission limit expressed in volts per metre is E -field measured at a defined point in space relative to the position of the equipment under test (EUT). More specifically, for measurements in the frequency range 30 MHz to 1 000 MHz on an OATS or in a SAC, the measurand is the maximum field strength as a function of horizontal and vertical polarization and at heights between 1 m and 4 m, and at a horizontal distance of 10 m from the EUT, while the EUT is rotated over all angles in the azimuth plane.

4.3 Frequency range 9 kHz to 150 kHz

4.3.1 General

Experience has shown that, in this frequency range, it is the magnetic field component that is primarily responsible for observed instances of interference.

4.3.2 Magnetic antenna

For measurement of the magnetic component of the radiation, either an electrically-screened loop antenna of dimension such that the antenna can be completely enclosed by a square having sides of 60 cm in length, or an appropriate ferrite-rod antenna, may be used.

The unit of magnetic field strength is $\mu\text{A/m}$. In logarithmic units H is in $\text{dB}(\mu\text{A/m})$, or 20 times the log of the measured field strength level. The associated emission limit shall be expressed in the same units.

NOTE Direct measurements can be made of the strength of the magnetic component, in $\text{dB}(\mu\text{A/m})$ or $\mu\text{A/m}$ of a radiated field under all conditions, that is, both in the near field and in the far field. However, many field strength measuring receivers are calibrated in terms of the equivalent plane wave E -field strength in $\text{dB}(\mu\text{V/m})$, i.e. assuming that the ratio of the E and H components is $120 \pi \Omega$ or 377Ω . Calculations for H are as follows.

$$H = \frac{E}{377 \Omega} \quad (1)$$

where H is typically in $\mu\text{A/m}$ and E in $\mu\text{V/m}$.

For measurements in dB:

$$H = E - 51,5 \quad (2)$$

where H is in $\text{dB}(\mu\text{A/m})$ and E in $\text{dB}(\mu\text{V/m})$.

The impedance used in the above conversions, $Z = 377 \Omega$, with $20 \log Z = 51,5 \text{ dB}(\Omega)$, is a constant originating from the calibration of field strength measuring equipment indicating the magnetic field in $\mu\text{V/m}$ [or $\text{dB}(\mu\text{V/m})$].

4.3.3 Shielding of loop antenna

Inadequate shielding of a loop antenna can result in E -field response. The E -field discrimination of the antenna shall be evaluated by rotating the antenna in a uniform field, such that the plane of the loop remains parallel to the E -field vector. When the plane of the loop antenna is perpendicular to the magnetic flux and then the antenna is rotated so that its plane is parallel to the magnetic flux, the measured response shall decrease by at least 20 dB.

4.4 Frequency range 150 kHz to 30 MHz

4.4.1 Electric antenna

For the measurement of the electric component of the radiation, either a balanced or an unbalanced antenna may be used. If an unbalanced antenna is used, the measurement will refer only to the effect of the E -field on a monopole (rod) antenna. The type of antenna used shall be stated with the results of the measurements.

Information pertaining to calculating the performance characteristics of a monopole (rod) antenna and the characterization of its matching network is specified in Annex B. Annex B states that the antenna factor derived by the Equivalent Capacitance Substitution Method (ECSM) has greater uncertainties for monopole lengths greater than one-eighth of a wavelength.

The unit of electric field strength shall be $\mu\text{V/m}$. In logarithmic units, E shall be expressed in $\text{dB}(\mu\text{V/m})$, or 20 times the log of the measured field strength level. The associated emission limit shall be expressed in the same units.

4.4.2 Magnetic antenna

For the measurement of the magnetic component of the radiation, an electrically-screened loop antenna, as described in 4.3.2 shall be used.

NOTE Tuned electrically balanced loop antennas may be used to make measurements of magnetic field strengths as low as $-51,5 \text{ dB}(\mu\text{A/m})$ using QP detection in the frequency range 1,6 MHz to 30 MHz, i.e. lower than with untuned electrically-screened loop antennas where the noise level is approximately 25 dB higher.

4.4.3 Balance/cross-polar performance of antennas

If a balanced E -field antenna is used, it shall comply with the requirement of 4.5.4. If a balanced magnetic field antenna is used, it shall comply with the requirement of 4.3.3.

4.5 Frequency range 30 MHz to 1 000 MHz

4.5.1 General

In this frequency range, the measurements are of the E -field, so magnetic field antennas are not included. The antenna shall be a dipole-like antenna designed to measure the E -field, and the free-space antenna factor shall be used. The antenna types include:

- a) tuned dipole antennas, whose element pairs are either straight rods or conical in shape;
- b) dipole arrays such as the log-periodic dipole array (LPDA) antennas, comprising a series of staggered sets of straight rod elements;
- c) and hybrid antennas.

4.5.2 Low-uncertainty antenna for use if there is an alleged non-compliance to the E -field limit

For lower measurement uncertainty, the value of E -field measured by a typical biconical antenna or LPDA antenna is preferred, in particular over hybrid antennas. Typical biconical and LPDA antennas are defined in Annex A and only calibrated antennas shall be used.

NOTE 1 Improved uncertainties are achieved by using the biconical antenna over the frequency range 30 MHz to 250 MHz and the LPDA antenna over the range 250 MHz to 1 GHz. Alternatively, a change-over frequency of 200 MHz can be used, but uncertainties due to phase centre variations of the LPDA will be higher and should be included in the reported radiated emissions measurement uncertainty budget.

NOTE 2 The measurement uncertainty of radiated emissions from an EUT depends on many different influence factors such as the quality of the site, antenna factor uncertainty, antenna type, and the measurement receiver characteristics. The reason for defining low-uncertainty antennas is to limit other antenna influences on the measurement uncertainty, such as the effect of mutual coupling with a ground plane, the radiation pattern with respect to height scanning, and the variable phase centre position. Verification of effects of these influences is a comparison of the readings of the two antennas at the selected change-over frequency, which should give the same value of E -field within a margin of $\pm 1 \text{ dB}$.

4.5.3 Antenna characteristics

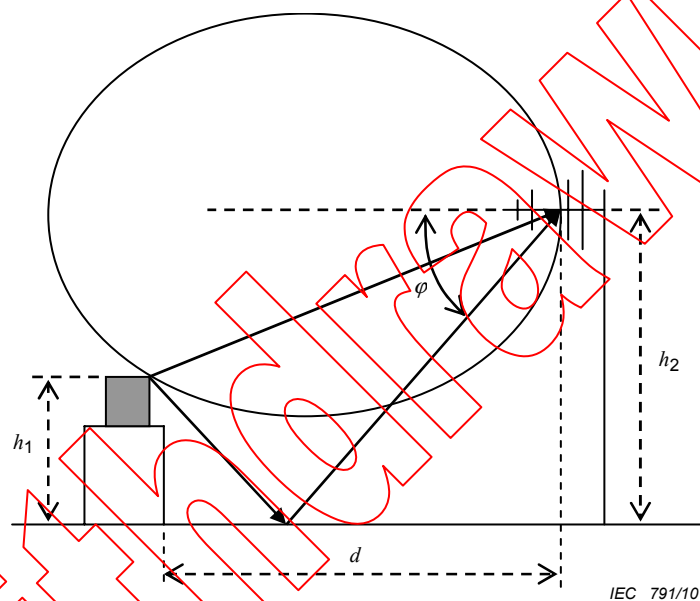
Given that at the frequencies in the range 300 MHz to 1 000 MHz, the sensitivity of the simple dipole antenna is low, a more complex antenna may be used. Such an antenna shall have characteristics as follows.

- a) The antenna shall be linearly polarized, which shall be evaluated by applying the cross-polarization test procedure of 4.5.5.
- b) Balanced dipole antennas, such as tuned-dipole and biconical antennas, shall have validated balun performance, which shall be evaluated by applying the balance test procedure of 4.5.4. This also applies to hybrid antennas below 200 MHz.

- c) A test site with a conducting ground plane is assumed. The amplitude of the received signal will be reduced if either or both the direct and ground reflected signals from the EUT to the antenna are not entering the main lobe of the radiation pattern of the antenna at its peak. The peak is usually in the boresight direction of the antenna. This reduction in amplitude is taken to be an error in the radiated emission; the ensuing uncertainty tolerance is based on the beamwidth, 2φ (see Figure 1).

Conditions for ensuring that this error is no larger than +1 dB are given below in item 1) for a 10 m site and item 2) for a 3 m site. Alternatively, a condition based on antenna gain is given in item 3) in order to bypass the laborious radiation pattern conditions.

Emission measurements are performed with the antenna horizontally and vertically polarized. If it is chosen to measure the radiation patterns in only one plane, the narrower patterns shall be used, as follows: the pattern of the antenna shall be verified in the horizontal plane while orienting it for horizontal polarization.



NOTE Quantities are defined in Equation (4).

Figure 1 – Schematic of radiation from EUT reaching an LPDA antenna directly and via ground reflections on a 3 m site, showing the half beamwidth, φ , at the reflected ray

- 1) For a 10 m OATS or SAC, the antenna response in the direction of the direct ray differs negligibly from the boresight amplitude when the antenna is aligned such that its boresight direction is parallel to the ground plane. The directivity component of the uncertainty in the emission measurement can be kept to less than +1 dB if the antenna response in the direction of the reflected ray is no more than 2 dB lower than the antenna boresight response. To ensure this condition, the total vertical beamwidth 2φ of the measurement antenna, within which the antenna gain is within 2 dB of its maximum, shall be such that:

$$\varphi > \tan^{-1} \frac{h_1 + h_2}{d} \quad (3)$$

- 2) For sites with less than 10 m separation, typically 3 m, the total vertical beamwidth 2φ of the measurement antenna, within which the antenna gain is within 1 dB of its maximum, shall be such that:

$$2\varphi > \left(\tan^{-1} \frac{h_1 + h_2}{d} \right) - \left(\tan^{-1} \frac{h_1 - h_2}{d} \right) \quad (4)$$

where

- h_1 is the height of the equipment under test;
- h_2 is the measurement antenna height;
- d is the horizontal distance between the phase centre of the measurement antenna and the device under test.

If antenna down-tilting that would reduce the associated uncertainties is not employed, the reduction in received signal shall be calculated from the radiation patterns and applied as corrections or as directivity uncertainties. Example uncertainty budgets are given in CISPR 16-4-2.

NOTE 1 Assuming an E -field radiation pattern normalised to unity on boresight (= peak of mainlobe) read the E -field at the angles of declination from the antenna for the direct, E_D , and reflected rays, E_R . The error, compared to an E -field of unity magnitude for each of the direct and reflected rays, is given in decibels by $20 \log [2/(E_D + E_R)]$.

NOTE 2 The reduction in signal strength caused by reduced directivity at angles off antenna boresight is a systematic error and therefore can be corrected. If a correction is applied, from knowledge of the radiation patterns at each frequency and polarization, the uncertainty in emitted signal strength can be reduced accordingly.

- 3) For broad beamwidth antenna types used for radiated emission testing, such as biconical, LPDA and hybrid antennas, the beamwidth is inversely related to antenna directivity. An alternative to the criterion based on beamwidths in items 1) and 2), is to specify the maximum gain of an antenna and to refer to generic uncertainty tolerances for the directivity component in the uncertainty budget for an emission test. The generic uncertainties, based on the narrowest beamwidths in the frequency range used for a given antenna, are given in CISPR 16-4-2. The maximum isotropic antenna gain for biconical antennas shall be 2 dB, and shall be 8 dB for log-periodic dipole array (LPDA) and hybrid antennas. For V-type LPDA antennas, whose H -plane beamwidth is equalised to the E -plane beamwidth, the maximum permissible isotropic gain shall be 9 dB.

NOTE 3 The directivity uncertainties given in CISPR 16-4-2 can be used for a 10 m separation, but revised uncertainties are needed for a 3 m separation.

- d) The return loss of the antenna with the antenna feeder connected shall not be less than 10 dB. A matching attenuator may be part of the feeder cable for antennas if needed to meet this requirement.
- e) A calibration factor shall be given making it possible to fulfil the requirements of 4.1.

4.5.4 Balance of antenna

4.5.4.1 General

In radiated emission measurements, common-mode (CM) currents may be present on the cable attached to the receiving antenna (the antenna cable). In turn, these CM currents create electromagnetic fields that may be picked up by the receiving antenna. Consequently, the radiated emission measuring results may be influenced.

The major contributions to the antenna cable CM currents stem from

- a) the E -field generated by the EUT, if that field has a component parallel to the antenna cable, and
- b) the conversion of the differential mode (DM) antenna signal (the desired signal) into a CM signal by the imperfection of the balun of the receiving antenna.

In general, log-periodic dipole array antennas do not exhibit significant DM/CM conversion and the following check applies to dipoles, biconical antennas and hybrid antennas.

4.5.4.2 Balun DM/CM conversion check

The following method describes the measurement of two voltages, U_1 and U_2 , in the frequency range for which the receiving antenna is to be used. The ratio of these voltages, both expressed in identical units, e.g. dB(μ V), is a measure for the DM/CM conversion.

- a) Set the receiving antenna under test vertically polarized with its centre at a height of 1,5 m above the ground plane. Extend a 1,5 m $\pm$ 0,1 m length of the antenna cable behind the rear active element of the receiving antenna at a height of 1,5 m above the ground plane and then allow it to drop vertically to the ground plane.
- b) Place a second (transmitting) antenna vertically polarized at a horizontal distance of 10 m from the centre of the antenna under test. The transmitting antenna shall be positioned such that the end of its largest active element is at a height of 0,10 m above the ground plane. If the range of the site used for emission testing is 3 m, do this check using a distance of 3 m (if the conversion check has already been made at 10 m distance and shows a difference between U_1 and U_2 of less than $\pm 0,5$ dB, it is not necessary to take a separate measurement at 3 m). The specification of the transmitting antenna shall include the frequency range of the antenna under test.
- c) Connect the transmitting antenna to a signal source, for example, a tracking generator, set the level of that generator in such a way that, over the frequency range of interest, the signal-to-ambient noise at the receiver is larger than 10 dB.
- d) Record the voltage U_1 at the receiver over the frequency range of interest.
- e) Invert the receiving antenna (rotate that antenna through 180°) without changing anything else in the set-up, in particular the receiving antenna cable, and without changing the setting of the signal source.
- f) Record the voltage U_2 at the receiver over the frequency range.
- g) The DM/CM conversion is sufficiently low if $20 \log (U_1/U_2) < 1$ dB.

NOTE 1 If the DM/CM conversion criterion is not met, ferrite rings around the antenna cable may reduce the DM/CM conversion. The addition of ferrites on the antenna cable may also be used to verify whether the contribution of item a) of 4.5.4.1 has a non-negligible effect. Repeat the test with four ferrites spaced approximately 20 cm apart. If the criterion is met by using these rings, they should be present in the actual emission measurement. Likewise, the interaction with the cable can be reduced by extending the cable several metres behind the antenna before dropping to ground.

NOTE 2 If the receiving antenna is used in a FAR, the DM/CM check may be performed in that room with the receiving antenna at its usual location and the transmitting antenna in the centre of the test volume of that room. The room should comply with the ± 4 dB criterion.

NOTE 3 The measuring site of which the ground plane forms a part, or the fully-anechoic room, should comply with their respective NSA (normalized site attenuation) requirements.

NOTE 4 The horizontal distance of 1,5 m over which the antenna cable runs horizontally behind the centre of the antenna should be kept as a minimum during actual vertically polarized radiated emissions measurements.

NOTE 5 It is not necessary to strictly define a test set-up because this effect is dominated by the interaction of the antenna and that part of the antenna cable that lies parallel to the antenna elements. There is a much smaller effect that is dependent on the uniformity of the field incident on the receiving antenna in normal EMC set-ups on an OATS or in a FAR.

NOTE 6 For baluns that have the receive cable connector mounted on the side (90° to the antenna boom), a right angle connector should be used to reduce the movement of the cable.

4.5.5 Cross-polar response of antenna

When an antenna is placed in a plane-polarized electromagnetic field, the terminal voltage when the antenna and field are cross-polarized shall be at least 20 dB below the terminal voltage when they are co-polarized.

It is intended that this test applies to log-periodic dipole array (LPDA) antennas for which the two halves of each dipole are in echelon. A test method to establish this requirement for LPDA antennas is presented. The majority of testing with such antennas is above 200 MHz, but the requirement applies over the entire frequency range of 30 MHz to 1 000 MHz. This test is not intended for in-line dipole and biconical antennas because a cross-polar rejection greater than 20 dB is intrinsic to their symmetrical design. Such antennas and horn antennas shall have a cross-polar rejection greater than 20 dB and a type test by the manufacturer should confirm this.

In order to achieve quasi-free space conditions, a high-quality anechoic chamber or towers of sufficient height above ground on an outdoor range can be used. To minimize ground reflections, set the antennas vertically polarized. A plane wave shall be set up at the antenna under test. The separation between the centre of the antenna under test and the source antenna shall be greater than one wavelength.

NOTE A good-quality site is needed to set up a plane wave at the antenna under test. The cross-polar discrimination afforded by the plane wave can be proven by transmitting between a pair of horn antennas or open-ended waveguides and checking that the combination of site error and inherent cross-polar performance of one horn antenna yields a suppression of the horizontal component by more than 30 dB. If the site errors are very low and if the horn antennas have identical performance, the cross-polar performance of one horn is approximately 6 dB lower than the combined cross-polar coupling of the pair of horns.

An interfering signal 20 dB lower in level than the desired signal gives a maximum error on the desired signal of $\pm 0,9$ dB. The maximum error occurs when the cross-polar signal is in phase with the co-polar signal. If the cross-polar response of the LPDA is worse than 20 dB, the operator shall calculate the uncertainty and declare it with the result. For example, a cross-polar level of 14 dB implies a maximum uncertainty of +1,6 dB to –1,9 dB. Take the larger value and assume a U-shaped distribution when calculating the standard uncertainty.

To add a signal of 0 dB to another of –14 dB, first convert to relative voltages by dividing by 20 and taking the anti-log. Then add the smaller signal to the unity signal. Take the log and multiply by 20. The result is the positive decibel error. Repeat, but subtract the smaller signal from the unity signal to give the negative decibel error.

For the purpose of calculating the uncertainty of a radiated emission measurement, if the signal level measured in one polarization exceeds the signal measured in the orthogonal polarization by 6 dB or more, then an LPDA whose cross-polar discrimination is only 14 dB will have been deemed to have met the specification of 20 dB. If the difference between the vertically and horizontally polarized signal levels is less than 6 dB, additional uncertainty shall be calculated if the sum of this difference and the cross-polarization is less than 20 dB.

4.6 Frequency range 1 GHz to 18 GHz

Radiated emissions measurements above 1 GHz shall be made using calibrated, linearly polarized antennas. Examples are LPDA antennas, double-ridged guide horns and standard gain horns. The "beam" or main lobe of the pattern of any antenna used shall be large enough to encompass the EUT when located at the measuring distance, or provisions shall be made for "scanning" the EUT to locate the direction or source of its radiated emissions. The width of the main lobe is defined as the 3 dB beamwidth of the antenna, and information enabling the determination of this parameter should be given in the antenna documentation. For horn antennas, the following condition shall be satisfied:

$$d \geq \frac{D^2}{2\lambda} \quad (5)$$

where

- d is the measurement distance (m);
- D is the largest dimension of the aperture of the antenna (m); and
- λ is the free space wavelength at the frequency of measurement (m).

4.7 Special antenna arrangements – Loop antenna system

In the frequency range 9 kHz to 30 MHz, the interference capability of the magnetic field component of the radiation of a single EUT can be determined by using a special loop antenna system (LAS). In the LAS, this capability is measured in terms of the currents induced by the magnetic field in the loop antennas of the LAS. The LAS measures the current induced by the magnetic field component of the single EUT. The LAS allows indoor measurements.

The LAS consists of three circular, mutually perpendicular large-loop antennas (LLAs), having a diameter of 2 m, supported by a non-metallic base. A full description of the LAS is given in Annex C.

The EUT is positioned in the centre of the LAS. The maximum dimensions of the EUT are limited so that the distance between the EUT and an LLA is at least 0,20 m. Guidelines for the routing of signal cables are given in Note 2 of Clause C.3, and Figure C.6. Cables should be routed together and leave the loop volume in the same octant of the cell and no closer than 0,4 m to any of the LAS loops.

The three mutually perpendicular LLAs allow measurement of the interference capability of all polarizations of the radiated field with the prescribed accuracy, and without rotation of the EUT or changing the orientation of the LLAs.

Each of the three LLAs shall comply with the validation requirements given in Clause C.4.

NOTE Circular LLAs having a diameter different from the standardized diameter of 2 m may be used, provided their diameter $D \leq 4$ m and the distance in m between the EUT and a LLA is at least $0,10 \times D$. Correction factors for non-standardized diameters are given in Clause C.6.

5 Test sites for measurement of radio disturbance field strength for the frequency range of 30 MHz to 1 000 MHz

5.1 General

An environment is required that assures valid, repeatable measurement results of disturbance field strength from equipment. For equipment that can only be tested in its place of use, different provisions have to be utilized.

5.2 OATS

5.2.1 General

Disturbance field-strength measurements are normally performed at an open area test site. OATS are areas characteristic of cleared level terrain. Such test sites shall be void of buildings, electric lines, fences, trees, etc. and free from underground cables, pipelines, etc., except as required to supply and operate the EUT. Refer to Annex D for specific construction recommendations for OATS for electromagnetic field tests in the range of 30 MHz to 1 GHz.

The site validation procedure for OATS is given in 5.2.6 with further details in Annex E. Annex F contains the acceptability criterion.

5.2.2 Weather protection enclosure

Weather protection is desirable if the test site is used throughout the year. A weather protection structure could protect either the whole test site (including EUT and field strength measuring antenna) or the EUT only. The materials used shall be RF transparent in order to cause no undesirable reflections and attenuation of the emitted field from the EUT (see 5.3.1).

The structure shall be shaped to allow easy removal of snow, ice or water. For further details, see Annex D.

5.2.3 Obstruction-free area

For open area test sites, an obstruction-free area surrounding the EUT and field-strength measuring antenna is required. The obstruction-free area shall be free from significant scatterers of electromagnetic fields, and shall be large enough so that scatterers outside the obstruction-free area will have little effect on the fields measured by the field-strength measuring antenna. To determine the adequacy of this area, site validation tests shall be performed.

Since the magnitude of the field scattered from an object depends on many factors (size of the object, distance from the EUT, orientation with respect to the EUT, conductivity and permittivity of the object, frequency, etc.), it is impractical to specify a reasonable obstruction-free area, which is necessary and sufficient for all applications. The size and shape of the obstruction-free area are dependent upon the measurement distance and whether or not the EUT will be rotated. If the site is equipped with a turntable, the recommended obstruction-free area is an ellipse with the receiving antenna and EUT at the two foci and having a major axis equal to twice the measurement distance and a minor axis equal to the product of the measurement distance and the square root of 3 (see Figure 2).

For this ellipse, the path of the undesired ray reflected from any object on the perimeter is twice the length of the direct ray path between the foci. If a large EUT is installed on the turntable, the obstruction-free area shall be expanded so that the obstruction clearance distances exist from the perimeter of the EUT.

If the site is not equipped with a turntable, that is, the EUT is stationary, the recommended obstruction-free area is a circular area such that the radial distance from the boundary of the EUT to the boundary of the area is greater than or equal to the measurement distance multiplied by 1,5 (see Figure 3). In this case, the antenna is moved around the EUT at the separation distance.

The terrain within the obstruction-free area shall be flat. Small slopes needed for adequate drainage are acceptable. The flatness of the metallic ground plane, if used, is discussed in Clause D.2. Measuring apparatus and test personnel shall be situated outside the obstruction free area.

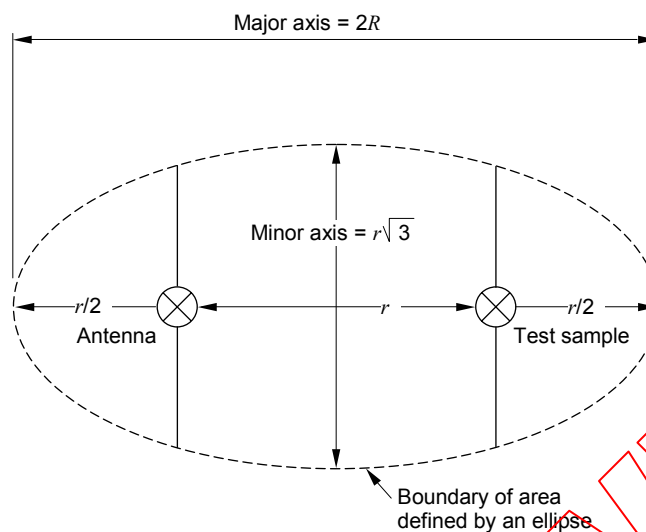


Figure 2 – Obstruction-free area of a test site with a turntable (see 5.2.3)

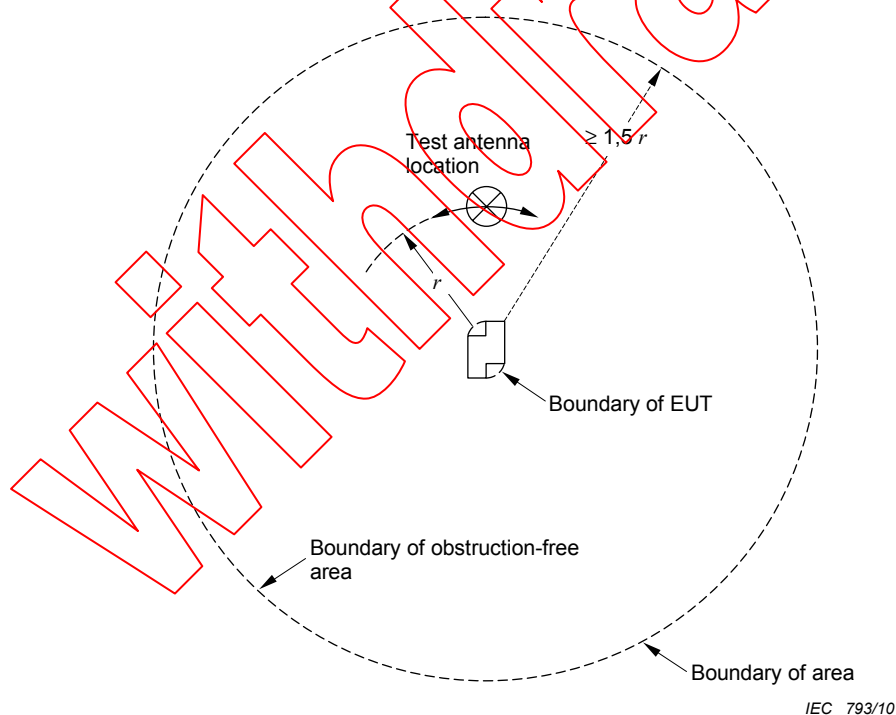


Figure 3 – Obstruction-free area with stationary EUT (see 5.2.3)

5.2.4 Ambient radio frequency environment of a test site

The ambient radio frequency levels at a test site shall be sufficiently low compared to the levels of measurements to be performed. The quality of the site in this respect may be assessed in four categories, listed below in their order of merit:

- a) the ambient emissions are 6 dB or more below the measurement levels;
- b) some ambient emissions are within 6 dB of the measurement levels;

- c) some ambient emissions are above the measurement levels, but are either aperiodic (i.e. sufficiently long in time between transmissions to allow a measurement to be made) or continuous, but only on limited identifiable frequencies;
- d) the ambient levels are above the measurement levels over a large portion of the measurement frequency range and occurring continuously.

The selection of a test site should ensure that the accuracy of the measurement is maintained given the environment and the degree of engineering skill available.

NOTE An ambient level of 20 dB or more below the measured emissions limit is considered optimum.

5.2.5 Ground plane

The ground plane may be composed of a wide range of material from earth to highly conductive, metallic material. The plane can be at earth level or elevated on a suitably sized platform or roof site. A metal ground plane is preferred, but for certain equipment and applications, it may not be recommended by certain product publications. Adequacy of the metal ground plane will be dependent on whether the test site meets the site validation requirements in 5.2.6. If no metallic material is used, caution is required to select a site that does not change its reflective characteristics with time, weather condition, or, due to buried metallic material such as pipes, conduits, and non-homogeneous soil. Such sites generally give different site attenuation characteristics compared to those with metallic surfaces.

5.2.6 OATS validation procedure

5.2.6.1 General

The validation procedure and the requirements for the NSA given here are used to qualify an OATS with a metallic ground plane. For other test sites, the validation procedure is of an informative nature, and will in general also identify possible site irregularities that should be investigated. Validation procedures applicable to absorber-lined rooms are given in 5.4.

The validation of an open area test site is performed with two antennas oriented horizontally and vertically with respect to the ground, as shown in Figures 4 and 5, respectively. Figure 5 shows the configuration for vertical polarization using tuned dipole antennas. For broadband antennas, the antenna heights shall be $h_1 = h_{2\min} = 1 \text{ m}$.

The open area site attenuation is obtained from the ratio of the source voltage, V_i connected to a transmitting antenna and the received voltage, V_R as measured on the receiving antenna terminals. The voltage measurements are performed in a 50Ω system. Suitable corrections for cable losses are required if V_R and V_i are not measured at the input and output of the transmit and receive antenna, respectively. This site attenuation ratio is then divided by the product of the antenna factors for the two antennas used. The resulting answer is the NSA and is expressed in dB. The site is considered suitable when the measured vertical and horizontal NSA values are within $\pm 4 \text{ dB}$ of the values given in Tables E.1, E.2, and E.3 as appropriate. If the $\pm 4 \text{ dB}$ criterion is exceeded, the test site shall be investigated per Clause E.4.

NOTE 1 The basis for the 4 dB site acceptability criterion is given in Annex F.

The deviation between a measured NSA value and the theoretical value shall not be used as a correction for a measured EUT field strength. This procedure shall be used only for validating a test site.

Table E.1 is used for broadband antennas such as biconical and log periodic arrays both horizontally and vertically aligned with respect to the ground plane. Table E.2 is for tuned half-wave dipoles aligned horizontally with respect to the ground plane. Table E.3 is for tuned half-wave dipoles vertically aligned with respect to the ground plane. Note that in Table E.3, there are restrictions in the scan height h_2 . This takes into account the fact that the lowest tip of the receive dipole is kept 25 cm or more from the ground plane.

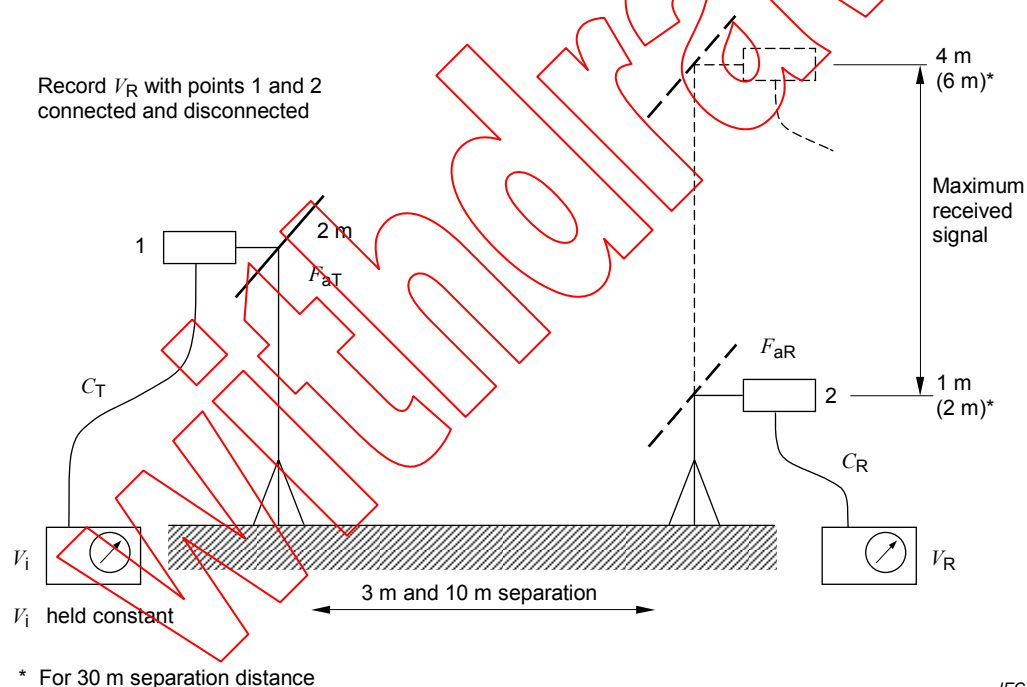
NOTE 2 The reason for the different Tables E.1, E.2 and E.3 is that different geometrical parameters are chosen for a broadband antenna and a tuned half-wave dipole, primarily because of practical restrictions needed for the latter.

NSA values for frequencies other than those shown in Tables E.1, E.2 and E.3 may be found using linear interpolation between the tabulated values.

The legend for each table is as follows:

- d horizontal separation distance between the projection of the transmit and receive antennas on the ground plane (m);
- h_1 height of the centre of the transmit antenna above the ground plane (m);
- h_2 range of heights of the centre of the receive antenna above the ground plane (m). The maximum received signal in this height scan range is used for NSA measurements;
- f_M frequency (MHz);
- A_N NSA [see Equation (6), below].

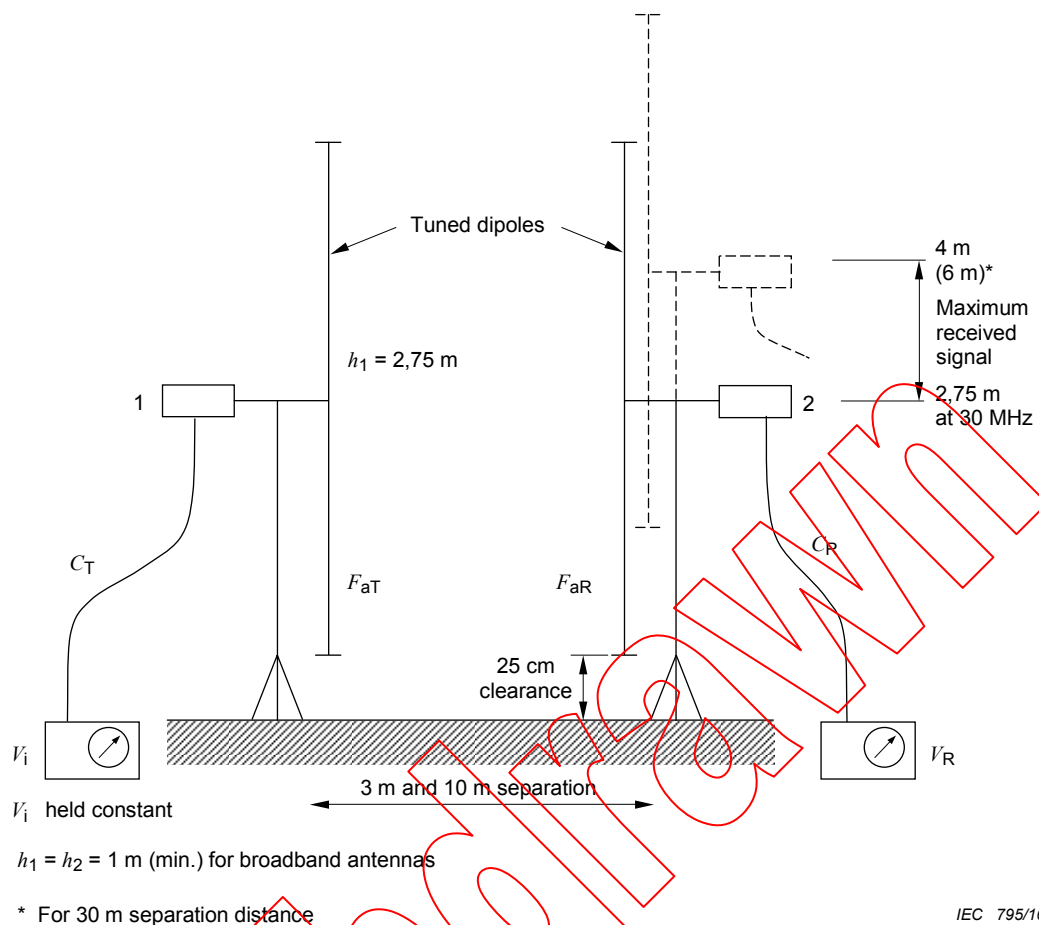
NOTE 3 The spacing d between log-periodic array antennas is measured from the projection on to the ground plane of the mid-point of the longitudinal axis of each antenna.



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NOTE Symbols are defined in 5.2.6.1 and 5.2.6.2.

Figure 4 – Configuration of equipment for measuring site attenuation in horizontal polarization (see 5.2.6 and Annex E)



NOTE Symbols are defined in 5.2.6.1 and 5.2.6.2.

Figure 5 – Configuration of equipment for measuring site attenuation in vertical polarization using tuned dipoles (see 5.2.6 and Annex E)

It is recommended that horizontal NSA measurements be performed first. Since such measurements are less sensitive than that for vertical polarization in finding site anomalies, the measured NSA should readily be within ± 4 dB of that shown in Tables E.1, E.2 and E.3. If not, recheck measurement technique, instrumentation drift and antenna factor calibrations. If the ± 4 dB criterion is still exceeded, a significant site anomaly is present that should be readily apparent and corrective action taken before proceeding to the vertical polarization NSA measurement.

5.2.6.2 General NSA measurement

For each polarization measurement, the NSA procedure requires two different measurements of the received voltage, V_R . The first reading of V_R (V_{DIRECT}) is with the two coaxial cables disconnected from the two antennas and connected to each other via an adapter. The second reading of V_R (V_{SITE}) is taken with the coaxial cables reconnected to their respective antennas and the maximum signal measured when the receive antenna is scanned in height. (1 m to 4 m for 3 m and 10 m separation distances and either 1 m to 4 m or 2 m to 6 m for the 30 m separation.) For both of these measurements, the signal source voltage, V_i , is kept constant. These are used in the following Equation (6) for the measured NSA, $A_{N \text{ meas}}$; all terms are in dB.

$$A_{N\text{meas}} = V_{\text{DIRECT}} - V_{\text{SITE}} - F_{aT} - F_{aR} - \Delta F_{a\text{TOT}} \quad (6)$$

where

- F_{aT} is the transmit antenna factor;
 F_{aR} is the receive antenna factor;
 $\Delta F_{a\text{TOT}}$ is the mutual impedance correction factor.

Note that the first two terms represent the actual measurement of site attenuation, i.e. the classical view of site attenuation is equal to $V_{\text{DIRECT}} - V_{\text{SITE}}$, which is constituted by the insertion loss of the propagation path with the inclusion of the properties of the two antennas used. Theoretical values for $\Delta F_{a\text{TOT}}$ are given in Table E.4. F_{aT} and F_{aR} shall be measured.

Note that:

$$V_{\text{DIRECT}} = V_i - C_T - C_R \quad (7)$$

where C_T and C_R are cable losses that do not need to be measured separately. The mutual impedance correction factor in Table E.4 applies only to the recommended site geometry of 3 m separation and with the use of half-wavelength tuned dipoles.

To accomplish these NSA measurements, two techniques can be used, depending on the instrumentation available and whether a broadband or tuned dipole is used. Both methods give essentially equal results if used correctly as outlined in Annex E. Briefly, each method is described as follows.

a) Discrete frequency method

For this method, specific frequencies given in Tables E.1, E.2 or E.3 are measured in turn. At each frequency, the receive antenna is scanned over the height range given in the appropriate table to maximize the received signal. These measured parameter values are inserted in Equation (6) to obtain the measured NSA. Annex E contains a suggested procedure approach to record the data, calculate the measured NSA, and then compare it with the theoretical NSA.

b) Swept frequency method

For this method, measurements using broadband antennas may be made using automatic measuring equipment having a peak hold (maximum hold), storage capability, and a tracking generator. In this method, both antenna height and frequency are scanned or swept over the required ranges. The frequency sweep speed shall be much greater than the antenna height scan rate. Otherwise the procedure is the same as in item a). A detailed procedure is given in Annex E.

5.2.6.3 Antenna factor determination

Accurate antenna factors are necessary in measuring NSA. In general, antenna factors provided with the antenna are inadequate unless they are specifically or individually measured. Linearly polarized antennas are required. A useful antenna calibration method is contained in Annex E. Manufacturer's antenna factors may account for losses due to the balun among other features. If a separate balun or any integrally associated cables are used, their effects shall be accounted for. The formula to use for tuned half-wave dipoles is also contained in Annex E.

5.2.6.4 Site attenuation deviations

If measurements of NSA deviate by more than ± 4 dB, several items should be re-checked first:

- a) measurement procedure;
- b) accuracy of antenna factors;
- c) drift in signal source or accuracy of receiver or spectrum analyzer input attenuator; and
- d) reading.

If no errors are found in items a), b), c) and d), then the site is at fault and detailed investigation of possible causes of site variability should be made. Annex F contains the errors that can occur with NSA measurements.

Note that since the vertical polarization is generally the more critical measurement, site anomalies should be investigated using this more sensitive measurement rather than the horizontal polarization results. Key items to investigate include:

- 1) ground plane size and construction inadequacy;
- 2) objects at the perimeter of the site that may be causing undesired scattering;
- 3) all-weather cover;
- 4) ground plane discontinuity at the turntable circumference when the turntable surface is conductive and at the same elevation as the ground plane;
- 5) thick dielectric ground plane covers;
- 6) openings in ground plane for stairways.

5.3 Test site suitability for other ground-plane test sites

5.3.1 General

There are many different test sites and facilities that have been constructed to make radiated emission measurements. Most are protected from the weather and the adverse effects of the radio frequency ambient. These include all weather-covered open area test sites and absorber-lined shielded rooms.

Whenever construction material encloses a test site, there is the possibility that the results of a single normalized site attenuation (NSA) measurement, as specified in 5.2.6, are not adequate to show such alternative site suitability.

To assess alternative test site suitability, the following procedure is recommended. It is based on making multiple NSA measurements throughout a volume occupied by the EUT. These NSA measurements shall all come within the error budget of ± 4 dB to be judged suitable as an equivalent to an open area test site.

The discussion in this subclause concerns alternative test sites that have a conducting ground plane.

5.3.2 Normalized site attenuation for alternative test sites

For an alternative test site, a single NSA measurement is insufficient to pick up possible reflections from the construction and/or RF-absorbing material comprising the walls and ceiling of the facility. For these sites, a "test volume" is defined as that volume traced out by the largest equipment or system to be tested as it is rotated about its centre location through 360° , such as by a turntable. In evaluating horizontal and vertical polarization, such as illustrated in Figure 6 and Figure 7, it may require a maximum of 20 separate site attenuation measurements, i.e. five positions in the horizontal plane (centre, left, right, front, and rear, measured with respect to the centre and a line drawn from the centre to the position of the measuring antenna), for two polarizations (horizontal and vertical), and for two heights (1 m and 2 m horizontal, 1 m and 1,5 m vertical).

These measurements are carried out with a broadband antenna and distances are measured with respect to the centre of the antenna. The transmit and receive antennas shall be aligned with the antenna elements parallel to each other and orthogonal to the measurement axis.

For vertical polarization, the off-centre positions of the transmit antenna are at the periphery of the test volume. Furthermore, the lower tip of the antenna shall be greater than 25 cm from the floor, which may require the centre of the antenna to be slightly higher than 1 m for the lowest height measurement.

For horizontal polarization measurements in the left and right positions if the distance between the construction and/or absorbing material on the side walls and EUT periphery is at least 1 m, the centre of the antenna is moved towards to central position so that the extreme tip of the antenna is either at the periphery or distant from the periphery by not more than 10 % of the test volume diameter. The front and rear positions are at the periphery of the test volume.

The number of required measurements can be reduced under the following circumstances.

- a) The vertical and horizontal polarization measurements in the rear position may be omitted if the closest point of the construction and/or absorbing material is at a distance greater than 1 m from the rear boundary of the test volume.

NOTE 1 Radiated emission sources located near dielectric interfaces have been shown to have variations in current distribution that can affect the radiated properties of the source at that location. When EUT can be located near these interfaces, additional site attenuation measurements are required.

- b) The total number of horizontal polarization measurements along the test volume diameter joining the left and right positions may be reduced to the minimum number necessary for the antenna footprints to cover 90 % of the diameter.
- c) The vertical polarization measurements at the 1,5 m height may be omitted if the top of the EUT, including any table mounting, is less than 1,5 m in height.
- d) If the test volume is no larger than 1 m in depth, by 1,5 m in width, by 1,5 m in height, including table if used, horizontal polarization measurements need only be made at the centre, front and rear positions but at the height of both 1 m and 2 m. If item a) above applies, the rear position may be omitted. This will require a minimum of eight measurements: four positions vertical polarization (left, centre, right, and front) for one height, and four positions horizontal polarization (centre and front) for two heights; see Figure 8 and Figure 9.

NSA measurements shall be performed with the transmit and receive antenna separation held constant according to Tables 1 and 2. Note that these tables have been modified to accommodate these NSA measurements by adding values for an additional transmit height and to limit the 30 m scan height to between 1 m and 4 m. The receive antenna shall be moved to maintain the appropriate separation along a line towards the turntable centre (see Figures 6, 7, 8, and 9). The alternative test site is considered suitable for performing radiated emission testing if all NSA measurements prescribed above meet the requirements of 5.3.3 and the ground plane requirements of 5.3.4 below.

NOTE 2 Studies are underway to determine if any further tests are required to show alternate test site suitability.

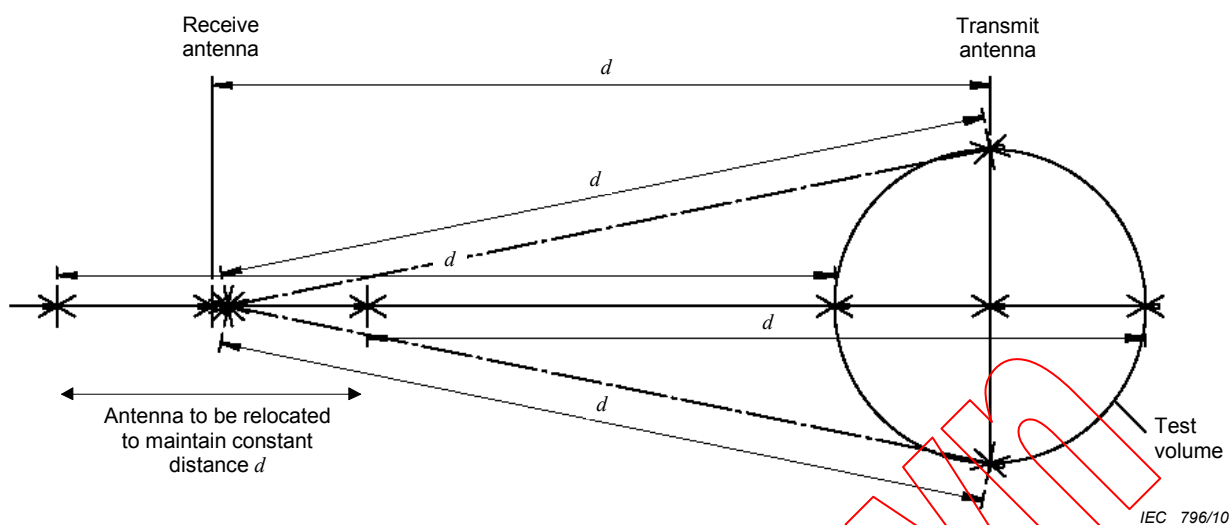


Figure 6 – Typical antenna positions for alternative test site – Vertical polarization NSA measurements

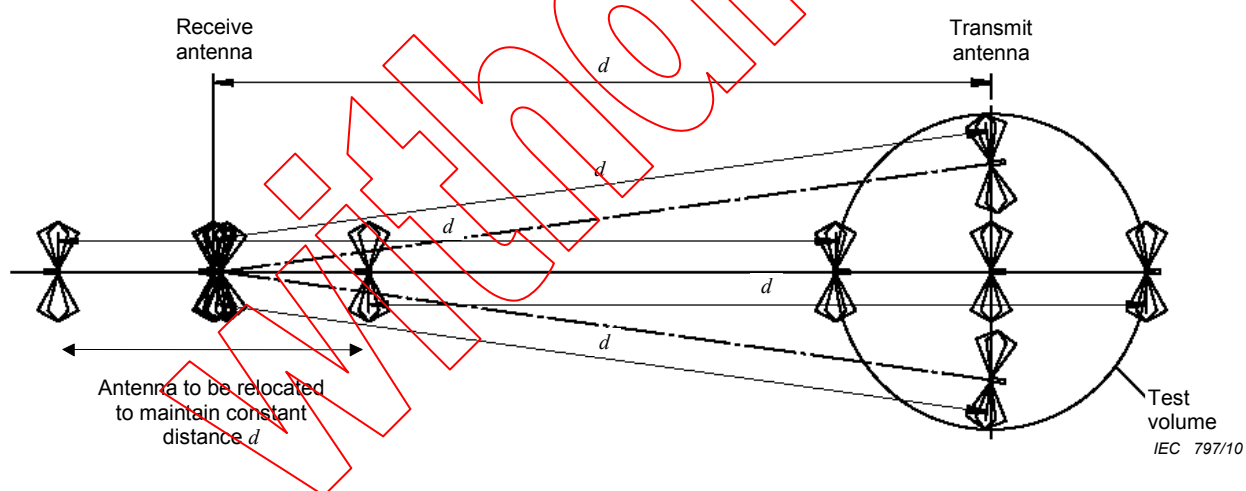
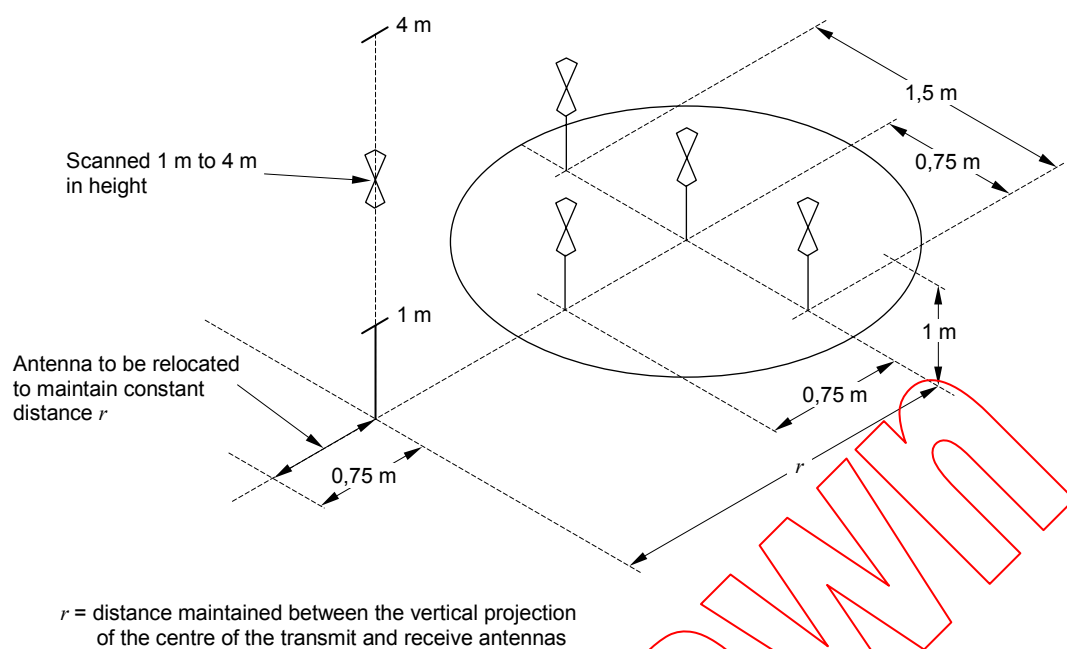
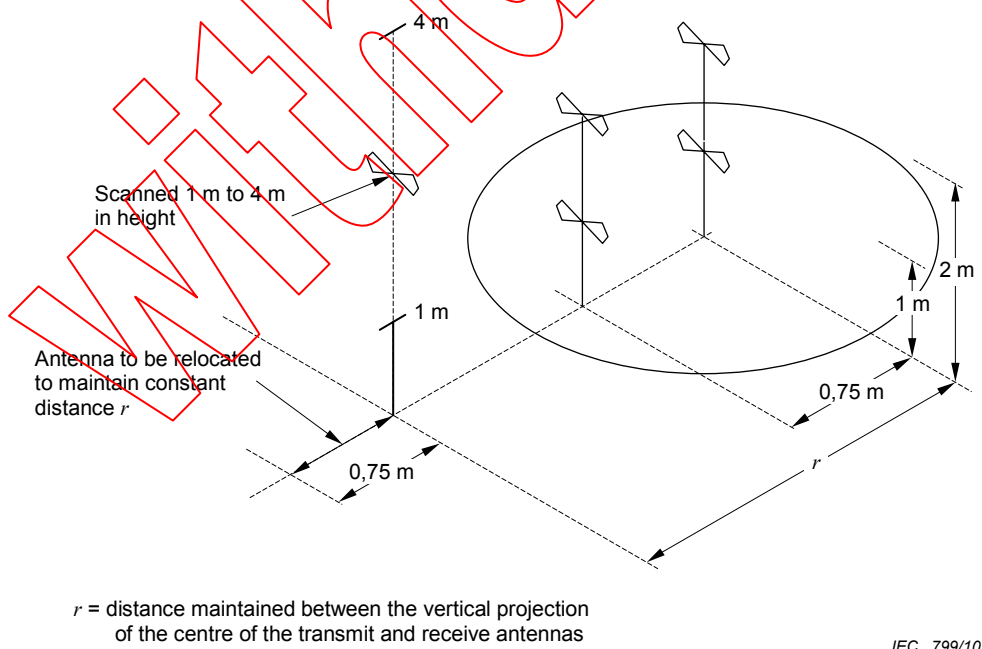


Figure 7 – Typical antenna positions for alternative test site – Horizontal polarization NSA measurements



NOTE EUT does not exceed a volume of 1 m depth, 1,5 m width, 1,5 m height, with the periphery greater than 1 m from the closest material that may cause undesirable reflections.

Figure 8 – Typical antenna positions for alternative test site – Vertical polarization NSA measurements for a smaller EUT



NOTE EUT does not exceed a volume of 1 m depth, 1,5 m width and 1,5 m height, with the periphery greater than 1 m from the closest material that may cause undesirable reflections.

Figure 9 – Typical antenna positions for alternative test site – Horizontal polarization NSA measurements for a smaller EUT

5.3.3 Site attenuation

A measurement site shall be considered acceptable for radiated electromagnetic field measurements if the measured horizontal and vertical NSA measurements are within ± 4 dB of the theoretical normalized site attenuation for an ideal site.

5.3.4 Conducting ground plane

A conducting ground plane is required at a radiated emission test site. The conducting ground plane shall extend at least 1 m beyond the periphery of the EUT and the largest measurement antenna, and cover the entire area between the EUT and the antenna. It shall be of metal with no holes or gaps having longitudinal dimensions larger than one-tenth of a wavelength at the highest frequency of measurement. A larger size conducting ground plane may be required if the NSA measurements do not meet the ± 4 dB criterion.

NOTE Ongoing studies may indicate the need for specifying minimum conductive ground plane size.

**Table 1 – Normalized site attenuation
(recommended geometries for tuned half-wave dipoles with horizontal polarization)**

Polarization	Horizontal	Horizontal	Horizontal
d	3 m	10 m	30 m
h_1	2 m	2 m	2 m
h_2	1 m to 4 m	1 m to 4 m	1 m to 4 m
f_M MHz	A_N dB		
30	11,0	24,1	41,7
35	8,8	21,6	39,1
40	7,0	19,4	36,8
45	5,5	17,5	34,7
50	4,2	15,9	32,9
60	2,2	13,1	29,8
70	0,6	10,9	27,2
80	-0,7	9,2	24,9
90	-1,8	7,8	23,0
100	-2,8	6,7	21,2
120	-4,4	5,0	18,2
140	-5,8	3,5	15,8
160	-6,7	2,3	13,8
180	-7,2	1,2	12,0
200	-8,4	0,3	10,6
250	-10,6	-1,7	7,8
300	-12,3	-3,3	6,1
400	-14,9	-5,8	3,5
500	-16,7	-7,6	1,6
600	-18,3	-9,3	0
700	-19,7	-10,6	-1,4
800	-20,8	-11,8	-2,5
900	-21,8	-12,9	-3,5
1 000	-22,7	-13,8	-4,5

Table 2 – Normalized site attenuation*
(recommended geometries for broadband antennas)

Polarization	Horizontal	Horizontal	Horizontal	Vertical	Vertical	Vertical	Vertical
d	3 m	10 m	30 m	3 m	3 m	10 m	30 m
h_1	1 m	1 m	1 m	1 m	1,5 m	1 m	1 m
h_2	1 m to 4 m	1 m to 4 m	1 m to 4 m	1 m to 4 m	1 m to 4 m	1 m to 4 m	1 m to 4 m
f_M MHz	A_N dB						
30	15,8	29,8	47,8	8,2	9,3	16,7	26,0
35	13,4	27,1	45,1	6,9	8,0	15,4	24,7
40	11,3	24,9	42,8	5,8	7,0	14,2	23,5
45	9,4	22,9	40,8	4,9	6,1	13,2	22,5
50	7,8	21,1	38,9	4,0	5,4	12,3	21,6
60	5,0	18,0	35,8	2,6	4,1	10,7	20
70	2,8	15,5	33,1	1,5	3,2	9,4	18,7
80	0,9	13,3	30,8	0,6	2,6	8,3	17,5
90	-0,7	11,4	28,8	-0,1	2,1	7,3	16,5
100	-2,0	9,7	27	-0,7	1,9	6,4	15,6
120	-4,2	7,0	23,9	-1,5	1,3	4,9	14,0
140	-6,0	4,8	21,2	-1,8	-1,5	3,7	12,7
160	-7,4	3,1	19	-1,7	-3,7	2,6	11,5
180	-8,6	1,7	17	-1,3	-5,3	1,8	10,5
200	-9,6	0,6	15,3	-3,6	-6,7	1,0	9,6
250	-11,7	-1,6	11,6	-7,7	-9,1	-0,5	7,7
300	-12,8	-3,3	8,8	-10,5	-10,9	-1,5	6,2
400	-14,8	-5,9	4,6	-14,0	-12,6	-4,1	3,9
500	-17,3	-7,9	1,8	-16,4	-15,1	-6,7	2,1
600	-19,1	-9,5	0	-16,3	-16,9	-8,7	0,8
700	-20,6	-10,8	-1,3	-18,4	-18,4	-10,2	-0,3
800	-21,3	-12,0	-2,5	-20,0	-19,3	-11,5	-1,1
900	-22,5	-12,8	-3,5	-21,3	-20,4	-12,6	-1,7
1 000	-23,5	-13,8	-4,4	-22,4	-21,4	-13,6	-3,5

* These data apply to antennas that have at least 25 cm of ground plane clearance when the centre of the antennas is 1 m above the ground plane in vertical polarization.

5.4 Test site suitability without ground plane

5.4.1 Measurement considerations for free space test sites, as realized by fully-absorber-lined shielded enclosures

A fully-absorber-lined shielded enclosure, also known as a fully-anechoic chamber (FAC), or a fully-anechoic room (FAR), may be used for radiated emission measurements. When the FAR method is used, appropriate radiated emission limits shall be defined in relevant standards (generic, product or product family standards). Compliance with the radio services protection requirements (limits) shall be established for FARs in a similar way as for tests on an OATS.

A FAR is intended to simulate a free space environment such that only the direct ray from the transmitting antenna or EUT reaches the receiving antenna. All indirect and reflected waves shall be minimized with the use of appropriate absorbing material on all walls, the ceiling and the floor of the FAR.

5.4.2 Site performance

5.4.2.1 General

Site performance may be validated by two methods that are described below, i.e. the reference site method and the NSA method.

5.4.2.2 Theoretical normalized site attenuation

The following describes the NSA theory for infinitely small antennas.

Site attenuation (SA, A_S as a quantity in dB) is the transmission loss measured between the connectors of two antennas on a particular site. For a free space environment, A_S (in dB) can be approximated by Equation (8) [5]¹⁾:

$$A_S = 20 \log \left(\frac{5Z_0}{2\pi} \times \frac{d}{\sqrt{1 - \frac{1}{(\beta d)^2} + \frac{1}{(\beta d)^4}}} \right) - 20 \log(f_M) + F_{aR} + F_{aT} \quad (8)$$

where

- F_{aR}, F_{aT} are the antenna factors of the receive and transmit antennas (dB/m);
- D is the distance between the phase centres of both antennas (m);
- Z_0 is the reference impedance (i.e. 50 Ω);
- β is defined as $2\pi/\lambda$; and
- f_M is the frequency (MHz).

The theoretical normalized site attenuation ($A_{N \text{ theo}}$) in dB is defined as site attenuation with respective antenna factors subtracted, thus:

$$A_{N \text{ theo}} = 20 \log \left(\frac{5Z_0}{2\pi} \times \frac{d}{\sqrt{1 - \frac{1}{(\beta d)^2} + \frac{1}{(\beta d)^4}}} \right) - 20 \log(f_M) \quad (9)$$

Below 60 MHz at a 5 m distance or 110 MHz at a 3 m distance, it is necessary to apply near field correction factors for each of the required test positions of Table 3 for comparison with the theoretical NSA of Figure 10 and Equation (8). Near field correction factors are specific to the antennas, test distance, and test volume used, and therefore are obtained by using a numerical modelling code such as NEC. Alternatively, the reference method of 5.4.2.3.2 provides cancellation of near field terms if the same antennas and frequencies are used for both the site reference measurement and FAR validation.

For measurement distances of 10 m and 30 m, the near-field terms in Equation (9) may be omitted, and the equation simplifies as follows:

¹⁾ Figures in square brackets refer to the Bibliography.

$$A_{N\text{theo}} = 20\log\left(\frac{5Z_0d}{2\pi}\right) - 20\log(f_M) \quad (10)$$

If simplified Equation (10) is used instead of Equation (8), the error introduced is less than 0,1 dB at frequencies above 60 MHz for 5 m distance and above 110 MHz for 3 m distance. The error will be greater than 0,1 dB below these frequencies due to near-field effects. For a 3 m distance, the maximum error is 1 dB at 30 MHz. To reduce this error, Equation (8) should be used.

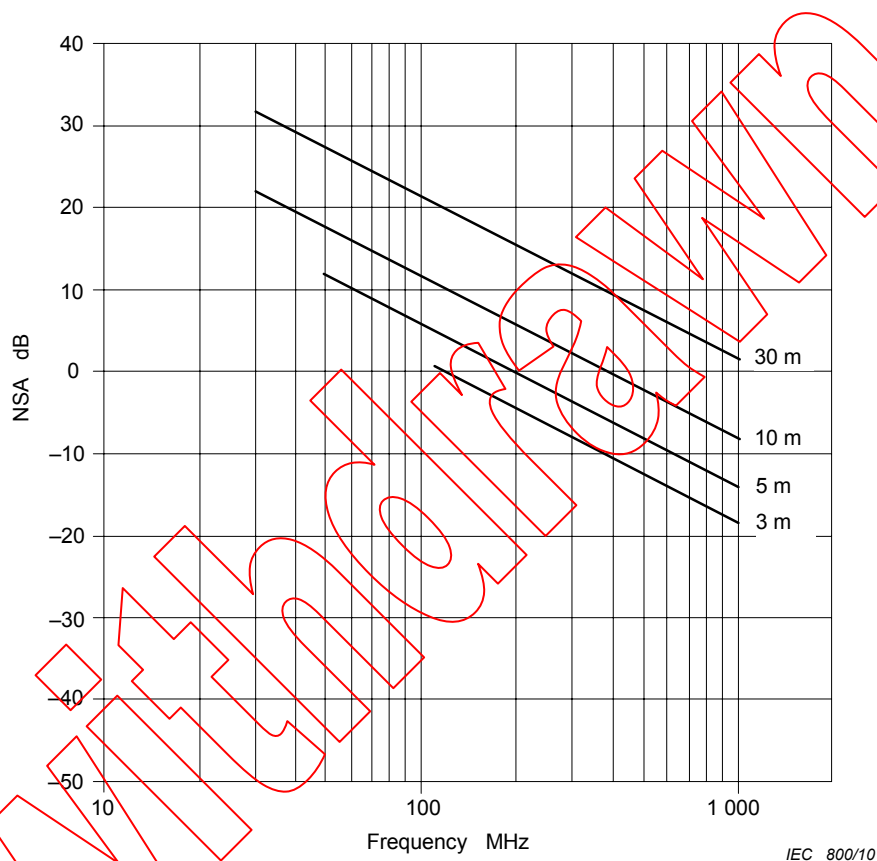


Figure 10 – Graph of theoretical free-space NSA as a function of the frequency for different measurement distances (see Equation (10))

NOTE Frequencies below 110 MHz for 3 m measurement and below 60 MHz for 5 m measurement distances include near field effects. These are calculated for each individual test site.

5.4.2.3 Site validation procedure

5.4.2.3.1 General

The NSA shall satisfy the requirement of 5.4.3 over a cylindrical test volume generated by the rotation of the EUT on the turntable. In this context, “the EUT” includes all components of a multi-unit EUT and the interconnecting cables. Table 3 defines the maximum height and diameter ($h_{\max} = d_{\max}$) of the test volume as a function of test distance. This ratio between diameter and test distance ensures an acceptable uncertainty in EUT emissions testing.

Table 3 – Maximum dimensions of test volume versus test distance

Maximum diameter $d_{\max}$ and height $h_{\max}$ of the test volume m	Test distance d_{nominal} m
1,5	3,0
2,5	5,0
5,0	10,0

A single position SA measurement may not be sufficient to pick up possible reflections from the room construction and/or absorbing material lining the walls, floor, ceiling and turntable of the FAR.

The fully-anechoic room SA measurements and validation shall therefore be performed at fifteen measurement positions for both horizontal and vertical antenna polarizations of the transmit antenna in the test volume (see Figure 11):

- at three heights of the test volume: bottom, middle and top;
- at five positions in all three horizontal planes: centre, left, right, front and rear positions in each horizontal plane. The rear position may be omitted if the distance between rear position and absorbers is more than 0,5 m. During EUT testing, the rear position on the turntable is also turned to the front, and the contribution of the back reflection will then not affect the maximum signal.

For SA measurements two broadband antennas shall be used: one transmit antenna with its reference point at the measurement positions of the test volume and one receive antenna outside this test volume at a prescribed orientation and position. The transmit antenna shall have an approximately omnidirectional H -plane pattern.

NOTE 1 The maximum dimension should not exceed 40 cm for a 3 m test distance; at larger distances, the size of the antenna can be scaled accordingly.

Typical receive antennas are hybrid (biconical/LPDA combination) antennas for 30 MHz to 1 000 MHz, or separate [biconical antennas (for 30 MHz to 200 MHz) and LPDA antennas (for 200 MHz to 1 000 MHz)].

NOTE 2 Use of a hybrid (biconical/LPDA combination) antenna is not recommended for either emission testing or chamber validation at 3 m distance, due to the large physical size of such antennas.

The same antennas, cables, ferrites, attenuators, amplifier, signal generator and receiver used to measure the SA of the FAR, shall be used to measure the reference SA on the quasi-free space test site (5.4.2.3.3). The receive antenna used during the room validation shall be of the same type as used during radiated emission testing of the EUT.

For test volume validation, both in horizontal and vertical polarization, and for all transmitting antenna positions in the test volume, the position in height of the receiving antenna in the FAR shall be set and remain at the fixed middle level of the test volume, as shown in Figures 11 and 12. Tilting the antennas shall be necessary to align the bore sight axis of both antennas in one measurement axis. The distance between the antenna reference point (defined in antenna calibration) and the front position of the test volume is d_{nominal} . When the transmit antenna is moved to other positions in the test volume, the receive antenna shall be translated along the measurement axis to maintain d_{nominal} . The measurement axis is the line between the transmit and receive antenna, along which d_{nominal} is defined. For all positions and polarizations, the receiving and the transmitting antenna shall face one another with the elements of both antennas parallel (tilting, see Figure 12). Any antenna masts and the supporting floors shall be in place during the validation procedure.

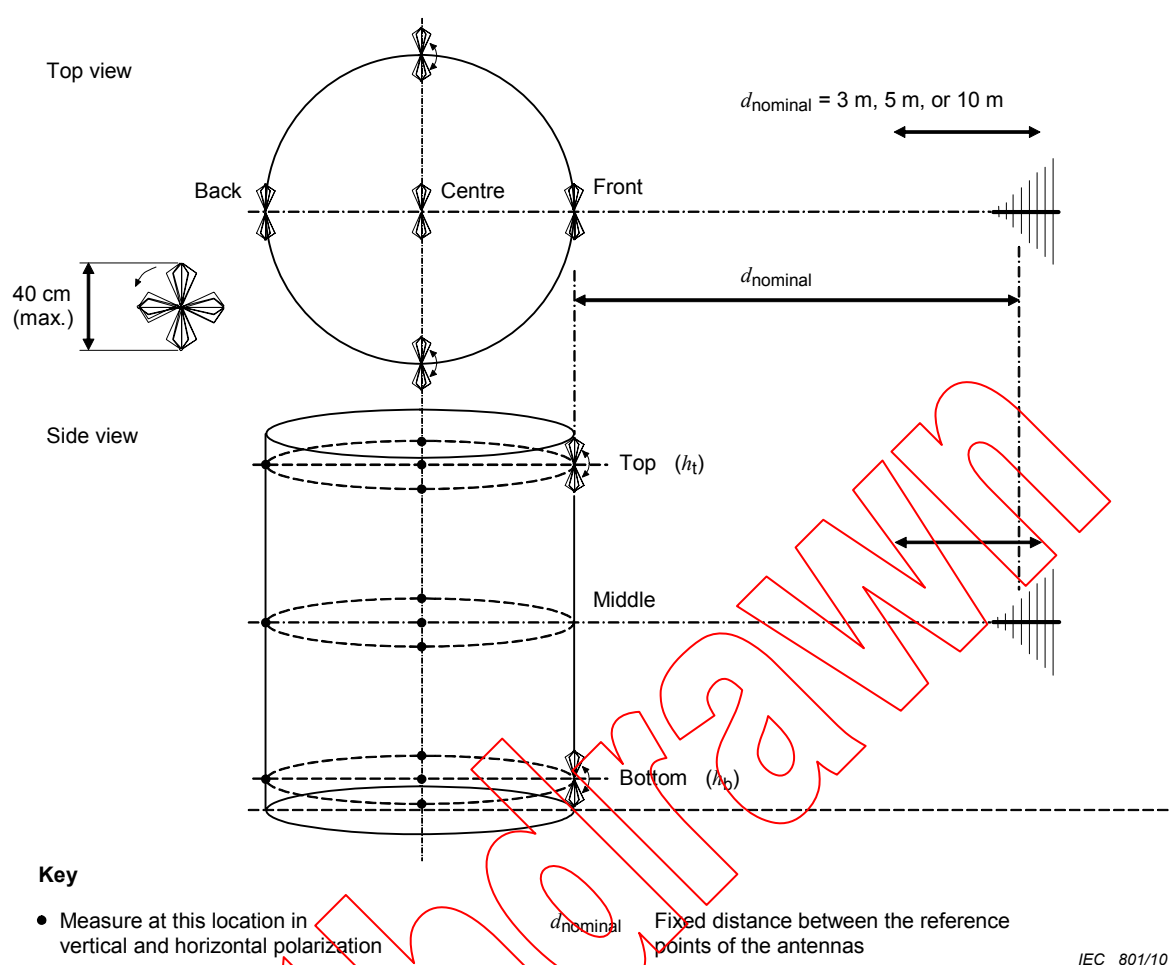


Figure 11 – Measurement positions for the site validation procedure

For all positions of the transmitting antenna in the test volume, in both horizontal and vertical polarizations, the transmitting and receiving antennas shall be aligned on the measurement axis.

Tilting the antennas is necessary to meet this requirement at certain positions (see Figure 12).

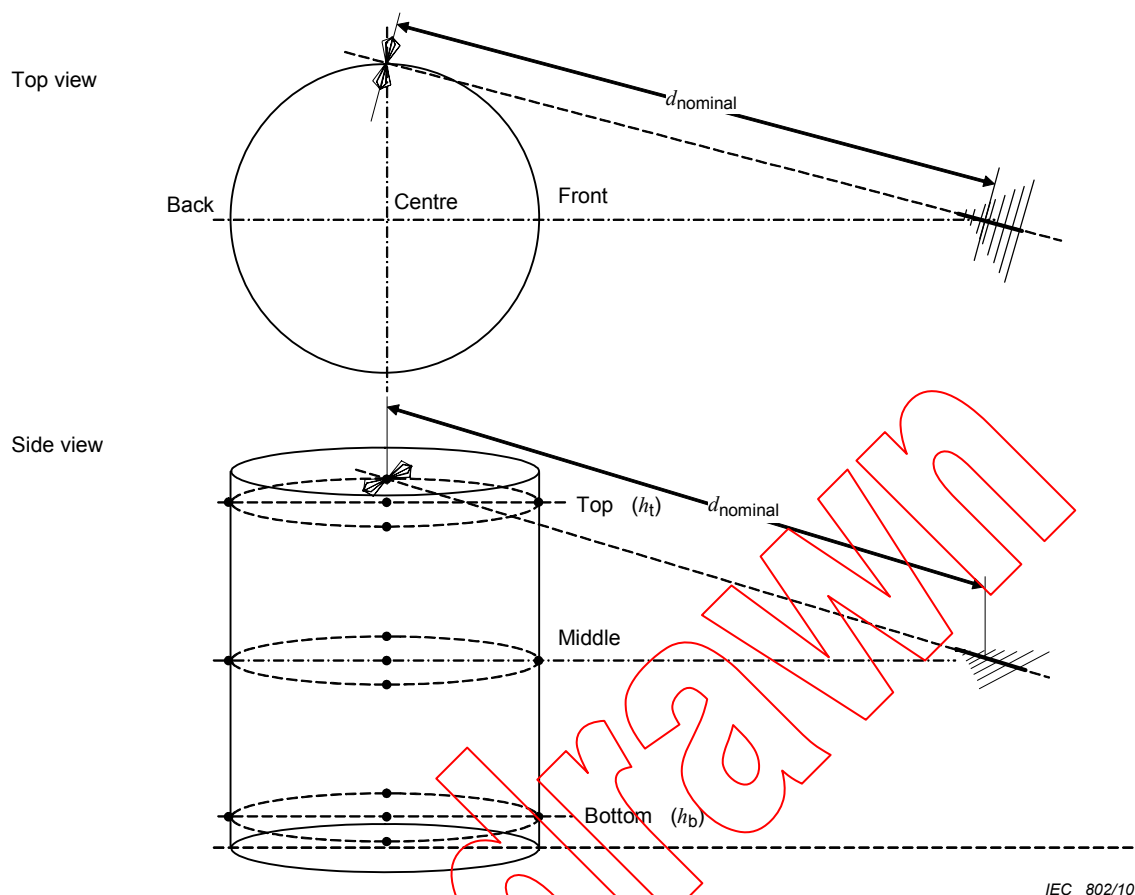
d_{nominal} {

- is the test distance associated with the limit;
- is the fixed antenna distance in the validation procedure;
- is the antenna separation in the antenna calibration procedure.

The transmit antenna height position in the test volume shall be determined as follows:

- “Middle” where possible along a virtual axis positioned at mid-height and mid-width of the FAR;
- “Top (h_t)” and “Bottom (h_b)” by half of h_{max} (see Table 3) minus half of the transmit antenna dimension (e.g. 20 cm for small biconical antenna).

These adjusted positions shall be used for both vertical and horizontal polarizations. The distance between the top and bottom planes and the ceiling and floor absorbers respectively is given by the absorber performance as determined by the volumetric NSA test, but at least 0,5 m, to avoid EUT to absorber coupling.



NOTE Antenna polarization horizontal, position top right.

Figure 12 – Example of one measurement position and antenna tilt for the site validation procedure

The maximum step size for the discrete-frequency measurement shall be as listed in Table 4:

Table 4 – Frequency ranges and step sizes

Frequency range MHz	Maximum frequency step MHz
30 to 100	1
100 to 500	5
500 to 1 000	10

Two methods are permissible for site validation:

- the reference site method, which is required for test distances less than 5 m;
- the NSA method, which is preferred for test distances greater than or equal to 5 m.

The SA measurement methods are intended to provide 0 dB deviation when performed on an ideal site. Any methods may be implemented to decrease measurement uncertainty, as long as these do not contradict the defined set-up and procedures or hide any site deficiencies, e.g. smoothed resonances.

Site validation measurement uncertainty can be decreased by the following measures.

- For a vertically-polarized antenna, shielded cables are to be extended by at least 2 m behind each antenna before dropping the cable to the ground. If possible, cables shall extend straight back to the bulkhead connectors in the wall of the room. Another possibility is the use of clip-on ferrites on the cables. Another alternative for reducing the influence of cables is through the use of optical links.
- Attenuators at the antenna connectors (e.g. 6 dB or 10 dB) will reduce the influence of any large impedance mismatch at the antennas.
- Antennas with good balance of the balun shall be used (the receiver reading changes less than $\pm 0,5$ dB when the antenna is rotated through 180° with respect to its bore sight axis. Antenna balance verification methods are described in 4.5.3).
- Separate biconical and LPDA antennas for chamber evaluation may be used (antenna type is changed at 200 MHz), if these will be used for EUT testing. A hybrid (biconical/LPDA combination) antenna is a combination of these two types and may be used as well if the mechanical dimensions are sufficiently small for the measurement distance.

The FAR site validation procedure shall be performed at regular intervals, to detect long-term changes in room characteristics, and when changes that might influence the electromagnetic wave transmission characteristics in the FAR occur.

5.4.2.3.2 The reference site method

SA measurements with the antenna pair (transmit and receive antenna) on a quasi-free space test site are required as a reference. The procedure for determining this reference site attenuation ($A_{S \text{ ref}}$) is described in 5.4.2.3.3. This method accounts for mutual coupling of the antennas and near field effects, which can have a significant influence at 3 m test distances. The reference site attenuation $A_{S \text{ ref}}(d)$ is performed at the nominal distance, d_{nominal} between the transmit and receive antennas.

The site validation procedure for each test volume position is performed in three steps.

- 1) M_0 is the reference level measured by the receiver in dB(μ V) with the cables connected together, normally done once before a series of volumetric tests.
- 2) M_1 is the level measured by the receiver in dB(μ V) with antennas installed.

The site attenuation of the validated site $A_{S \text{ val}}$ can be calculated by

$$A_{S \text{ val}} = M_0 - M_1 \quad \text{in dB} \quad (11)$$

- 3) The deviation of the measured site attenuation (ΔA_s) from reference site attenuation $A_{S \text{ ref}}(d)$ is calculated using Equation (12).

$$\Delta A_s = A_{S \text{ ref}}(d) - A_{S \text{ val}} \quad \text{in dB} \quad (12)$$

5.4.2.3.3 Determining the site reference

For accurate site validations at distances less than 5 m, it is recommended that dedicated pairs of antennas be used to determine the site reference (transmit and receive antenna). A quasi-free space test site is required. It consists of 2 non-metallic antenna masts (wood or plastic with $\epsilon_r \leq 2,5$, low loss, diameter as small as possible retaining mechanical strength), which allow the placement of antennas at a certain height above the ground level (Figure 13). One possible method of realization of the ± 1 dB performance of the reference site is to choose the height (h) of the antennas as follows:

$$h \geq d \times \frac{8}{3} \quad (13)$$

where d is the antenna separation.

A height of $h = d \times 8/3$ is recommended to suppress the influence of the ground, or substantial absorbers which work down to 30 MHz, need to be placed on the ground.

NOTE At 3 m separation at 30 MHz there is a significant near field term ($1/d^2$) that alone contributes an error of 0,8 dB for a height of 5/3. This was verified by the national measurement institutes of both the UK and Austria. For a site reference with an uncertainty of less than $\pm 0,5$ dB, a height of 8/3 is recommended if no absorber is placed at the ground.

The distance shall be equal to the actual distance d_{nominal} between the antennas used in the FAR. The antennas are polarized vertically (horizontal polarization shall not be used because of stronger interference with the ground-reflected signal). It also provides a good approximation of free-space. The clearance from buildings, trees, etc. shall be greater than $d \times 8/3$ because there may be an influence for vertically polarized antennas.

Care has to be taken that the antenna feed cables do not affect the test result. This is best avoided by a cable arrangement as shown in Figure 13, or using RF-optical links.

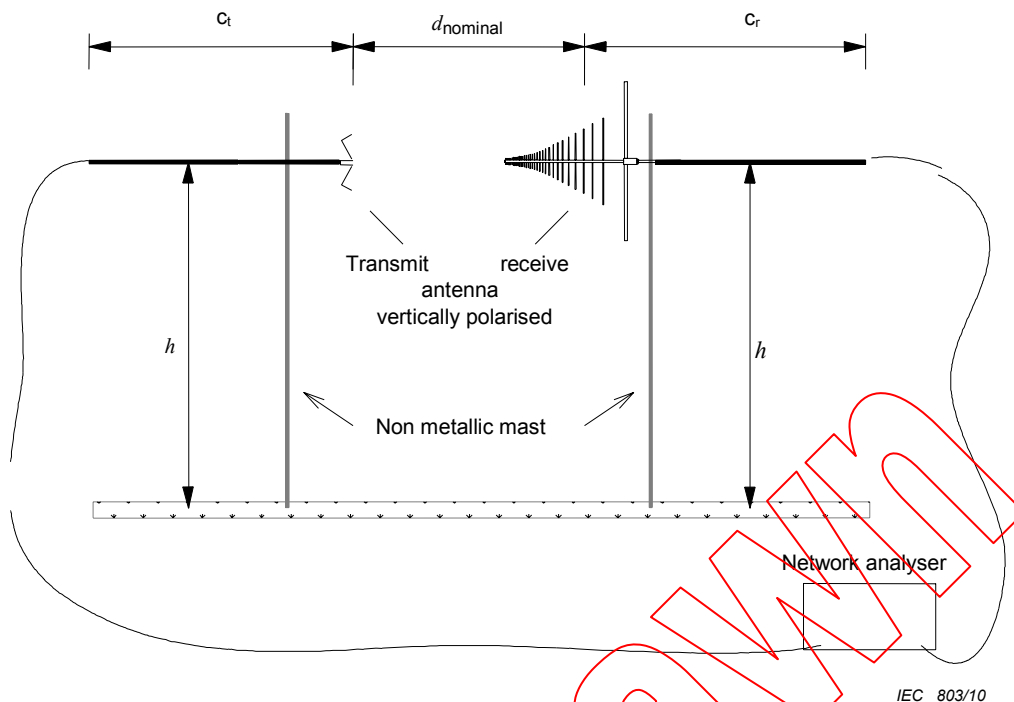
The quality of the reference set-up directly influences the FAR evaluation result.

The reference site attenuation ($A_{S \text{ ref}}$) is determined in three steps, as follows.

- 1) $M_{0 \text{ RS}}$ is the reference level measured by the receiver in dB(μ V) with the cables connected together.
- 2) $M_{1 \text{ RS}}(d)$ is the level measured by the receiver in dB(μ V) with the antennas installed at the required distance d_{nominal} .
- 3) The $A_{S \text{ ref}}(d)$ is calculated according to Equation (14)

$$A_{S \text{ ref}}(d) = M_{0 \text{ RS}} - M_{1 \text{ RS}}(d) \text{ in dB} \quad (14)$$

For 3 m site validation, a height of at least 4 m above ground shall be used, which is a typical capability of remotely controllable antenna masts that are used for emission measurements. In this case, electromagnetic absorbers shall be placed on the ground between the antennas, with the absorber patch extending for a minimum area beyond the antennas in all directions and it shall be proven that quasi-free space condition, as defined in 5.4.1, is fulfilled. For site validation with $d > 3$ m, the equation $h > d \times 8/3$ is used, or an alternative set-up that has been demonstrated to fulfil the ± 1 dB reference site attenuation.

**Key**

d_{nominal} validation distance

h height of the antennas above a ground plane or above ground level

C_t, C_r coaxial feed cables for transmit and receive antenna oriented horizontally behind the antenna for a distance as close to 2 m as physically possible. In a FAR, route the cables horizontally as far as possible, preferably straight through a hole in the chamber wall, or use optical fibre connected to an RF-optical link on the output of the antenna.

NOTE Reference site attenuation is obtained separately for all geometries of Figure 13.

Figure 13 – Typical free-space reference site attenuation measurement set-up

5.4.2.3.4 The NSA method

The free space antenna factors of the transmit and receive antennas are required for this procedure. The site validation for each measurement position is performed in four steps as follows.

- 1) M_0 is the reference level measured by the receiver with the cables connected together.
- 2) M_1 is the level measured by the receiver with the antennas installed.
- 3) The measured NSA ($A_{N \text{ meas}}$) is calculated in dB according to Equation (15)

$$A_{N \text{ meas}} = M_0 - M_1 - F_{aT} - F_{aR} \text{ in dB} \quad (15)$$

where F_{aT} and F_{aR} are free space antenna factors in dB/m.

- 4) The deviation ΔA_N is calculated in dB according to Equation (16)

$$\Delta A_N = A_{N \text{ meas}} - A_{N \text{ theo}} \quad (16)$$

where $A_{N \text{ theo}}$ is calculated using Equation (10), and ΔA_N is compared with the applicable NSA criterion, e.g. ± 4 dB, as specified in 5.4.3.

NOTE The distance d between the reference points of the transmit and receive antennas (defined by antenna calibration) is used as d_{nominal} . The effective distance between the antennas varies with frequency due to their phase centre positions. The transmission loss is compensated by the ratio of the effective distance to d_{nominal} .

5.4.3 Site validation criteria

A measurement site shall comply with the following requirements:

- deviations of the SA or the NSA [Equation (12) or Equation (16)] shall be less than ± 4 dB for both horizontal and vertical polarization and for each measurement position and measurement frequency;
- the uncertainty budget of the site evaluation according to CISPR 16-4-2 recommendations shall be reported and shall have the same components as required for field strength measurements on alternative test sites with ground plane.

5.5 Evaluation of set-up table and antenna tower

5.5.1 General

A set-up table as specified in Clause D.5 typically positions the EUT for field strength measurements. The shape, construction and material permittivity of the set-up table can influence the field strength measurement results (see [2], [6], [7], [10]). The following subclause (i.e. 5.5.2) describes a procedure to determine the influence of the set-up table for the 30 MHz to 18 GHz frequency range and to estimate its related uncertainty contribution to field strength measurements. An evaluation shall be performed on any set-up table with a height of more than 0,15 m.

NOTE Only horizontal polarization of a transmit antenna above the set-up table is used in the evaluation. Horizontal polarization, as opposed to vertical, accounts for the worst-case effects from the table.

The antenna tower does not require additional evaluation because any perturbation effects will be included in the NSA measurement (see 5.2.6) and in the S_{VSWR} measurement (see 8.3).

5.5.2 Evaluation procedure for set-up table influences

To evaluate the influence of the set-up table, two transmission measurements are performed: one with the set-up table present, the second with the set-up table absent. During the two measurements, a transmit antenna is maintained in a specific arrangement. The difference between the measurement results with and without the set-up table gives an estimate of the influence caused by the set-up table. The measurement procedure is as follows.

The set-up table shall be placed in the typical position on the test site with the largest dimension (i.e. the diagonal for a set-up table with a rectangular top, or the radius for a table with a circular top) oriented in the direction of the receive antenna (see Figure 14).

For frequencies up to 1 GHz, a small biconical antenna with an overall length of less than 0,40 m shall be used. For frequencies above 1 GHz, an antenna in accordance with 8.3.3.1 (for example a broadband dipole) shall be used.

Refer to Figure 14 and Figure 15 for placement of the transmit antenna. The antenna shall be placed above the set-up table in a horizontal polarization with a distance of 0,1 m between the table surface and the antenna reference point (balun). The antenna shall be positioned with the reference point midway between the centre and the edge of the set-up table top in the direction of the receive antenna. A signal generator shall feed the antenna. The transmit and receive antennas shall be aligned with the antenna elements parallel to each other and orthogonal to the measurement axis. During measurement, frequency steps shall be less than or equal to 0,5 % of the highest frequency used. The receive antenna voltage shall be at least 20 dB above the noise level of the measurement equipment. The influence of cabling can be minimized by using long cables or by using ferrite tubes. Routing the cables horizontally to the rear a minimum of 2 m is typically sufficient. Either way, the influence shall be defined as negligible if the receive voltage does not change by more than 0,3 dB when the cable routing is changed by more than 0,5 m from its original position.

EXAMPLE A cable with ferrite tubes is routed horizontally for a distance of 1,6 m. To check the cable influence, the cable is re-routed to drop vertically from a point 2,1 m from the connection to the antenna. Then the field strength is re-measured to determine if the influence is no more than 0,3 dB.

The aim is that there are no changes in the measurement set-up apart from the table being present or absent. The transmit antenna, and its cable connecting to the signal generator, shall be supported in such a way that they retain identical positions in space with and without the table. A mast, tripod or tower as used during NSA measurements or S_{VSWR} shall be used to support the transmit antenna and cable.

Antenna heights and distances shall be as follows:

- For all frequencies, the distance between the receive and transmit antennas shall be as required for the radiated disturbance measurement.
- At or below 1 GHz, measurements shall be made from at least 200 MHz to 1 GHz. In an OATS or SAC, the receive antenna height shall be scanned as required in the radiated disturbance measurement (typically between 1 m and 4 m). In a FAR, the receive antenna shall be fixed at the height required for the radiated disturbance measurement.

NOTE Below 200 MHz the influence of the set-up table is negligible when applying this verification procedure.

- Above 1 GHz, measurements shall be performed over the same frequency range (e.g. 1 GHz to 18 GHz), and the antenna height shall be set (e.g. 1 m to 4 m), as required for the radiated disturbance measurement.

The magnitude of the difference between the two measurement results at each frequency step, written as $\Delta(f)$ and expressed in dB, shall be calculated using Equation (17).

$$\Delta(f) = |V_{R,with}(f) - V_{R,without}(f)| \quad (17)$$

where

$V_{R,with}(f)$ is the maximum voltage at the receive antenna at a specific frequency, expressed in dB(μ V), measured in the presence of the set-up table;

$V_{R,without}(f)$ is the maximum voltage at the receive antenna at a specific frequency, expressed in dB(μ V), measured in the absence of the set-up table.

The maximum magnitude of the difference between the two measurement results recorded across the frequency range, written as Δ_{max} and expressed in dB, shall be used as the estimated maximum deviation. This shall be calculated in accordance with Equation (18).

$$\Delta_{max} = \max |V_{R,with}(f) - V_{R,without}(f)| \quad (18)$$

The standard uncertainty u_{table} caused by the set-up table is estimated by assuming a rectangular distribution for the measured maximum difference Δ_{max} . So u_{table} (in dB) can be calculated using Equation (19).

$$u_{table} = \frac{1}{\sqrt{3}} \Delta_{max} \quad (19)$$

The value u_{table} shall be measured and considered in the uncertainty budget (see CISPR 16-4-2) in the following frequency ranges:

- 200 MHz to 1 GHz;
- 1 GHz to 6 GHz;
- 6 GHz to 18 GHz.

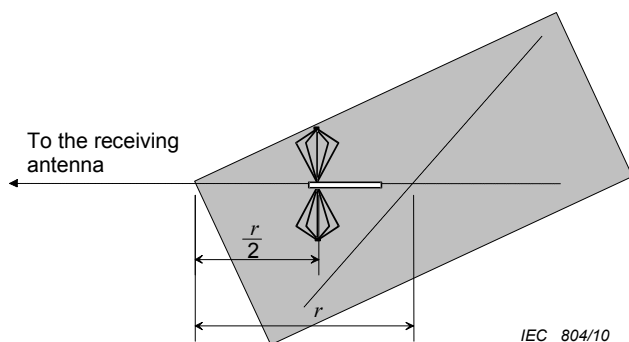


Figure 14 – Position of the antenna relative to the edge above a rectangle set-up table (top view)

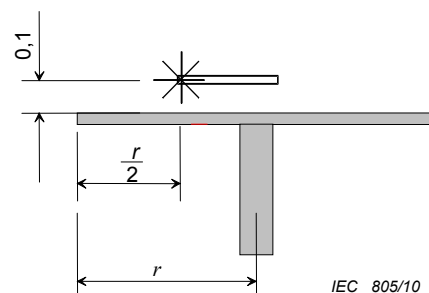


Figure 15 – Antenna position above the set-up table (side view)

NOTE Set-up table construction and the type of materials will vary among test laboratories. It is sufficient to determine the worst-case value of Δ (or $V_{R,with}$) in the determination of u_{table} .

6 Reverberating chamber for total radiated power measurement

6.1 General

For some types of equipment operating in the microwave frequency range, because of the existence of complex three-dimensional radiation patterns which are sensitive to equipment operating conditions and its surroundings, the measurement of total radiated power is considered to be a significant parameter related to disturbance control. It can be measured by placing the equipment in a suitable chamber with metal walls. To avoid effects of standing waves that would otherwise produce non-uniform distribution of energy density with position in the chamber, rotating stirrers are installed. With proper size, shape and position, the energy density at any position in the chamber varies randomly with a constant statistical distribution law in phase, amplitude and polarization.

6.2 Chamber

6.2.1 Chamber size and shape

The linear dimensions of the chamber shall be large relative to the wavelength of the lowest frequency of interest. It shall also be large enough to accommodate the equipment under test, the stirrers and the measuring antennas. Microwave equipment varies in size from the small table top oven having a volume of about $0,2 \text{ m}^3$ to large units $1,7 \text{ m}$ high with a 760 mm base. The chamber may be of any shape provided its three dimensions are of the same order. The three dimensions should preferably be different. For a lowest frequency of 1 GHz , the chamber shall have a volume at least 8 m^3 . The actual dimensions will depend on the physical characteristics of the chamber. See 6.2.4 for method of test of the suitability of the chamber.

The walls and the stirrers shall be metallic. Joints between the metallic members shall be mechanically sound and of low electrical resistance along the whole length, and there shall be no surface corrosion. No absorbing material, such as wood, shall be placed inside the chamber.

6.2.2 Door, openings in walls, and mounting brackets

The enclosure door shall be large enough to allow the passage of operators and equipment. It shall open outward, and fit tightly to minimize energy losses. For convenience in mounting, transmitting and receiving antennas inside the chamber, mounting brackets may be fixed to the walls.

6.2.3 Stirrers

6.2.3.1 General

The following describes two examples of stirrers. Other shapes are permissible provided stirring efficiency meets the criteria in 6.2.4.

6.2.3.2 Rotating vanes

If rotating vanes are used, two vanes are placed on adjacent walls of the chamber spaced at least $1/4$ of the maximum wavelength used from the walls and of sufficient thickness to be rigid. They shall be of the maximum length allowed by the wall sizes and their width shall be about $1/5$ of the length.

6.2.3.3 Rotating paddles

If rotating paddles are used, two or three paddles are mounted on the walls of the chamber. The paddles shall be mutually at right angles. The paddles may be of the shape shown in Figure 16 and rotate about an axis parallel to their length. The diameter of the swept tubular space shall be at least equal to the maximum wavelength used, and the lengths shall be the maximum allowed by the wall sizes. The structure shall be rigid.

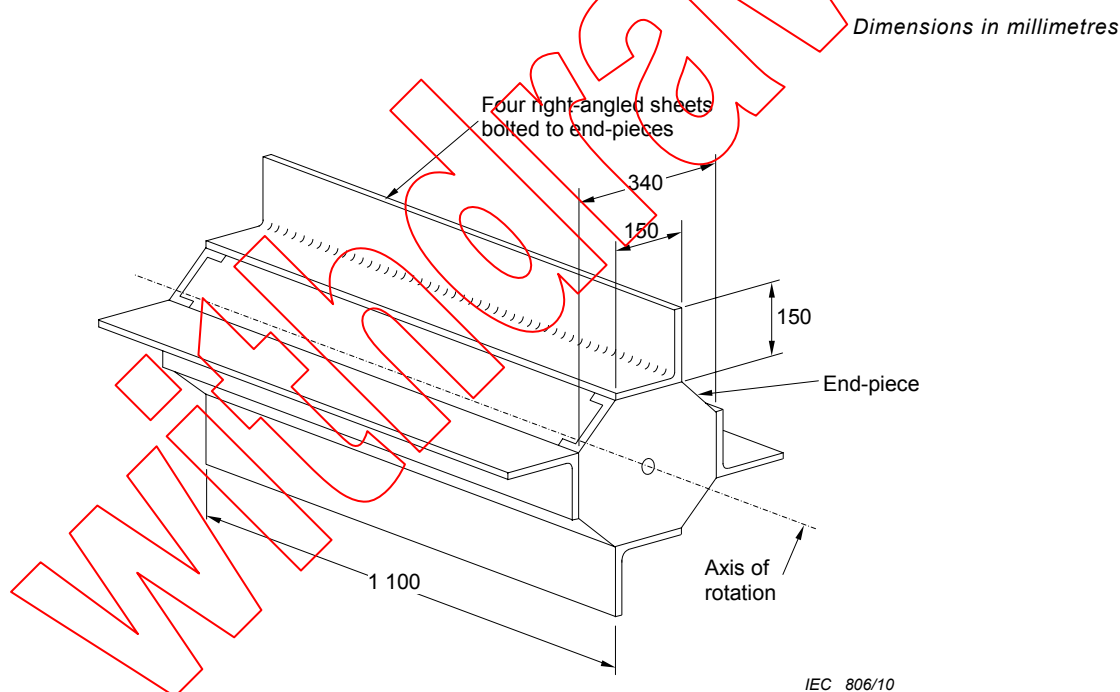


Figure 16 – Example of a typical paddle stirrer

6.2.3.4 Rotating speed

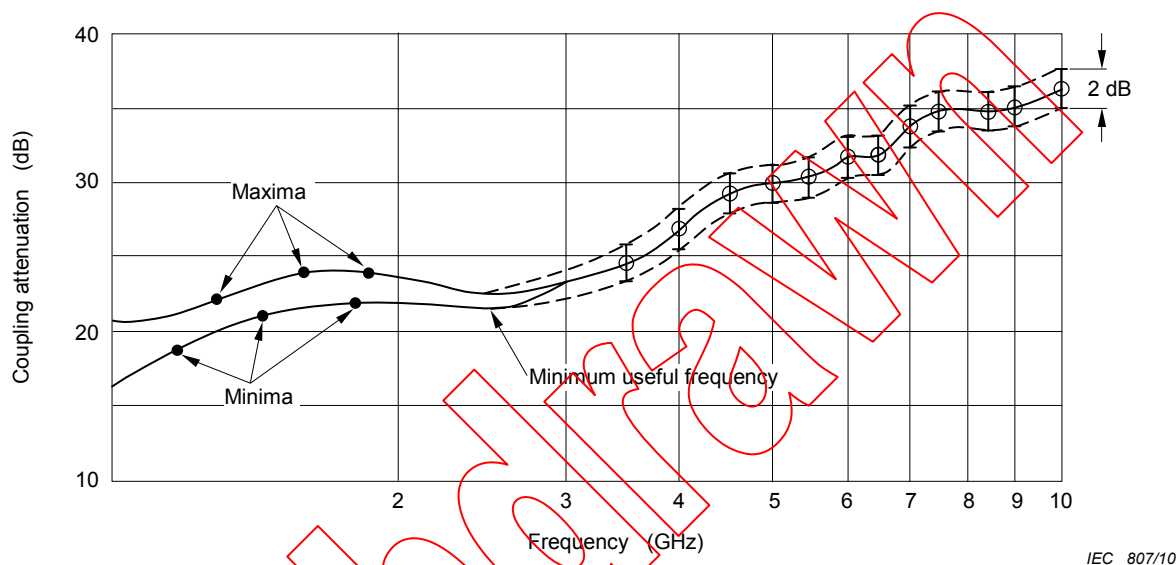
The rotation speeds of the stirrers shall be different. The longest time for one rotation of the stirrers shall be less than $1/5$ of the integrating time of the measuring instrument. For the measuring equipment described in 6.2.5, a suitable rate is between 50 r/min and 200 r/min. The motors used to rotate the stirrers, together with their reduction gear, should preferably be outside the walls of the chamber.

6.2.4 Test for the efficiency of the stirrers

The desired uniform distribution of energy in the chamber is shown by the smoothness of the variation with frequency of coupling attenuation (described in 6.2.5). At low frequencies, due to the longer wavelengths, it is more difficult to achieve this uniformity and there exist pronounced

maxima and minima. The greater the efficiency of the stirrers, the smaller are these maxima and minima and hence the usable frequency is lower.

The coupling attenuation is measured over the usable frequency range of the chamber. At the lower frequencies where the maxima and minima are observable, values shall be measured at about 100 MHz intervals. The receiving antenna then remains fixed, the transmitting antenna is rotated at 45° intervals and the test is repeated for each position and at each frequency. The whole test shall be repeated again with the receiving antenna rotated at 90°. The stirrers are considered satisfactory when: (1) the envelope of the graph of the maxima and the minima does not exceed 2 dB in any position of the transmitting antenna, and, (2) the means of the four graphs are within an envelope of 2 dB or less. Figure 17 shows a typical result.



NOTE All measured points should lie inside the 2 dB envelope marked by the dotted line.

Figure 17 – Range of coupling attenuation as a function of frequency for a chamber using the stirrer shown in Figure 16

6.2.5 Coupling attenuation

The coupling attenuation of a chamber is the insertion loss measured between the terminals of the transmitting and the receiving antennas in the chamber. A calibrated signal generator whose power output can be accurately measured is used to feed power to a low-loss transmitting antenna (e.g. a horn antenna) located inside the chamber or on a chamber wall. A receiving antenna may be placed at any point in the chamber provided it is at least 1/4 wavelength from the walls and not pointing toward the transmitting antenna, towards the nearest chamber wall, or aligned with any of the chamber axis.

A low-noise RF amplifier is connected to the receiving antenna via a high-pass filter; its output is connected through a band-pass filter to a diode detector. The band-pass filter shall be tuned to the frequency of interest and be of the specified bandwidth. The output of the detector is connected to a peak reading voltmeter with a specified peak-hold time (the hold time will depend on the equipment being measured). A spectrum analyzer may also be used for this measurement. The power absorbed by the transmitting antenna, P , is noted. The signal generator is then connected to the input of the low-noise amplifier, and its power output, p , is adjusted to give the same voltmeter reading. The power absorbed by the low-noise amplifier is noted. The coupling attenuation is given by $10 \log (P/p)$ dB.

7 TEM cells for immunity to radiated disturbance measurement

Radiated immunity measurements may be performed in TEM waveguides using the methods specified in IEC 61000-4-20.

8 Test sites for measurement of radio disturbance field strength for the frequency range 1 GHz to 18 GHz

8.1 General

The test site shall rely on reflection-free conditions. It may be necessary to use absorbing material and/or to raise the height of the EUT to achieve these free-space conditions.

NOTE In the case of floor standing equipment tests, reflection-free conditions may not be achieved close to the ground.

8.2 Reference test site

The reference test site shall be a free-space, open area test site (FSOATS) with precautions to ensure that reflections do not influence the measurement.

NOTE The FSOATS is the concept of the test site. A practical approximation is a FAR that meets the validation requirements given below.

8.3 Validation of the test site

8.3.1 General

A test site shall be considered acceptable for radiated electromagnetic field measurements in 1 GHz to 18 GHz if it satisfies the criterion provided in 8.3.2; 8.3.3 provides the site validation procedure. For the purposes of testing per CISPR standards, site validation measurements shall be performed from 1 GHz to the maximum frequency in use at the test facility; the maximum frequency shall be at least 2 GHz.

Test sites used for measurements in 1 GHz to 18 GHz shall have a design that minimizes the influence of reflections upon the received signal, for example an anechoic chamber. If the site is not designed to provide fully anechoic conditions, for example a semi-anechoic chamber, use of absorbing material to cover part of the metal ground plane is required, as described below.

In cases where the test volume extends from the conducting floor of the facility to above the EUT, as may be typical for facilities used primarily for testing floor-standing EUTs, absorber shall be placed in the test volume for the validation as necessary. To accommodate testing of floor-standing equipment that cannot be positioned above the ground plane, illumination of the test volume for a height of up to 30 cm may be obstructed by absorber placed on the ground plane.

During the emission testing of a floor-standing EUT, floor absorber used during the site validation may be removed in the immediate area (footprint) of the EUT, and for up to 10 cm surrounding the EUT footprint.

In facilities where the test volume is above the height of the absorber, as may be typical of facilities used for testing table-top equipment, absorber may be placed under the test volume for both site validation and equipment tests. Photographs showing the site absorber configuration and transmit/receive antenna locations shall be included in the site validation report.

Site validation is performed by measurements of the so-called site voltage standing-wave ratio (S_{VSWR}). The site validation method evaluates a given test volume for the specific combination of site, receive antenna, test distance (described in CISPR 16-2-3), and absorbing material placed on the ground plane, if needed to meet the criterion of 8.3.2.

Influences of the receive antenna mast located as used for the site validation tests, and permanently-fixed objects in the test volume (such as a permanently-installed turntable), are evaluated by and included in this site validation procedure. Removable objects, such as a removable test table, are not required to be in place during the site validation tests if their influence is to be evaluated separately using the additional procedures of 5.4 of this standard.

CISPR 16-2-3 provides a description of the EUT measurement method used for testing in 1 GHz to 18 GHz. The purpose of the S_{VSWR} procedure is to check for the influence of reflections that may be incident upon an EUT of arbitrary size and shape placed within the test volume as evaluated using this procedure.

The S_{VSWR} is the ratio of maximum received signal to minimum received signal, caused by interference between direct (intended) and reflected signals, or

$$S_{VSWR} = \frac{E_{\max}}{E_{\min}} = \frac{V_{\max}}{V_{\min}} \quad (20)$$

where

$E_{\max}$ and $E_{\min}$ are the maximum and minimum received signals, and

$V_{\max}$ and $V_{\min}$ are the corresponding measured voltages when a receiver or spectrum analyzer is used for reception.

For the procedures that follow, decibels (dB) are typically employed for measurements and calculations. In this case, S_{VSWR} is given by

$$S_{VSWR,dB} = 20 \log \left(\frac{V_{\max}}{V_{\min}} \right) = 20 \log \left(\frac{E_{\max}}{E_{\min}} \right) = V_{\max,dB} - V_{\min,dB} = E_{\max,dB} - E_{\min,dB} \quad (21)$$

NOTE 1 When decibels are employed, $S_{VSWR,dB}$ may be taken as the difference of maximum to minimum signal received in units of dBm, dB(μV), or dB(μV/m), as appropriate for the instrumentation or signal detector used.

NOTE 2 The value of S_{VSWR} or $S_{VSWR,dB}$ is computed separately from the maximum and minimum signal obtained at each frequency and polarization for a set of six measurements as described in 8.3.3.

8.3.2 Acceptance criterion for site validation

The S_{VSWR} is directly related to influences of undesired reflections. The acceptance criterion for 1 GHz to 18 GHz site validations is:

$$S_{VSWR} \leq 2:1, \text{ or } S_{VSWR,dB} \leq 6,0 \text{ dB},$$

for S_{VSWR} measured in accordance with the procedures of 8.3.3.

8.3.3 Site validation procedures – evaluation of S_{VSWR}

8.3.3.1 Antenna requirements

8.3.3.1.1 General

To provide illumination of all reflecting surfaces during this test, and to simulate the possible low-directivity antenna gains exhibited by many actual EUTs, this subclause specifies characteristics for equipment used for S_{VSWR} testing. Manufacturer-supplied data may be used to evaluate whether the test-equipment requirements are met.

8.3.3.1.2 Test equipment for the standard S_{VSWR} procedure (i.e. 8.3.3.3)

8.3.3.1.2.1 General

The receive antenna shall be linearly polarized, and shall be the same type as used for EUT emissions measurements. For the transmit antenna, the 0°-reference angle for the pattern specifications is the angle where the antenna faces the receive antenna (aperture planes parallel); this is also deemed the “boresight” direction, Θ_B .

The antenna used as a transmit source shall be linearly polarized and shall have a dipole-like radiation pattern with the following detailed characteristics. Radiation pattern data shall be available with a frequency step size less than or equal to 1 GHz.

NOTE It is assumed that the antenna also meets the requirements at other frequencies used for the S_{VSWR} test.

8.3.3.1.2.2 Transmit antenna *E*-plane radiation pattern

An *E*-plane radiation pattern for an antenna with simple linear polarization can be measured at one of many possible cut planes (constant azimuth angle) around the radiation sphere. The cut plane for pattern measurements shall be selected by the antenna manufacturer and described in the antenna characterization report. One convenient choice typically is the plane containing the connector and the cable routing.

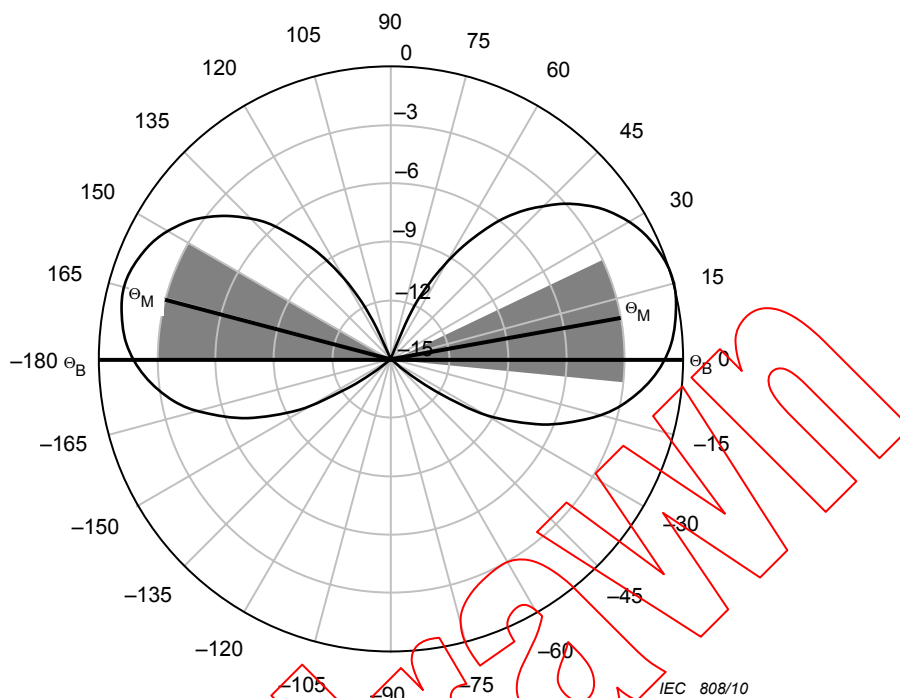
- Choose a main lobe direction, designated as Θ_M , for the right and the left side of each pattern. Θ_M shall be between $0^\circ \pm 15^\circ$ and $180^\circ \pm 15^\circ$, respectively.
- Draw the so-called forbidden area symmetrical to the main lobe directions on both sides of the pattern²⁾ where amplitude is ≤ -3 dB for $\pm 15^\circ$.

NOTE This limit ensures a smooth pattern in the boresight region, and an acceptable omnidirectional behaviour.

- The *E*-plane pattern shall not enter the forbidden area.

Figure 18 shows an example radiation pattern that meets the preceding *E*-plane requirements.

²⁾ This limit ensures a smooth pattern in the boresight region, and an acceptable omnidirectional behaviour.



NOTE The example plot is for an antenna that meets the *E*-plane requirements of this subclause. The main lobe directions, Θ_M , for the right and the left side of each pattern are between $0^\circ \pm 15^\circ$ and $180^\circ \pm 15^\circ$ respectively. The shaded areas represent the “forbidden area” where amplitude would be ≤ -3 dB for $\pm 15^\circ$ of each main lobe. The antenna pattern does not enter the forbidden area.

**Figure 18 – Transmit antenna *E*-plane radiation pattern example
(this example is for informative purposes only)**

8.3.3.1.2.3 Transmit antenna *H*-plane radiation pattern

There is only one possible plane in which to measure the *H*-plane pattern of a dipole antenna, which is the plane orthogonal to the dipole axis intersecting the centre of the dipole. This plane may include a balun, an input connector, and the input cable, depending whether a metal or optical fiber is used. The manufacturer of the antenna shall describe the set-up used to measure radiation patterns, including the feed cabling and connector locations, in the test report of the antenna.

- Average the radiation pattern data (in dB) over the range of $\pm 135^\circ$ (0° is the boresight angle, Θ_B). The maximum step size for this pattern data is 5° in the frequency range of 1 GHz to 6 GHz, and 1° from 6 GHz to 18 GHz.
- The pattern shall not exceed the following deviations from the $\pm 135^\circ$ -averaged value:

Angle range	1 GHz to 6 GHz	6 GHz to 18 GHz
-60° to 60°	± 2 dB	± 3 dB
-60° to -135° , 60° to 135°	± 3 dB	± 4 dB
-135° to -180° , 135° to 180°	$< +3$ dB	$< +4$ dB

NOTE Although a lower bound on the *H*-plane pattern is not specified outside of $\pm 135^\circ$, it is desirable for the *H*-plane pattern not to show a null at $\pm 180^\circ$, but to be omnidirectional as best as possible. Guidance provided by the antenna manufacturer on the routing of the feed cabling and antenna mast should be followed, if available, to minimize the possible influence on *H*-plane pattern outside of $\pm 135^\circ$.